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Development of a wearable computing glove to detect spasms and log information to support therapy

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Abstract

This thesis is about the development of a device called "spasmglove" which is designed to help and assist people suffering from cerebral palsy in their daily lives. The main goal of this thesis is to discover whether a spasm measuring device can be used as a training device for reducing the count of occurring spasms or not. To gain information about cerebral palsy, neuroplasticity and already existing wearable devices literature is used. In addition semi structured interviews are conducted with an affected person, his father and a therapist in order to gain as much information as possible from different points of view. This thesis is part of a joint master thesis and focuses on designing issues and technical aspects such as conducting interviews, the design of the glove, selecting the needed hardware, establishing connections between hardware components, building the prototypes and redesigning issues in order to fit the needs of an affected person. The development of several steps of the prototype as well as an evaluation with a patient are described. An additional goal of this master thesis is the development of a wearable prototype that does not interfere with the users daily life and in addition is easy to use. The goal of developing a full functional spasm detecting device could be achieved by working closely together with an affected person. According to the patient the number of occurring spasms could be reduced significantly. Beside the evaluation a discussion about the functionality of the prototype is presented as well as a conclusion containing some future possibilities that can be realized by enhancing the prototype.

Kurzfassung

Die nachfolgend vorgestellte Diplomarbeit beschäftigt sich mit der Aufgabe ein assistierendes technisches Hilfsmittel für an Zerebralparese leidende Personen zu entwickeln, welches in der Lage ist Spastiken zu erkennen. Die Fragestellung zielt darauf ab zu überprüfen ob es möglich ist, unter Zuhilfenahme dieses Gerätes, eine deutliche Reduzierung der auftretenden Spastiken zu erreichen. Um sich einen Überblick über, für die Entwicklung notwendige Themenbereiche, wie Zerebralparese, Neuroplastizität sowie bereits existierende Geräte zu verschaffen wurde eine umfangreiche Literaturrecherche durchgeführt und die Ergebnisse beziehungsweise Erkenntnisse der selbigen schriftlich festgehalten. Zusätzlich wurden drei Interviews mit einer betroffenen Person, deren Vater sowie einer Therapeutin geführt um die jeweilige persönliche Meinung in Bezug auf Anforderungen an das zu entwickelnde Gerät sowie Einschränkungen im Alltag in Erfahrung zu bringen. Diese Diplomarbeit ist Teil einer geteilten Diplomarbeit und beschäftigt sich im Allgemeinen mit dem erfolgreichen Design eines Handschuhs, welcher in der Lage ist Spastiken in den Handgelenken zu erkennen. Die Durchführung der Interviews sowie daraus resultierende technische Aspekte wie etwa die Auswahl passender Hardware, die Zusammenstellung der Prototypen sowie das Durchlaufen mehrerer Design Iterationen werden im Verlauf der Diplomarbeit detailliert vorgestellt. Die abschließende Evaluierungsphase mit dem Patienten ermöglicht es, die bereits erwähnte Fragestellung der Sinnhaftigkeit eines solchen Gerätes zu bejahen. Die Anzahl der auftretenden Spastiken konnte nach Aussage des Patienten deutlich reduziert werden. Den Abschluss der Diplomarbeit bilden eine Diskussion über die erzielten Ergebnisse sowie eine Schlussfolgerung in wie fern die bereits erreichten Ergebnisse in naher Zukunft noch verbessert werden könnten.

Contents

Part I

Thesis

CHAPTER 1

Introduction

Cerebral palsy is a huge problem all over the world. Caused by a pre born damage to the brain affected people have to deal with challenges that healthy people can master alone. Writing, eating, dressing or even walking, such simple things can not be mastered alone. To overcome these problems people suffering from cerebral palsy need help. Members of the family, friends and therapists are needed to support people that are currently affected.

There are many symptoms people suffering from cerebral palsy have to deal with. Motor impairments, global physical and mental dysfunctions, tremors, epileptic seizures and muscle spasms. These muscle spasms, which usually occur in the wrist which then is hold in a cramped position, often can not be recognized by the patients themselves because they are distracted by anything that has a significant impact on their emotional condition. Spasms often occur if people are in an exceptional emotional condition. This behaviour is the reason for not recognizing the spasm and in addition the resulting pain from the spastic muscles.

These spasms that affected people can not recognize on their own motivated us to design a device that is able to detect occurring spasms in the wrist and in addition alerts the user of the occurring spasm. To support people suffering from cerebral palsy the designed device is able to measure the angle of the wrist and provides feedback for the users.

The first research field that was investigated in this paper was cerebral palsy itself. In order to design a device which should be able to detect spasms it was necessary to get knowledge about the disease and its sequiturs.

In addition other wearable devices have been examined to gain insight into the designing process of wearable devices. Assistive technology products have been examined in order to gain insight into existing devices which try to help people with different impairments. The

last part of the "Related Work" section deals with the phrase "Neuroplasticity" which stands for training the brain in order to train and use healthy brain regions instead of damaged ones to solve problems of the daily life. The designed device should be able to reduce occurring spasms with the help of a neuroplastic effect.

To get a concrete idea of the problems people suffering from cerebral palsy have to deal with, interviews were conducted. To get response from as many points of view as possible we conducted three interviews:

1. A person suffering from cerebral palsy: T.
2. The father of T.
3. A therapist

The guidelines of the interviews are presented and in addition an analysis of the interviews is given. Through the gained statements of those interviews we were able to design the device.

This paper describes all the necessary technical steps to build a full functional spasm detection device including:

- The design of the Proof-of-Concept prototype.
- The building of the Proof-of-Concept prototype.
- The enhancement of the Proof-of-Concept prototype.
- The evaluation of the prototype.

The section "Designing the Proof-of-Concept prototype" deals with the design of the Proof-of-Concept prototype with the help of the information gained through the interviews and the literature. How to measure the angle of the wrist and which sensor fulfils our needs are discussed and the Arduino board which is used for reading out the data from the sensor is presented. In addition the necessary data transmission, a feedback and a logging device are introduced and the additional software which is going to be used is described.

Once the components have been chosen we built our Proof-of-Concept prototype consisting of the mechanical components and the necessary additional software. This Proof-of-Concept prototype is built into a fingerless glove with the sensor on the back of the hand which does not affect the user in his daily life. All the necessary steps of implementing a first full functional Proof-of-Concept prototype including the Laptop, Putty, the Arduino programming environment, the code for the micro-chip of the Arduino, the cable system, Amarino and the logging software are described. The section "Building the Proof-of-Concept prototype" describes all the necessary steps of implementation.

After building the Proof-of-Concept prototype it was tested with friends and family. Soon some disadvantages of the Proof-of-Concept prototype appeared. A battery has to be attached to the device in order to use it in public and not only next to the Laptop used as a current supplier. A self made sensor is introduced in order to achieve more precise data sets and a smaller Arduino board - the Arduino Pro, is used to make the case smaller. Due to the necessary case and the smaller Arduino board a FTDI adapter was used and all the electronic components got soldered together in order to make it more resistant against vibrations. The necessary modifications to make a wearable device out of the Proof-of-Concept prototype are presented in the section "Enhancing the Proof-of-Concept prototype".

After the Proof-of-Concept prototype has been enhanced and evolved into a real prototype an evaluation has been conducted with the help of T., a person suffering from cerebral palsy, who was willing to cooperate with us. The findings of this evaluation are described in the chapter "Evaluation of the prototype". It contains a description of the process of re-designing the device according to the feedback of T. as well as a rating of the functionality.

In the end of the paper possible future improvements are presented and the conclusion is drawn.

1.1 Splitting

This paper is part of a joint master thesis together with my colleague Harald STIX [56]. The second part of the master thesis deals with programming the logger, the feedback device and the motivational system. The device itself is built together which leads to some parts that overlap. These overlapping parts, as long as they are not relevant for further findings, are only described shortly. There will be a sign where to find more detailed information. Figure 1.1 and Figure 1.2 display the divided work and responsibilities in detail.

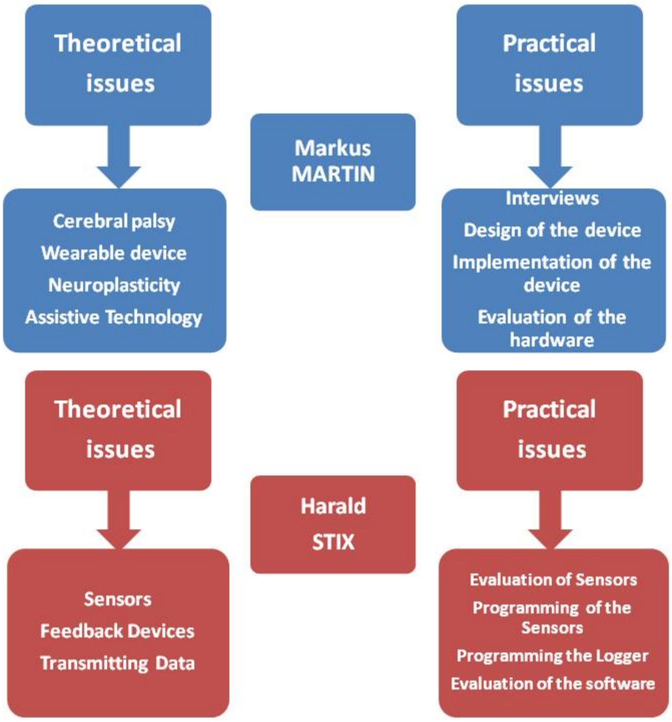

Figure 1.1: A detailed view of the divided responsibilities and work.

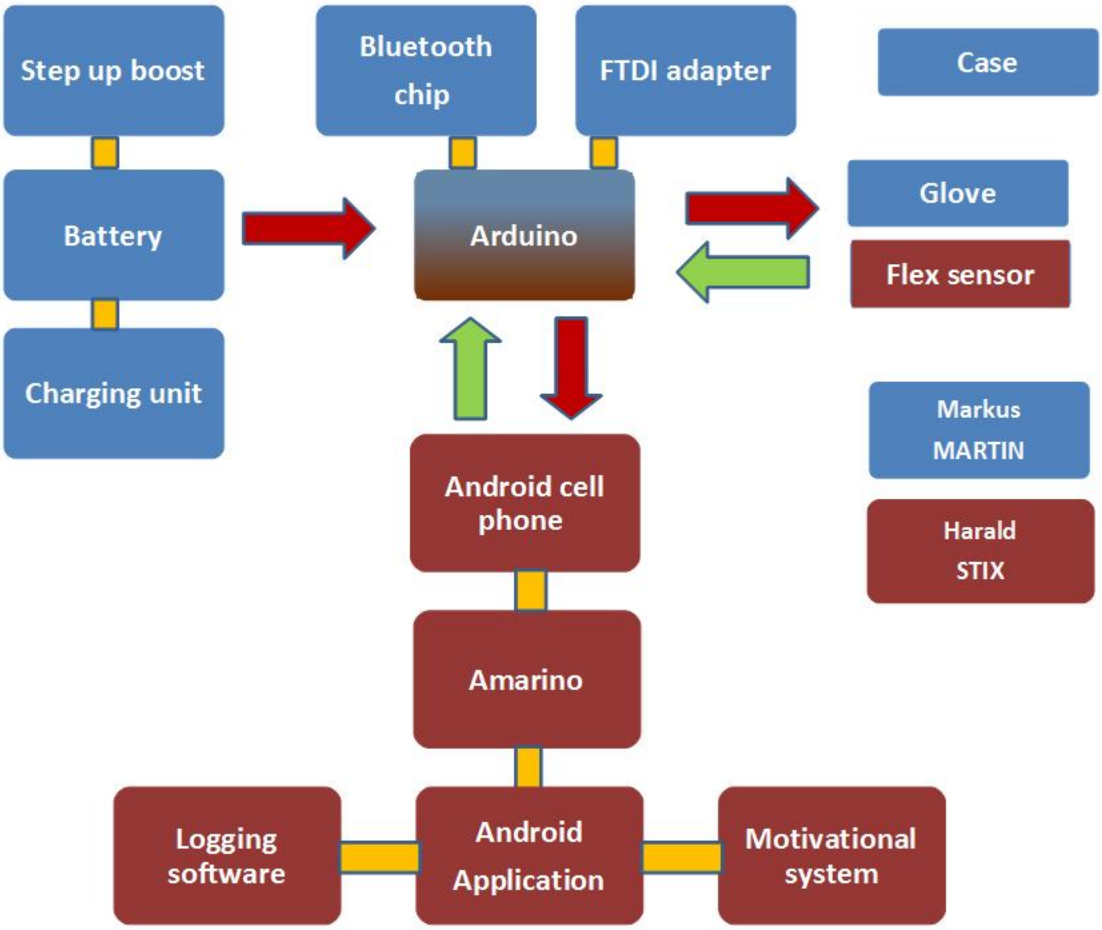

Figure 1.2: The basic scheme of the prototype displays the divided responsibilities.

CHAPTER 2

Motivation and research question of the master thesis

2.1 Motivation

When it was time to think about the upcoming diploma thesis we decided to visit the Human Computer Interaction group of the Technical University of Vienna. We got into contact with Mag. Dipl.Ing. Florian Güldenpfennig who told us that he has a friend suffering from cerebral palsy living in Germany. Soon the idea was born to develop a tool that helps him in his everyday life and maybe can be used as an assistive technology or even training device in order to reduce his occurring spasms.

The motivation of the thesis is to develop a sensor-based device that helps people suffering from spasms and provides feedback if a spasm occurs. By measuring the angle of the wrist these spasms should be detected. Upon this feedback, the user knows that he has to react on the spasm and relax his muscles.

The expected outcome should be a device, that on the one hand detects occurring spasms with sensors, triggers a feedback and keeps track of when and possibly why the spasm occurred and on the other hand forces the user to react on the spasm. Through an integrated motivational achievement system the user should be able to obtain achievements if he reacts fast enough to the occurring spasm. In addition the integrated logger should be able to log important information about the occurring spasms such as duration and time of appearance. These information should be useful for the user himself, therapists and could be used for an advanced medical therapy by analysing it.

Another additional goal of developing this device is to achieve a neuroplastic effect inside the brain of the affected person. This effect should result in new additional neurons which

overtake responsibilities from injured neurons. Such a behaviour should be achieved by training with the device over a long time.

2.2 Research questions

Basically there are three main research questions which shall be answered within this master thesis:

1. Is it possible to design and implement a device which is able to detect occurring spasms in the wrist?
2. Are the logged information useful to support an additional physical therapy or to fit any other needs of analysis?
3. Is it possible to reduce occurring spasms and achieve a neuroplastic effect inside the brain by a permanent training with the device?

The first question is about if it is possible to detect occurring spasms in the wrist by measuring the angle of the wrist. Questions about the necessary hardware and software in order to achieve this goal have to be examined and finally solved. What can be measured by a wearable device? How accurate or reliable is it? What form of feedback will work best for the user? What qualities does the feedback need to respect?

The second question deals with the topic of supporting a possible additional physical therapy. Are there any special circumstances, conditions or moods which intensify the appearance of spasms? Can the automatically logged information and entered comments of the user be used to avoid such situations? Are there any other information that could be useful and therefore should be logged in order to assist therapist or even the user? Or are there any other cases in which the collected data can be useful?

The last question deals with the topic of neuroplasticity. Can the device be used to force the brain to build new neuronal pathways which overtake responsibilities from injured ones? Results the use of the device in a neuroplastic change of the brain and therefore reduces the spasms and how long does it take to make these changes visible? Can this training result in a neuroplastic effect that enables the user to automatically react on an occurring spasm.

This master thesis, in collaboration with my colleague's master thesis [56], tries to answer these questions. In the following chapters and sections of this and my colleague's theses all the work is described in detail and the findings are presented.

CHAPTER 3

Methodical approach

To be able to create a suitable prototype the following methodical approach has been used:

- Searching for relevant literature.
- Interviews with medical experts (e.g. therapists) recruited from hospitals and universities, people suffering from cerebral palsy and relatives from affected people.
- Information gained from the interviews and literature will be used for creating necessary requirements for the product.
- Construction of a Proof-of-Concept prototype.
- First evaluation procedure with healthy people from our environment which should answer the following basic questions:
  - Does the device always work as planned?
  - Can the device be used in daily routine?
- Enhancement of the Proof-of-Concept prototype due to the information from the first testing procedure. This step should evolve the Proof-of-Concept prototype into a real prototype.
- Second evaluation procedure with the help of affected people which should answer the following basic questions:
  - Is the device acceptable?
  - Does it capture all relevant data?
  - Is enough information gained to help?
  - Can the effect be improved any further?

- Possible redesign of the prototype according to the second evaluation procedure.
- Summative evaluation if the wearing of the device actually results in ability to control spasms, decreased spasms and possible evidence of neuroplastic change.

The approach of creating a full functional spasm detection device involved four main steps. First of all appropriate literature had to be found in order to achieve knowledge of the basic theoretical issues like for example cerebral palsy.

The second step included qualitative semi structured interviews with different people. The goal was to find people who are suffering from cerebral palsy, relatives of these patients and therapists. This broad selection of people should guarantee detailed information from different points of view such as requirements and restrictions for building a useful device for affected people.

Once all the necessary information had been obtained, the designing and building of the Proof-of-Concept prototype could be started. The combined knowledge from both, the literature and the conducted interviews, were taken into consideration and resulted in a suitable device for detecting and dealing with spasms.

After building a first Proof-of-Concept prototype the evaluation process started. First this constructed prototype was tested by ourselves and friends to receive a first feedback. After some improvements by which the Proof-of-Concept prototype had been evolved to a real prototype the device was tested by affected people themselves in order to guarantee the usefulness for them.

More details about each step of the methodical approach can be found at the following sections.

3.1 Literature

This master thesis is part of a joint master thesis. Since the work is divided and presented in two different documents each of them focuses on different theoretical and practical issues. As far as the theory is concerned this master thesis focuses on cerebral palsy, wearable devices, neuroplasticity and assistive technology literature.

Reading literature dealing with cerebral palsy results in gaining knowledge about spasms, how they occur, how they affect people suffering from that disease and how they can be treated.

Literature about existing wearable devices and assistive technology devices provides information about the current state of wearable computing. In particular wearable computing will be examined to find opportunities of how to provide help for affected people.

Finally literature about neuroplasticity results in gaining knowledge of the complex functionality of the human brain and how an intensive training can be used to train healthy regions of the brain to overtake tasks from injured regions.

Information about other useful areas of research such as sensors, feedback devices and transmitting the collected data can be obtained from the second master thesis [56].

3.2 Interviews

These examined parts of theory were combined with qualitative semi structured interviews to get a concrete idea of how to design a device that matches the needs of the future user best and to achieve the best medical effect. One part of this thesis was to explore the design space.

To get an idea of what it means to cope with cerebral palsy in daily life and to get deeper involved into it, several interviews have been conducted. Although we wrote several e-mails or even phone called specific neurological institutes like the NRZ- Rosenhügel or the neurological institute of the AKH Vienna we did not find people who were willing to cooperate with us or gave us the chance to talk with them. Most of the physicians we talked to said that they do not have enough time to deal with our project. People suffering from cerebral palsy we asked for help mentioned that they do not want to participate because they will feel themselves uncomfortable while talking with us. Finally we got in contact with three people which were willing to cooperate with us. These people are presented in the chapter "Interviews". As a method of research we used semi structured interviews, which were quite flexible and allowed new questions to rise during the interview as a result of what the interviewee said. Before the interviews we set up a framework of themes to be explored. In the appendix section the used guidelines for the semi structured interviews are presented.

3.3 Building a prototype

After the necessary literature had been examined and the interviews had been conducted the gained information were used to create a specification for the spasm glove. This specification included all necessary requirements for developing a first attempt of a suitable proof-of-concept prototype which was able to detect occurring spasms in the hand by measuring the angle of the wrist. In addition the user was alerted and encouraged to react to the spasm. This often repeated training with the device should hopefully result in a neuroplastic effect inside the brain of the user and therefore reduce the amount of occurring spasms over the course of time. The process of building multiple versions of the prototype is described in detail in the section "Development of the prototype".

3.4 Evaluation of the prototype

After building a first proof-of-concept prototype, a first evaluation procedure was started, including tests conducted by ourselves, friends and family members. The goal of this first testing procedure was to gain information about the usefulness of the current state of development. The results of the first testing procedure are described in detail in the section "Enhancing the Proof-of-Concept prototype". Once the necessary adoptions of the Proof-of-Concept prototype had been realized and the Proof-of-Concept prototype had been evolved into a real prototype the second evaluation procedure including the tests with an affected person named T. was started and possible resulting final necessary adoptions were implemented. The process of the evaluation is described in detail in the chapter "Evaluation of the prototype".

CHAPTER 4

Related Work

4.1 Cerebral palsy

Overview

One of 400 worldwide born babies is suffering from cerebral palsy. Currently there are no available pre – born opportunities to test if a child is affected. The typical symptoms of cerebral palsy are motor impairments, global physical and mental dysfunctions, caused by damage to the developing brain, usually before birth. In general three main types of cerebral palsy can be distinguished, but all of them affect the way of how a person moves, resulting in unpredictable movements, stiff or tight muscles, shaky moments or tremor. The range of cerebral palsy can differ from a small weakness in one hand to a complete loss of the ability to control movements in the other hand [36].

In addition affected people often suffer from epileptic seizures or other dysfunctions concerning their speech, vision, intellect, hearing or perception. There is no cure for cerebral palsy at the moment but different ways of therapy, trying to provide help for affected people [36].

Clinical symptoms

Although cerebral palsy in most cases already exists before birth, the classical symptoms usually occur or can be discovered after 12 - 18 months, usually when the parents of the child start to recognize that their child behaves or moves differently than other contemporaries. The symptoms of patients suffering from cerebral palsy are characterized by a high degree of diversity. An inability to fully control motor function, particularly muscle control and coordination are only some of the occurring symptoms. Due to spasticity muscle imbalance can lead to complete dislocation of hips. Some people concerned have disorders of hearing or eyesight, others suffer from epilepsy with recurring seizures [52].

Mental disability and learning difficulties are also within the scope of cerebral palsy. The degree of learning difficulties and intellectual disabilities may range from soft to very significant [52].

Perceptual difficulties, which mean that the ability to create information from the senses is aggrieved, can also occur. The brain of affected people has problems of handling the information gained from the senses [52].

Speech, eating and drinking difficulties are serious problems due to certain muscles which are responsible for opening and closing the mouth, lips and the tongue. This results in problems with speaking, chewing or swallowing food [36].

Difficulties with feeding, bladder and bowel control can appear. Skin disorders because of pressure sores and problems with breathing due to postural difficulties may also arise [36].

Impaired oral-motor function occurs commonly in patients with cerebral palsy, precipitating hypoxemia, temporomandibular joint contractures, vomiting, and aspiration pneumonia associated with gastroesophageal reflux. These conditions can cause lengthy mealtimes and fatigue, contributing to malnourishment [52].

Reduced bone mass can occur, resulting in osteopenia, osteoporosis and fractures in most cases [52].

Patients with cerebral palsy have a higher risk to suffer from ischemic heart disease, cerebrovascular disease and digestive disorder, resulting in a higher mortality compared to healthy people. In addition the risk of getting brain and breast cancer is highly increased [52].

Most of the patients suffering from cerebral palsy are under the influence of chronic pain, social isolation and loss of independence resulting in problems with mental health and depressions [52].

Concurrent causes

The reason for cerebral palsy is an injury to the brain before the development is completed. The human brain still develops until the first two years of life, so a serious brain damage can occur during the prenatal or postnatal period [36].

Most of the affected people suffering from cerebral palsy are born with the disease, although the classical symptoms can occur years later. This kind of cerebral palsy is named congenital cerebral palsy. Explanations for this medical condition are problems occurring during labor for example the lack of oxygen during birth (asphyxia, 5-10 percent).

By contrast only a few of the affected patients are suffering from acquired cerebral palsy which means that the disorder takes place after the birth. Explanatory reasons are brain infections or head injuries [34].

The remaining 90-95 percent can be divided in three specific types of brain damage [34]:

- Damage to the white matter of the brain (periventricular leukomalacia)
  The transmission of signals in the brain and the rest of the remaining body are functionally limited.
- Abnormal development of the brain (cerebral dysgenesis)
  Mutations of genes, infections, fever or trauma restrict a healthy development of the brain.
- Bleeding in the brain (intracranial hemorrhage)
  Caused by blocked or broken blood vessels.

Risk factors

In addition to the causes risk factors exist which are responsible for increasing the risk of suffering from cerebral palsy. Premature babies who do not cry, babies who need to breed on a ventilator or newborns with broken blood vessels which cause brain bleedings have a highly increased risk to come down with cerebral palsy. Also seizures of the baby can be responsible of getting affected [43].

The health status and social habits of the mother have a significant impact on the health of an unborn baby. Drugs, alcohol, malnutrition or even smoking can lead to a low birth weight or even damage the brain of the baby. The age of the pregnant woman and the age of the father is also important. Mothers over 40 and fathers less than 20 years old have a higher risk of getting a baby suffering from cerebral palsy [43].

Infections and blood diseases of the pregnant mother are also associated with increasing the risk of developing cerebral palsy for the baby. Rubella, toxoplasmosis and cytomegalovirus can lead to brain damage of the fetus [43].

Medical mistakes such as not performing a cesarian section when the fetus is in danger or not responding to high blood pressure of the mother can also cause cerebral palsy of the unborn baby [43].

Main types of cerebral palsy

Three main types of cerebral palsy can be distinguished [52]:

- Spastic cerebral palsy
  Stiff or tight muscles make movement difficult or nearly impossible. Approximately 80 percent of patients suffering from cerebral palsy are affected.

- Dyskinetic cerebral palsy
  Affected are about 10-20 percent of people suffering from cerebral palsy. There are two forms:

  - Athetosis
    Uncontrolled, slow movements.
  - Dystonia
    Sustained or intermittent muscle contractions causing twisting or repetitive movements.

- Ataxic cerebral palsy
  Least common type of cerebral palsy, 6-9 percent of patients are affected. Characteristic are shaky movements influencing balance and coordination.

Many patients suffer from more than one of the three types. The most common mixed form includes spasticity and dystonic movements.

Affected parts of the body

Cerebral palsy can affect different parts of the human body. Which part of the body is concerned differs from patient to patient. To describe the affected regions of the body there are some standardized terms [52]:

- Hemiplegia
  Leg and arm of one side of the body are affected (Figure 4.1).

- Diplegia
  Both legs and arms are affected, the legs considerably stronger (Figure 4.1).

- Quadriplegia
  Both legs and arms, sometimes the muscles of the trunk, face and mouth are affected (Figure 4.1).

Figure 4.1 shows the possible different affected areas in detail.

Diagnosis

By the monitoring of slow motor development, abnormal muscle tone and unusual posture compared to other commensurable children it is possible to gain the first indication of cerebral palsy. By measuring persistent infantile reflexes it is also possible to gain a more detailed assessment of the disease [8].

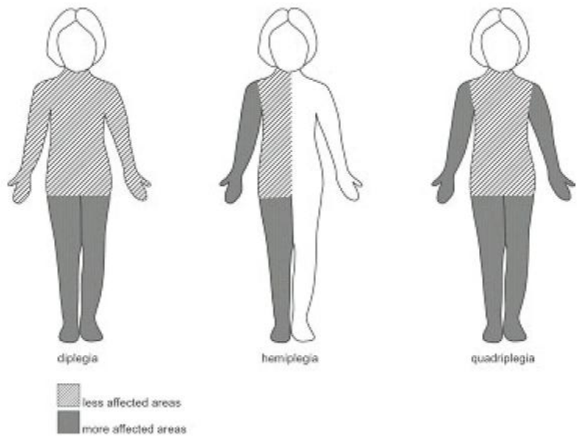

Figure 4.1: Standardized terms of cerebral palsy [52].

In response to a certain act the human body reacts with a specific movement automatically. This reaction is called reflex. For example the Moro reflex: a typical reaction of babies which are held on their backs and tilted so that their legs are above their heads, resulting in extending their arms in a gesture that looks like an embrace. Normally newborns loose this reflex after 6 months but babies suffering from cerebral palsy retain it for a longer period of their life [8].

Another possibility is to determine the hand preference of a baby. Unaffected babies usually develop this ability within 12 months of their life, but infants suffering from spastic hemiplegia develop a preference earlier, since the hand of the unaffected side is much stronger and more useful for the baby [8].

If a baby is suffering from movement problems, it does not necessarily mean that cerebral palsy is responsible for that condition. The next step of the diagnosis strategy is to rule out other disorders, like tumors in the nervous system or muscle diseases. Although the typical symptoms can change over time, cerebral palsy is not progressive. If the medical condition of a child is getting worse over the time, the reason can sometimes be found in other diseases. To rule out other disorders the child's medical history is very important and additionally repeated check-ups are performed [8].

Nowadays the strategy to examine if someone is affected consists of the clinical picture, patterns of development of symptoms, family history, targeted laboratory tests and cerebral imaging such as computed tomography and magnetic resonance imaging. Scans from the brain can be useful to find underdeveloped areas or abnormal cysts filled with liquid inside the brain [8].

Another technical approach to determine whether the brain is affected or not, is called ultrasonography. The advantage of ultrasonography is that it can be used before the bones of the skull harden and close and is also able to analyze the brain of the infant [8].

The final step of the investigation is to look for disorders that are linked to cerebral palsy such as seizures, mental impairments or hearing, vision and eating problems [8].

Assessment instruments

Due to the fact that cerebral palsy is not curable at all, it is necessary to classify all disorders of the affected people. This is useful to assess the quality of life of people suffering from cerebral palsy and to assist the people who take care of the patients [30].

There is a large amount of such instruments such as the Child Health Questionaire [30], the Wong-Baker FACES Pain Raiting Scale [30] or the Gross Motor Function Classification System for Cerebral Palsy [30].

Functional Classification Systems like the Gross Motor Function Classification System for Cerebral Palsy [30] try to classify movements of affected people and measure changes in gross motor functions over time in order to predict how the disease could develop.

Figure 4.2 shows the Gross Motor Function Classification System for Cerebral Palsy.

In addition to functional classification systems there are other classification systems which try to measure the amount of assistance a person would require to survive, to measure the level of pain a person is exposed or to grade muscle spasticity [30].

Therapy

Cerebral palsy is currently not curable at all. The objective is not to cure but to increase functionality, social interaction and independence. The best results can be achieved with a team approach, consisting of physicians, orthopaedists, physical therapists, occupational therapists, speech and language pathologists, social workers, psychologists and educators. Modern treatments consist of a global strategy that tries to improve the medical condition of the whole patient, not only the improvement of a single symptom. Due to the specific symptoms of the patient the range of the applied therapy differs from physical therapy to medication use or even surgery [34].

A common global strategy to enhance the medical condition of people suffering from cerebral palsy is called Neurodevelopmental treatment. The goal of this strategy is to control sensorimotor components of muscle tone, reflexes, abnormal movement patterns, postural control, sensation, perception and memory by utilizing specific handling techniques. Another approach, conductive education, focuses on an integrated model of education and

Gross Motor Function Classification System for Cerebral Palsy

Before second birthday

Level I	Infants move in and out of sitting and floor sit with both hands free to manipulate objects. Infants crawl on hands and knees, pull to stand, and take steps holding onto furniture. Infants walk between 18 months and two years of age without the need for any assistive mobility device.
Level II	Infants maintain floor sitting but may need to use their hands for support to maintain balance. Infants creep on their stomachs or crawl on hands and knees. Infants may pull to stand and take steps holding onto furniture.
Level III	Infants maintain floor sitting when the low back is supported. Infants roll and creep forward on their stomachs.
Level IV	Infants have head control but trunk support is required for floor sitting. Infants can roll to supine and may roll to prone.
Level V	Physical impairments limit voluntary control of movement. Infants are unable to maintain antigravity head and trunk postures in prone and sitting. Infants require adult assistance to roll.

Figure 4.2: Gross Motor Function Classification System for Cerebral Palsy [30], extracted from the whole classification system.

rehabilitation rather than a medical approach. Beside this form of therapy there are many other physical therapies available [34], [43].

Physical exercises strengthen the muscles, but supporters of the neurodevelopmental treatment try to avoid fitness programmes because they are suspected to strengthen spasticity. Several case studies rejected this opinion and figured out the effectiveness of resistive exercises [34], [43].

Medication is also very common within the therapy of cerebral palsy. Botolinum toxin (Botox), derived from the bacterium Clostridium botulinum is able to block the release of acetylcholine and relaxes muscles. Baclofen (Lioresal) is used within spastic and dystonic cerebral palsy [29], [34], [43].

To reduce effects of cerebral palsy, surgery can be used. To eliminate spasticity, selective dorsal rhizotomy, has been invented. During this procedure dorsal rootlets from spinal cord segments L1 to S2 are selectively resected. Harmful secondary effects of this procedure can be bladder or bowel dysfunction, prolonged marked hypotonia, back pain or spinal deformities [34], [43].

Due to spasticity muscle imbalance can lead to complete dislocation of hips. Approximately 59 percent of people suffering from cerebral palsy have problems with their hips. The treatment containing surgical interventions consists of non-invasive abduction bracing, soft tissue releases, major reconstructive femoral osteotomies and salvage procedures such as proximal femoral resection [34], [43].

Problems with swallowing food can be treated by feeding the patient with the help of nasogastric tubes. Secondary effects of this treatment include nasal discomfort, recurrent aspiration pneumonia caused by tube displacement and decreased survival [34], [43].

Due to chronic pain, social isolation and loss of independence people suffering from cerebral palsy have often problems with their mental health. Specialized devices such as motorized wheelchairs and voice synthesizers provide help for decreasing occurring barriers. Assessments are necessary to ensure that the provided equipment fit the needs of the handicapped patients. Caregivers ensure that the patients are familiar with utilising their equipment, avoid dangerous situations in traffic and daily life. Care plans should incorporate all family members, not only the patients, and the prime target should be the well being of all involved people [34], [43].

Due to increased survival of newborns with low birth weight and increased longevity of the adult population the number of adults with cerebral palsy is currently increasing. Older patients often suffer under more restrictive abilities of gaining help including technical devices or medical services from the authorities because of declining services and aging caregivers. To ensure a continuity of care attorneys, placement options, medical surrogate identification and living wills should be explored [34], [43].

Challenges for people suffering from cerebral palsy

Since the second half of the 20th century, people suffering from Cerebral Palsy regularly survived to their adulthood, because of improvements in medical care, rehabilitation and assistive technologies. This causes some medical and functional problems [34], [43]:

- Premature aging:
  The majority of affected people will experience some form of premature aging caused by extra stress and strain put upon their bodies by the disease. The organ systems are kept from developing to their full capacity and therefore have to work harder and age prematurely.

- Functional issues at work:
  The daily challenges at work will increase when an employee suffering from cerebral palsy reaches middle age. Some can continue working with supportive therapy, adjusted work schedule or assistive technologies, but for others, early retirement may be necessary.

- Depression:
  This can occur independently from the severity of the decease and depends on how successful people are coping with disappointment and stress and if they have optimistic future prospects or not.

- Post-impairment Syndrome:
  A combination of fatigue, pain and weakness can occur because of muscle abnormalities, bone deformities and arthritis. Especially fatigue often is a problem, caused by the higher amount of energy that is needed by people suffering from cerebral palsy to walk and move.

- Pain:
  This issue often goes unrecognised by medical healthcare, because people suffering from cerebral palsy may not be able to describe where the pain is located exactly and how strong it is. It can be chronic or acute and most commonly experienced in the hips, knees, ankles and back. The best treatment for this pain is preventive with corrections of muscle and skeletal abnormalities.

- Because of the longer life of affected people, they often outlive their main caregivers which causes an issue of long-term care and support which should be taken care of.

4.2 Wearable devices

Overview

To assess occurring disabilities within hand functions several kinds of measurements are required. Grip and pinch strength, sensitivity to temperature and vibrations, joint range of motion (ROM), and functional abilities have to be assessed in order to get a useful diagnosis and being able of planning the rehabilitative treatment [16].

The required measurements are traditionally performed by therapists via mechanical goniometers placed on each hand joint. In this case the data recording is performed manually although several sources of errors like the examiner or the patient himself can affect the measurement [16].

Typical problems with goniometric measurements which may affect the result [16]:

- Inexperienced examiners
- Instrument errors
- Wrong choice of the size of the goniometer corresponding to the size of the measured hand joint
- The physical condition of the patient
- ROM informations have to be captured simultaneously from all hand joints

- Static ROM measurements by goniometric devices do not fulfil complex and dynamic hand tasks

To overcome these restrictions the use of glove based devices can be recommended. These devices, usually designed for gesture based applications, are able to erase the occurring problems with goniometers by establishing an objective, standardized procedure for measurement of hand function. The subjective interpretation of the examiner is also eliminated by the use of glove based devices. In the following subsection some glove based devices are introduced [16].

Glove based devices

Humanglove

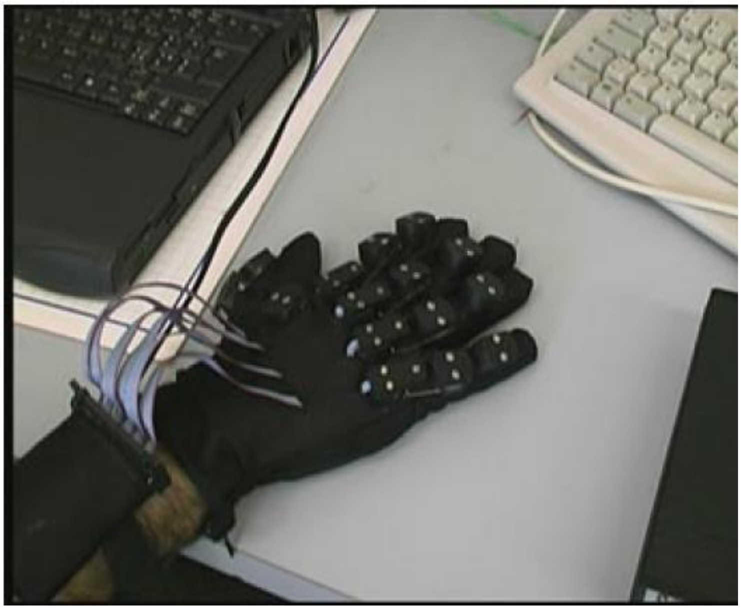

Figure 4.3: The Humanglove [16]

The Humanglove [16] is one of this glove based devices, commercialized by Humanware. It is a simple sensorized elastic fabric glove. 20 Hall effect sensors are placed on it. Each of the sensors measures data related to a degree of freedom of the hand. Through a standart RS-232 the glove is connected to a computer, hosting the graphical software package Graphical Virtual Hand. The programme is responsible for calibrating the glove and displaying a virtual hand on the screen corresponding to the movements of the user. The data is stored in ASCII format in the background. Figure 4.3 shows the Humanglove.

Digital Data Entry Glove

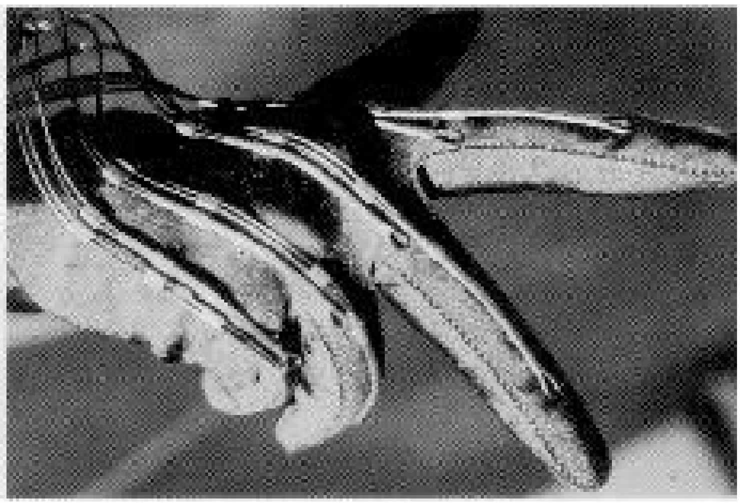

Figure 4.4: The Digital Data Entry Glove [18]

The digital data entry glove was developed by Visual Programming Language, Inc., as a gesture recognition tool. The movements and inflections of the individual fingers of the hand are measured by fiber optic cables on the back of the hand. For each finger (except the thumb) two cables are provided. One of these cables is placed on the first finger joint, the second one on the second joint. The cables are running back in a loop from the controller to the fingers. At one end of each cable light is sent via an LED into the cable. At the other end of the cable the incoming light intensity is measured by a photocell and converted into identifiable electrical signals. Through this signals the computer is able to visualize the finger movements of the hand [57]. Figure 4.4 shows the Digital Data Entry Glove.

Cyber Glove

The Cyber Glove was developed by the Virtual Space Exploration Laboratory of Center for Design Research, Stanford University. It is based on piezoresistive sensors and currently there are two different versions available [61]:

- 18 – sensors: two bend sensors on each finger, four abduction, sensors measuring thumb crossover, palm arch, wrist flexion and wrist abduction. Open fingertips are useful for writing, typing and grasping objects.
- 22 – sensors: three flexion sensors on each finger, four abduction sensors, one palm arch sensor and sensors to measure flexion and abduction.

Through its stretch fabric construction principle the Cyber Glove is very comfortable. A mesh palm is used for ventilation during the usage. The basic Cyber Glove package contains one glove, two batteries, a battery charger and USB/Bluetooth adaptors. On the wristband there is a software programmable switch and LED to permit system software

Figure 4.5: The Cyber Glove [40]

developers to provide the Cyber Glove user with additional input/output capability [61]. Figure 4.5 shows the Cyber Glove.

Fakespace Pinch Glove

The Fakespace Pinch Glove was developed as a reliable and low cost device for recognizing natural gestures. It is a hand gesture interface system that is able to allow developers and users of immersive applications to use hand interaction to work within the virtual environment [20], [62].

In each fingertip of the cloth gloves are electrical sensors. The contact between two or more sensors completes a conductive path. A complex variety of actions based on these simple gestures can be programmed into applications. In addition to the Pinch Glove Fakespace provides a huge range of additional products and services for virtual environment technology such as hardware, software tools and peripherals.

Figure 4.6: The Fakespace Pinch Glove [1]

The basic setting contains a pair of gloves, interface electronics, a user guide, software and tracker mounts. With a standardized RS-232 cable the gloves can be used with any workstations or personal computers around. Figure 4.6 shows the Fakespace Pinch Glove.

4.3 Neuroplasticity

Overview

The design of the spasm glove is based on two main ideas. First it should be able to detect occurring spasms by measuring the angle of the wrist and alerting the user. The second goal is to achieve a reaction inside the white matter of the brain by using the device and the especially the software again and again.

The human brain is able to recover from serious damages to a limited extent. The medical term for this process is "Neuroplasticity". By forming new neural connections throughout life the brain's ability to reorganize is given. Responsible for this are tiny neurons which react to new situations or changes in their environment by adjusting their activities and therefore compensate for injuries and diseases [24].

Axons of healthy neurons are able to grow new nerve endings to reconnect damaged neurons which nerve endings are dysfunctional. In addition healthy or undamaged axons can sprout out new nerve endings and connect with other healthy nerve endings in order to form new neural pathways to accomplish a needed function which can not be performed any more due to damaged pathways [24].

The ability of the neurons to compensate for damage by forming new connections can be used to recover from serious damage to the brain too. Healthy regions may take over functions from damaged areas by forming new neural connections. To achieve such a behaviour of the neurons they need to be correctly stimulated through activity [24].

The process of neuroplasticity

The human brain consists of millions of cells. These cells are connected with neurons which have many axons that establish a connection between the cells. Chemical informations called neurotransmitters can be released by an axon to a network of other neurons where dendrites capture the signal. On the dendrites are many synapses consisting of signaling and receiving cells. These synapses are responsible for transmitting the information encoded in chemical informations between the network of neurons [23].

If the brain or the spinal cord is damaged, like in the case of people suffering from cerebral palsy, the damaged areas perhaps can be repaired with the help of Neuroplasticity. Inside the human brain are so called stem cells. These cells are uncommitted and when they divide they can on the one hand rise to itself or on the other hand rise to a neuron [23].

Studies like [22] showed that if these stem cells are extracted, cultured an transplanted back in the nervous system they evolve from stem cells to neurons. The brain therefore is able to repair itself to a limited extend. As a stem cell divides itself a new stem cell is born. In order to survive it has to move away from the origin stem cell. Nearly 50 percent of newborn stem cells die on their way to other areas of the brain. They need a month counting from the birth to get fully functional cells. According to [23] many factors like brain-derived neurotrophic factor (BDNF) and insulin-like growth factor play an important role if a new cell survives and can get functional without an extraction and implantation.

If a region of the brain is damaged the brain tries to bring new cells to that region. Unfortunately for the most diseases this micro-repair is not enough to establish a 100 percent recovery. The medicine today has to learn about the factors that regulate each of the components of Neuroplasticity in order to controll [23]:

- Cell proliferation
- Migration of new cells to damaged areas
- Specialise the cells into the needed type

According to [22], [23] the future will bring medication that will be able to stimulate components of Neuroplasticity. Combined with a very specific physical therapy that activates affected areas of the brain and therefore ensures that new cells are accepted and integrated correctly a cure for diseases like cerebral palsy or spinal cord injuries can be found.

Classification of neuroplasticity

As stated in [23] the human brain is able to repair itself to a limited extend. Unfortunately this skill is to weak to secure 100 percent of recovery. The complex processes of Neuroplasticity are currently under investigation but according to [60] there are four main types of the plasticity of the human brain:

- Evolutionary plasticity
- Reactive plasticity
- Adaptation plasticity
- Reparation plasticity

Evolutionary plasticity stands for the growing of the human nervous system since the birth. This may result in negative effects like diseases.

Reactive plasticity may appear after a transient exposition to a significant stimulus. It can be seen as a reaction of the human brain to an event.

Adaptation plasticity is the opposite form of the Reactive plasticity. In this case the stimulus is present over a long time or repeated several times. This form can be used for training programmes and rehabilitation issues.

The last case, Reparation plasticity, appears if neurons are impaired. It results in functional and structural recovery of the affected neurons. It is also used for rehabilitation issues through training specific tasks.

An example of neuroplasticity: The musician's brain

According to [60] the human brain is able to react to a certain stimulus. If the stimulus is strong enough or repeated many times the neurological network gets restructured due to the stimulus. In [33] an interesting study concerning the plasticity of the human brain is presented. In this study the prove is given that musicians have larger responses to tones than non musicians. In addition the musicians are even better in detecting errors in compositions and they are more able to distinguish tones. After years of musical training the neurological network of the brain of musicians seems to be more shaped than the brain of non musicians. The parameters that are needed for acquiring these skills are unknown but scientists believe that a continuous stimulus is responsible for building new neurological pathways in the brain which equip the musician with these skills.

Due to a continuous stimulus the brain is able to build new connections [33]. The human brain consists of various areas which are responsible for different tasks. Through multiple high resolution magnetic resonance imaging scientists are nowadays able to find out the main reason for gaining new skills: Anatomical differences inside the brain between people with different professions. In the case of the musicians the study shows that many different areas of the brain have been restructured:

- The planum temporale
- The anterior corpus callosum
- The primary hand motor area
- The cerebellum

These modifications inside the brain have a significant impact on the skills of a musician. Due to the study [33] the planum temporale for example is responsible for cerebral dominance as a reaction to handedness whereas the cerebellum is responsible for the timing of the movements.

According to [19] motor learning occurs in three phases:

- Fast initial phase of performance gain

- Period of consolidation for several hours
- Slow learning phase which finally leads to an improvement of the skills

The fast initial phase occurs directly after the stimulus has been set. Performance gains can be observed but these gains soon disappear if the stimulus, in the case of the musicians the practice of playing an instrument, is stopped.

The period of consolidation last for a few hours. In this phase the new obtained skills can be improved and "mentally saved" to the brain. Nevertheless the skills can disappear after a few days without practice or stimulus.

Finally the slow learning phase is responsible for changing the brains anatomy. Due a continuous stimulus or learning process lasting for at least months or even years the brain reacts to the stimulus and reconstructs its network [19]. This reconstruction in some areas of the brain is responsible for creating abilities that other humans don't possess.

According to [33] there exists also a dark side of Neuroplasticity which can also be observed at the example of musicians. A disorder named "musicians cramp" or "focal dystonia" which stands for loss of control and degradation of skilled hand movements. Responsible for this disorder are rapid, stereotypical movements in a learning context. These often repeated movements which typically appear while learning to play an instrument are unfortunately able to affect or even degrade the cortical representations of sensory information that are responsible for fine hand movements [12].

Neuroplasticity and pain

People suffering from cerebral palsy often have to deal with pain issues. Acute pain like a muscle spasm can develop into chronic pain over time even no spasm occurs. Through the invention of MRI scans researcher nowadays are able to examine the brain of affected people while they experience chronic pain. In [5] is stated that patients suffering from chronic pain often have brain atrophy in the brain due to degeneration of the neurons. The loss of gray matter seems to be the connection between neuroplasticity and chronic pain.

The relevant changes are due to pain memory and not from pain related activity or medication. No matter what is causing the chronic pain there is an neuroplastic reaction in the brain in the same areas. Regions of the brain that are responsible for suppression or lessening of painful sensations are affected by the loss of gray matter.

Rehabilitation

Santiago Ramon y Cajal [64] stated that the human central nervous system is hard-wired, non malleable and incapable of repairing itself. Nowadays the medical opinion about that differs from this approach.

In [9] is stated that the old used system for rehabilitation issues was a compensatory clinical model. Patients have to compensate their restrictions, use other abilities or simply modify the task to complete it. The cause of the restriction is not treated but the effects of the cause can get circumvented. In contrast to this approach a new model has been invented: Activity-Dependent Plasticity and Recovery.

With the help of this new approach therapists consider the use of assistant devices within the context of providing a training experience. Therefore therapists shift their paradigm of rehabilitation from compensation to recovery.

A simple example for understanding the main difference between the two rehabilitation models delivers a person suffering from an injury of the spinal cord resulting in a paresis of the legs which leads to problems while walking. In the compensation approach the first step will be an operation. If the operation is performed but the paresis is still present the compensatory model will recommend using walking canes or even the use of a wheel chair instead of walking in order to reduce or eliminate the disfunction.

The second approach, the recovery model, will focus on relearning of walking without walking canes or the wheelchair. The neurons are able to reconnect over time if they are stimulated by a training program that delivers enough qualitative input. Maybe helpful devices are used at the begin of the training program but the main goal of the Activity-Dependent Plasticity and Recovery approach is to gain a total recovery from the injury over the time. Healthy neurons should learn and incur tasks and responsibilities from injured regions.

Neuroplasticity and the spasm glove

The spasm glove should be designed to fit two requirements. First the angle of the wrist should be measured in order to detect an occurring spasm. With the required equipment the user should be warned and informed over a developed software on the smartphone.

The second goal of our project deals with the topic of Neuroplasticity. The software which is going to be written in Android should be able to alert the user of an occurring spasm and in addition provide the possibility to react and deal with the spasm as good as possible.

Studies like [19], [23] or [33] showed that an often repeated stimulus can have an significant impact on the brains neuronal network. The brain tries to react on this input and establishes new connections between neurons which leads to improved or even new skills. In case of a disease of the brain it is also possible to force healthy neurons to undertake tasks from injured brain regions.

The disability to use the hand for example is often considered as a long term effect of a stroke. Through an intensive training programme in a rehabilitation institute people suffering from this issue are often able to use their hands or feet again. Although the functionality of their extremities can often not be restored to 100 percent an improvement can be achieved in almost every single case.

The software running on the smartphone should be designed to force the user to deal with an occurring spasm. Components like rewards for a fast reaction and a dedicated achievement system as well as instructions by the software should lead to a stimulus for the brain.

Through an often repeated handling with the spasm glove and the software on the smart phone a training effect should occur. To achieve this it is necessary to wear the device as often and as long as possible. To sum up the spasm glove should be able to establish a permanent training environment for the user initiated by occurring spasms. On the one hand the hardware will be able to detect the spasms and on the other hand the software on the smartphone will be designed to generate a stimulus for the brain in order to achieve a kind of Neuroplasticity over time which hopefully increase the quality of life of people suffering from cerebral palsy.

4.4 Existing assistive technology

Classification of disabilities

According to the World Health Organization different disabilities can be classified into three main categories. These categories are described in a program entitled "International Classification of Functioning, Disability and Health" [35].

- Impairments
- Disabilities
- Handicaps

Impairments are classified as a disturbance of the biological and / or mental structure and function. In addition a loss or a standard deviation in the psychological, physiological or anatomical structure are described by this term.

Disabilities are considered as levels of disturbance of the ability of the concerned person, to carry out purposeful actions and restrictions or any loss of ability, as a result of damage, to perform activities in the manner or to the extent that is considered normal for a human being. Disabilities are basically considered to have an impact on activities.

Handicaps are levels of disruption in social positions and roles of the person or their abilities to participate in social life. Handicaps are basically considered to have an impact on participation issues.

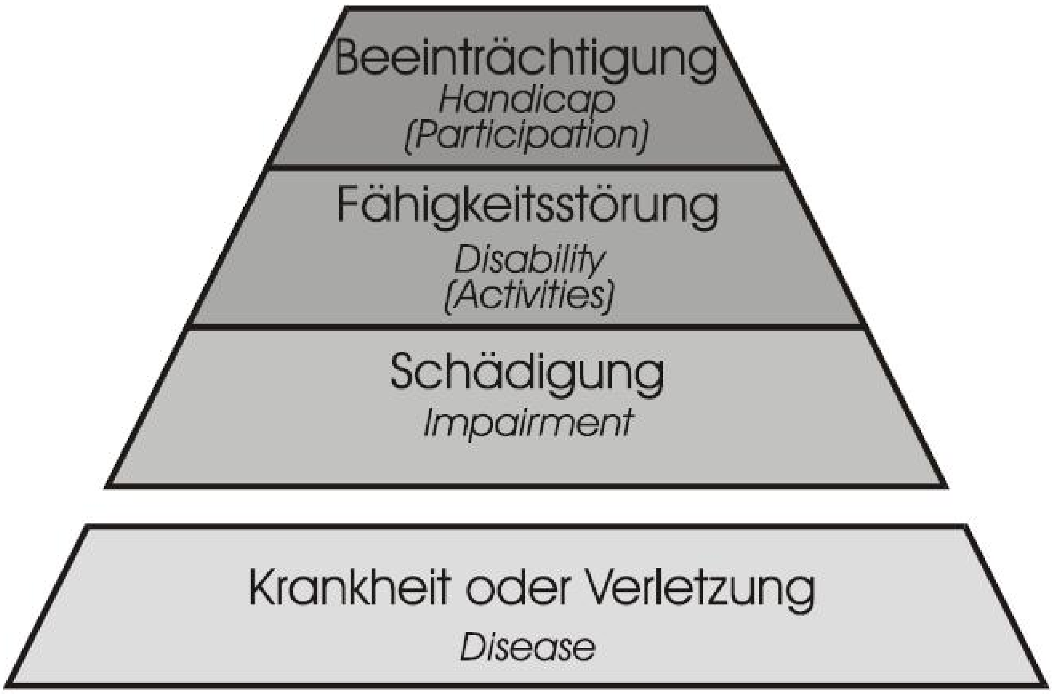

Figure 4.7: The pyramid of classification [66]

Figure 4.7 displays the pyramid of classification from the World Health Organisation [35].

Rehabilitation technology

Medicine today consist of several steps [66]:

1. Prevention
2. Clinical diagnostics
3. Therapy

4. Aftertreatment

5. Rehabilitation technology

In order to prevent some diseases, prevention issues can be used. Sports, for example, are considered to prevent people from suffering from musculoskeletal system diseases.

If there are already symptoms which indicate a disease, clinical diagnostics are used to specify the kind of illness.

A suitable therapy can be used to get rid of the symptoms and be healthy again.

If it is not possible to recover from the disease immediately, a long term rehabilitation can be useful to become healthy again.

If it is not possible to recover after a long term rehabilitation, the application of technical devices or systems that can compensate a functional restriction can be useful.

The goals of nowadays rehabilitation and assistive technologies are to equip people with handicaps and / or disabilities, with devices that are developed to overcome certain impairments to a mostly limited extinct. In addition it should be possible to overcome effects of illnesses and disabilities without having the possibility to cure the illnesses or injuries [66].

There are three approaches to achieve these goals [66]:

1. Trying to restore or improve a function affected by damage.

2. Trying to overcome the effects of damage without restoring the damaged function.

3. Trying to eliminate occurring barriers.

The use of assistive or rehabilitation technology can be suitable to reach these approaches.

Examples for assistive technologies

In the following subsections some examples from the huge range of available assistive and rehabilitation technologies are presented.

Figure 4.8: An approach to control a computer mouse for people suffering from cerebral palsy [66].

Figure 4.9: An approach of an adapted keyboard for people with disabilities in using both hands [66].

Human-machine interface: Input

People affected from cerebral palsy often suffer from spasms in their hands which make the use of a normal keyboard or mouse to control a personal computer or laptop difficult. To overcome these problems there are many different input technologies available. Figure 4.8 displays an approach for an alternative input technology using buttons to control the mouse. Figure 4.9 displays a keyboard which can be controlled by the use of only one healthy hand [66].

Another approach for using a different input technology would be the use of speech recognition. Through the past few years advances have been made within this technology and the ability to control a device with the use of speech recognition is nowadays given [31].

Human-machine interface: Output

Figure 4.10: A Braille display [66].

One approach of providing output for people with disabilities and handicaps is the use of Braille displays. Through little bars which are submersible, output can be generated and perceived by for example blind people [66]. Figure 4.10 displays such a Braille display.

In contrast to speech recognition which can be used to control devices [31], speech synthesis can be used to deliver output for people with visual impairments [31].

Perceptual aids

People suffering from defective sight can use a wide range of existing assistive or rehabilitation devices. An interesting project is the Portable Optoelectronic Vision Enhancement System developed by an European consortium including the Technical University of Vienna.

The Portable Optoelectronic Vision Enhancement System is designed to compensate visual impairments, which can not be compensated by conventional optical means like glasses. Figure 4.11 displays the Poves-system [14].

The environment is captured by the help of a little camera and processed by a control unit. The produced pictures are displayed by two little monitors mounted inside the spectacles.

Mobility aids

There are different devices available on the market which on the one hand try to improve the range of mobility of the user (e.g. wheelchairs) and on the other hand support the user during the process of walking (e.g. crutches). The most common used mobility aids are crutches, mechanical wheelchairs, electronic wheelchairs and autonomic wheelchairs

Figure 4.11: The Portable Optoelectronic Vision Enhancement System [14].

which are equipped with sensors to capture the environment and therefore are able to avoid crashes with obstacles [65]. Beside common methods to overcome mobility impairments there are new approaches too. Figure 4.12 displays a system called Mobic which stands for "Mobility for Blind and elderly people Interacting with Computers" [17].

This outdoor system consists of a GPS-antenna, a small computer powered by batteries, small headphones, a compass and a little keyboard. The user is guided through the landscape by the system and warned through the headphones if he passes roads or other dangerous places.

Communication aids

According to [65] examples for communication aids are hearings aids, cochlear implants, text telephones, optical signalling systems, amplifier and clarifier for the voice, symbolic languages and embossed printing.

Manipulation aids

Examples for manipulation aids are simple mechanical grippers, environmental controls, manipulators and robots [65]. Mechanical grippers can be used to manipulate switches or to pick something up. Environmental controls are used to control devices and perform activities that otherwise would lie outside the functional range. Such an environmental control system basically consists of the following parts:

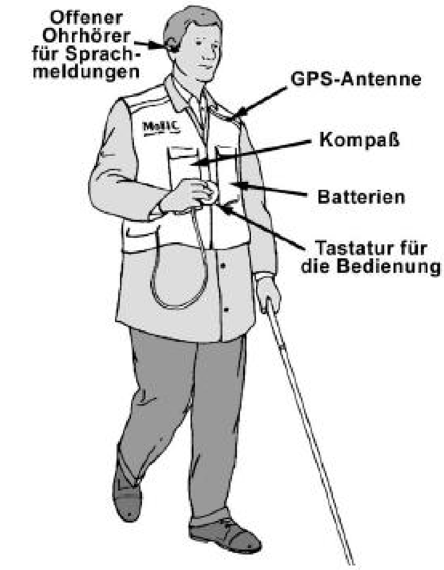

Figure 4.12: Mobility for Blind and elderly people Interacting with Computers [17], [66].

1. Human-machine interface
2. Control
3. Transmitter
4. Transmission channel
5. Receiver
6. Target device
7. Feedback

Manipulators and robots are steered by an affected person and act as a prosthesis. In addition robots execute orders of greater complexity independently and behave like a human assistant. Typical activities are [65]:

- Fetch and carry objects
- Assistance with eating
- Assistance with personal hygiene
- Movement Training
- Games as an extension of the possibilities of highly disabled children

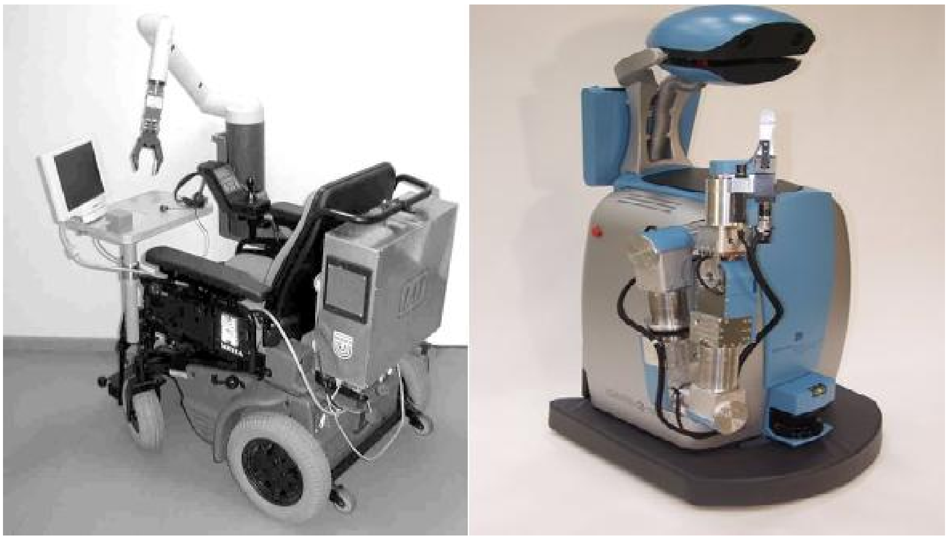

Figure 4.13: MANUS and Care-o-Bot 2 [66], [26].

Figure 4.13 displays a wheelchair with an attached gripper on the left side (MANUS) and a robot on the right side (Care-o-Bot 2).

Training and therapy aids

During rehabilitation and training programs, devices or systems are used to train affected parts of the human body to become full functional again or to improve the functionality. According to [65] perception and cognitive training, movement training and pronunciation training are examples considered as training and therapy aids.

Figure 4.14 displays a gait analysis system developed to analyse walking movements of people suffering from disabilities with their locomotory system [54].

Workplace and daily living aids

A few examples for workplace and daily living aids are speakable watches for blind people, speakable domestic appliances, emergency facilities, fire detectors with voice output and light systems for deaf people [66], [65].

Assistive technologies for people suffering from cerebral palsy

People suffering from cerebral palsy are confronted with different kinds of impairments. The kind of disability is individual for each patient and therefore many different assistive and rehabilitation devices can be useful regarding each patients medical condition. All of the presented devices in the previous sections can be used to improve the functionality of affected body functions or at least overcome the daily life of patients.

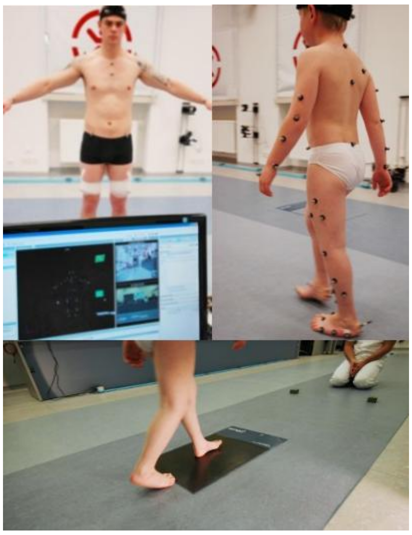

Figure 4.14: A gait analysis system [54].

Although people suffering from cerebral palsy can suffer from eyesight disabilities and other presented impairments too, the most common used assistive and rehabilitation devices for affected people are [15]:

- Standing aids
- Walking aids
- Mobility aids
- Eating and writing aids
- Transfer, care and bathing aids
- Communication aids

Figure 4.15 displays a standing aid used to familiarise the body to the process of standing tall and strengthening the necessary muscles.

Figure 4.16 displays a device used to strengthen the muscles of the lower extremities.

Finally figure 4.17 displays a device which is designed to help affected people to walk on their own.

Figure 4.15: A standing device [55].

Figure 4.16: A device used to train the lower extremities [4].

4.5 Existing sensor technology

In order to find a sensor that fits our needs of being able to detect the angle of the wrist multiple sensor technologies have been seen through: [56]

- Accelerometers: measure proper acceleration.
- Gyroscopes: measure or maintain orientation.
- Combination of Accelerometer and Gyroscope.
- Strain Gage: strain can either be compressive or tensile and can be measured. A strain Gage converts the mechanical motion into an electronic signal.
- Motion sensor: for example a camera which compares taken pictures.

Figure 4.17: "Thomy Walker" - a device used to support patients while walking independently [55].

These sensor categories were compared with each other. After analysing and discussing the advantages and disadvantages of these sensor categories we decided to use the strain gage approach. The later used Flex sensor is based on the strain gage principle. More information about the possible sensors can be found at [56].

4.6 Feedback devices

The choice of an appropriate feedback device to alert and inform the user of an occurring spasm is necessary. According to [56] several possibilities have been found:

- Electro-tactile displays
- Vibro-tactile displays

The process of searching for a usable feedback device as well as a discussion and an analysis of the possibilities can be found at [56].

4.7 Data transmission

The data transmission is needed to transmit the data from the sensor which measures the angle of the wrist to the logging and the feedback device. Basically there are three main types of transmitting the data:

- Transmission over an Universal Serial Bus cable
- Transmission over Wireless Local Area Network access
- Transmission over Blue tooth

The analysis and discussion about the possibilities can be found at [56].

CHAPTER 5

Interviews

5.1 Introduction of T. as key participant

With the help of Florian Güldenpfennig we got in contact with a young man living in Germany who is suffering from cerebral palsy since he was born and who was willing to join our project and to provide necessary information for us. At the present time T. is 24 years old. Through the big distance the interview with T. was conducted over Skype. We audio recorded the interview because this made it possible to listen to the interview again to make sure that important facts can not be dropped. To remain anonymous the real name will not be mentioned and the concerned person will be named T..

The interview with T. who suffers from cerebral palsy deals with the question of how the disease affects him in everyday life and how he tries to handle occurring problems. Also design issues of our prototype were discussed and analysed.

Unfortunately T. is the only affected person who was willing to cooperate with us. This circumstance made him very important for us because the device should be developed especially for affected people. T.'s opinion, his specific needs and requirements for the product made him a key participant in our project. Therefore he is especially involved in design issues as well as in building and evaluation processes. The developed device was built especially for him and configured in that way that fits his personal needs and preferences best. The main evaluation process was carried out with his participation.

A more detailed introduction to T. as well as more important facts about him, his life and his specific needs can be found in the section "Analysis of the conducted interviews".

5.2 Introduction of the father of T.

The interview with the father of T. was also very useful for us. As an expert in T.'s care and very important person in T.'s life we were interested in his point of view. He lives with his wife and his son in Germany and takes care of T. most of the time. At the present time he is 56 years old. We wanted to learn from him and understand things from his perspective. Through the big distance the interview with K. was conducted over Skype. We audio recorded the interview because this made it possible to listen to the interview again to make sure that important facts can not be dropped. To remain anonymous the real name will not be mentioned and the concerned person will be named K..

A more detailed introduction to K. as well as more important facts about him and his life can be found in the section "Analysis of the conducted interviews".

5.3 Introduction of a therapist working with affected people

Finally, an interview with a therapist, working in Austria together with people suffering from cerebral palsy, has been conducted which was quite useful for understanding current available therapies and devices. In addition we gained knowledge of the problems people suffering from cerebral palsy are confronted with. Through the big distance of different cities the interview with B. was conducted over Skype. We audio recorded the interview because this made it possible to listen to the interview again to make sure that important facts can not be dropped. To remain anonymous the real name will not be mentioned and the concerned person will be named B..

A more detailed introduction to B. as well as more important facts about her and her life can be found in the section "Analysis of the conducted interviews".

5.4 Analyses of the conducted interviews

After the interviews were conducted we wrote down the most important statements of the interviewee. With the help of the collected information we were able to gain insight into the life of T. and his family. In addition we used the gathered information to build our prototypes. The most useful collected information and statements for our design process are summarized in the following sections.

Interview with T.

First we started to introduce ourselves to T. who is currently suffering from cerebral palsy. We talked with him about our Master thesis and tried to explain the goals of our project. Tobias agreed to record the interview.

When we asked him about a typical week in his life, he told us that he gets up early to have breakfast in the morning. After consuming the breakfast he starts to perform his therapies which contain different exercises such as physiotherapy or occupational therapy differing from day to day. The goal is to enhance the physical condition of his body. Most of the time he uses his wheelchair which is quite more comfortable for him than walking around with his feet. At the moment he is jobless, but he tries hard to find a new workplace in his leisure. In addition to finding a new job, he enjoys going to the cinema or meeting with friends. Another hobby of the interviewed person is reading books.

The village of T. has a health therapy practice which is quite comfortable for him. They offer various therapies for him. For example he mentioned that he joins a riding therapy one day a week and a manual therapy in addition to physiotherapy and occupational therapy.

T. is suffering from cerebral palsy since he was born. His mother had appendicitis during her pregnancy and because of the necessity of a surgery Tobias was born by a caesarean section seven weeks too early. On the 7th day after birth he had a brain hemorrhage resulting in spasticity in all four extremities.

The spasticity in the legs is much stronger than in his arms. He is not able to walk alone without help. The right limbs are more affected by spasms. Due to that he uses his left hand in daily life. He is not able to dress himself without help and needs help when using the toilet. Small distances can be overcome with the help of walking sticks. He is able to eat without help since he trained it. Before he joined an occupational therapy group he was not able to chunk the food.

With the help of the therapies T. attempts to learn to cope better in daily life alone. He mentioned that a progress can be observed from year to year. The therapies are very demanding and due to that Tobias often loses his motivation. Such a lack of motivation worsens his physical condition. Typically after two or three weeks of regeneration his motivation comes back again.

His goal for future therapies is to achieve a progress in walking alone and to reduce occurring spasms. They often occur when he is upset or happy about something and he often doesn't even notice an occurring spasm. In such a situation he has to calm down first to reduce occurring spasms.

Family has a very high significance in T.'s life. Beside his parents he has three sisters which all stand behind him and try to provide as much assistance as possible. Also his friends often offer him help.

Talking about the spasm glove he said that the feedback should not be a loud melody but a vibration which doesn't disturb other people in his environment. The vibrating feedback

should not be given directly in the glove. Important for him is that the design of glove is not too conspicuous. The glove should be made of soft material which allows wearing the glove several hours a day. In Addition the glove should not affect him in everyday life.

T. is available for further interviews and he would be willing to come to Vienna for further tests. He confirmed to ask treating physicians and therapists for more interviews with us. The possibility to interview his parents or siblings is given.

Interview with the father of T.

First we started to introduce ourselves to the father of T. We talked with him about our Master thesis and tried to explain the goals of our project. K. agreed to record the interview.

When we asked him about a typical week in his life, he told us that the whole day is about providing assistance to his son T. as good as possible. Through his spastics T. is most of the time at home where his parents have to take care of him. For all transfers he needs help. In the house the usage of a wheelchair is not possible because of many stairs. K. mentioned that T. walks alone but through the missing equilibrium he needs his parents to sustain him.

T. is able to eat alone and to shave or brush his teeth but his parents control him every day. In case he needs help his parents assist him too. Taking a shower alone or using the toilet without help is not possible for him. In addition he needs help with dressing or undressing.

His father mentioned that they always try to motivate their son to do as much things in daily life as possible on his own. Activities such as cutting food or brushing his teeth alone could therefore be learned.

Therapeutic measures are conducted with the help of the father because T.'s mother is too weak. If T. is alone with his friends on the road they take care of him.

Talking about the intensity of T.'s training his father explained that all therapeutic measures have to be done each day for at least two times. If the intensity of therapy is not high enough it has no impact on T.'s body. Through this it is important for K. that our prototype can be used over a long period of time every day. He said that if the prototype doesn't hinder him in everyday life he will use it consequently.

Talking about the feedback signal K. said that T. should have the possibility to mute the device. K. is interested in getting informed too by the device about occurring spasms. He would like to get informed too because of the resulting possibility to watch his son's reactions on the feedback. According to the current situation of T. the provided feedback should be an audio signal or a vibrating signal.

Logging information could be useful to support therapies. K. is interested in measuring and logging the degree of T.'s wrist angle while he has a spasm. According to a normal position of the wrist T. should be informed if he falls out of a predefined wrist angle range.

Spasms often occur if T. is upset or happy about something. In such a case he has to calm down and relax his muscles. K. is worried about T.'s mood while wearing the device. He mentioned that if too much feedback is given T. could get nervous and this might results in more spasms.

Some years ago T. joined another project to detect spasms but the device was very complicated and so he never used it alone.

K. is available for further interviews and he would be willing to come to Vienna for further tests. He confirmed to ask treating physicians and therapists for more interviews with us.

Interview with a therapist

First we started to introduce ourselves to the therapist. We talked with her about our Master thesis and tried to explain the goals of our project. B. agreed to record the interview.

Since twenty-six years B. works as a therapist. As a therapist she works with people suffering from spastics caused by strokes, hypoxia and multiple sclerosis and other concurrent causes. She worked in a hospital for ten years until she started to work as a freelancer. She owns a little practice and in addition she drives from door to door to work with her patients which are not able to visit her medical office.

Talking about the occurring problems people suffering from cerebral palsy have to deal with she mentioned that most of her patients have problems with their fine motor skills and/or walking. That depends on the degree of the spastic. According to B. the main problems concern the writing and the eating.

Concerning the current available training methods she mentioned that she works with a training programme called "BOBATH" [10]. This methodical approach is especially designed for people suffering from neurological diseases. The concept of this training approach is quite simple: healthy brain regions should learn and take over tasks from the affected regions which performed this tasks previously. The spastics can be reduced through this therapy. Another approach of reducing occurring spastics is to distend the musculature. In addition the mood of a patient is very important. The risk of having a spasm is much less if the patient is in a relaxed mood. Most of the time patients themselves recognise if a spasm occurs but if the are excited they sometimes don't recognise the spasm. According to B. in this case the device can be useful. She also explained that she has not much experience in using technical equipment for the therapy.

Logging the information of occurring spasms can be useful for the health insurance to demonstrate that more therapies are necessary. In addition the collected data can be used to find conspicuities in the behaviour of the patient and when thereby spasms occur.

B. explained that the device can also be useful for alerting relatives or friends of a patient that a spasm occurs. If they get alerted they could help immediately. For B. the most useful effect of the glove should be a mechanical reaction to the spasm. If a spasm is detected by the device and the patient is not able to terminate the spasm on his own the glove should bring the fingers or the wrist of the patient in a normal position. This could be a positive feature of possible upcoming future work.

B. is available for further interviews.

CHAPTER 6

Development of the prototype

6.1 Designing the Proof-of-Concept prototype

Overview

After the first interviews were conducted and the obtained information was analysed the progress of building the first prototype started. The gained information from the interviews were taken into consideration.

The most useful information for the design process received from the interview with T.:

- "...The glove should be made of soft material which allows me wearing the glove several hours a day..."
- "...The design of the glove should not be too conspicuous; I don't want to attract attention in public..."
- "...The glove should not affect me in everyday life..."
- "...The provided feedback should not be a loud melody but a vibration which doesn't disturb other people in my environment, for example in the cinema..."
- "...The vibrating feedback should not be given directly in the glove..."

The most useful information for the design process received from the interview with K.:

- "...The possibility to change the feedback from vibrating to an audio signal should be given..."
- "...The possibility to wear the glove the whole day or at least several hours a day should be given, otherwise the training effect could be too weak to have an impact on his physical condition..."

- “...If too much feedback is given T. could get nervous which will cause more and especially stronger spasms, so i suggest not to provide to much feedback...”
- “...Logging the data is useful, i am interested in logging the wrist angle. My son should get informed if he falls out of a pre defined "normal" range...”
- “...My son already participated in a very similar project some years ago but he never used the prototype because the device was far to complicated for him. Your device should be made very simple to handle...”

The most useful information for the design process received from the interview with B.:

- “...If the device is able to help people relaxing when they have to collect achievements that can be useful to reduce occurring spasms...”
- “...The collected data can be useful to find conspicuities in the behaviour of the patient...”
- “...The device can also be useful to alert relatives or friends of the patient so that they can help immediately...”
- “...Logging information is nowadays very important for health insurances. With the collected data a prove can be given that new therapies are necessary and have to be paid by the health insurances...”
- “...The device can also react on spasms in a mechanical way, if the patient is not able to get rid of the spasm on his own. In this case the device should stretch the fingers automatically for example...”

Due to this gained information a specification was created. This specification includes the necessary requirements a first Proof-of-Concept prototype has to fulfil in order to fit T.’s basic needs. The specification can be found in the following section.

Specification of a first Proof-of-Concept prototype

The following requirements have been discovered from the literature and the conducted interviews and are presented with the help of a diagram which displays the priority of developing for each requirement. Figure 6.1 displays the requirements for a first Proof-of-Concept prototype. The right column displays the sequence priority of development starting by one and ending with fifteen. For a first Proof-of-Concept prototype not all features can be considered. The main goal of the Proof-of-Concept prototype is to ensure that the main ideas of developing are suitable and can be used to build a full functional prototype. The section "Enhancing the Proof-of-Concept prototype" will finally result in our first version of the spasm glove which then will be tested with the participation of T. and therefore undergoes possible modifications. Some of the now presented requirements are not necessary for a first Proof-of-Concept prototype and will finally be implemented in the section "Enhancing the Proof-of-Concept prototype". In addition some features are

Feature	Priority
As small as possible	1
As light as possible	2
As unobtrusively as possible	3
Glove out of soft material	4
Not obstructive in daily life	5
Different alerting signals	6
Feedback not in the glove	7
Wearable a long time	8
Not to much feedback	9
Logging wrist angle	10
Simple to handle	11
Device should help relaxing	12
Alert relatives too	13
React to spasms in a mechanical way	14
Logged information as basis for analysis	15

Figure 6.1: The used requirements for developing a first Proof-of-concept prototype.

not implemented within this theses and are only presented as possible future work in the chapters "Summary" and "Conclusion".

Data transmission

A big question of designing the prototype is how the collected data will be transmitted from the used hardware to the logging device. There are basically three different possibilities to transmit the data:

- USB
- Wireless LAN or Blue tooth

At the beginning of the design process the idea was born to use an USB connection between the logging device and the sensor equipment. This method is the most common one since there are some important advantages: The logging device can power the sensor and the data can easily be transmitted. The disadvantages of this approach are the limitation of mobility through an additional necessary cable which may annoys the user during his activities and the restriction of modern smart phones which do no allow data transmission to an external device other than a computer. These disadvantages make the use of an USB

connection already useless for our purpose but we explained the idea of using an USB connection to T. to gain inside into his point of view. During the interview with T. the idea was explained to him and T. mentioned that the use of an USB-cable is not efficient for him because the cable may disturbs him and the logging device is bound to the sensor equipment. After analysing the interview the idea of using an USB-cable has been dropped.

Using a wireless LAN or Blue tooth connection fits the needs of T. in a better way than using wires. The data can be send easily and in addition the transmitted data can be visualized on a computer to monitor the patient's data which might is useful for therapists. After some research the SHIMMER device [37], which is a solution for wireless LAN support for sensors, has been found. This device is set up with accelerometers and provides full support for receiving data on the computer but unfortunately there is no support for smart phones included. Using a Blue tooth connection has the same advantages like using a wireless LAN connection. Instead of the SHIMMER platform there is Android for this purpose. Again after some research a small Blue tooth device called Blue tooth MATE [46] has been discovered. This small device can easily be attached to the Arduino board. In addition an application called Amarino [28] already exists. This application installed on an Android smart phone is able to communicate with the logger. The decision to use Android for programming the logger is responsible for choosing the Blue tooth connection instead of wireless LAN.

To sum using Blue tooth seems to be the best choice to fit T.'s needs. There are no additional cables which will disturb T. in his daily life. Choosing a Blue tooth connection fits the feature "Not obstructive in daily life" from the specification list as good as possible.

Feedback device

Since the feedback device is one of the key components of the device there are some requirements that have to be fulfilled. The main goal of a feedback device is to provide feedback if a certain circumstance occurs. There are basically three main kinds of giving feedback: by audio, video or a tactor. Providing a video feedback would not be useful since this attracts the user and may annoys him in daily life. The remaining possibilities are therefore to provide feedback via an audio or a vibrating signal.

Another important requirement is the question of how the feedback device is adequately supplied with current. Possibilities are either a power delivery over the logging device or the use of batteries which are heavy and expensive.

The third requirement concerns the placement of the feedback device. The decision where to place the feedback device might differs from user to user and therefore it has to be flexible. According to [13] the best place to provide feedback is the wrist or the forearm.

According to T. and his father feedback of an occurring spasm should be given. While T. is worried about a simple sound signal and prefers a vibrating signal his father would like to get informed by a loud sign in order to observe the reactions of his son. Therefore the user should be able to mute the device in public and to receive a vibrating signal instead. It is also important to distinguish between two different kinds of the provided feedback:

- Warning feedback:
  This signal should be clearly recognizable as a spasm warning and distinguishable from any other alerts like ring tones. At the beginning of the design process the idea was born to give the feedback directly in the glove which sounds good first but T. mentioned that this kind of feedback may disturbs him or even worse he would not be able to recognize it because he even does not recognize occurring spasms. Since the decision was made to use Blue tooth as data connection between the glove and the logging device a smart phone itself seems to be the best choice of feedback device. It is able to switch from vibration to audible, can be used as logging device and provides both kinds of feedback at the same time.

- Motivational feedback:
  Since the smart phone is the central device of the spasm it is also responsible to attract the attention of the user. There is a motivational system running on the smart phone designed to improve the users reactions on an occurring spasm. A description of the motivational system can be found at [56].

The use of a smart phone seems to be the best choice. Features like "Not obstructive in daily life", "Different alerting signals", "Feedback not in the glove" and "Logged information as basis for analysis" can be implemented within this solution since nowadays nearly every person has a smart phone while being in public, it has the possibility to provide different alerting signals, the feedback is provided at the smart phone and not on the glove and it can be used as a storing device for the collected data. If some additional Android applications are developed in the future the use of the smart phone as analyses tool is even possible for analysing the collected data. More information about feedback devices can be found at [56].

Logger

The logger running on the smart phone is designed to log important informations of the user like time stamps of occurring spasms, the users progress in dealing with spasms or the achievements he unlocked. The idea of using the logger running at a smart phone for collecting data is suitable for fitting the features "As small as possible" and "As light as possible" from the specification list since there is no additional hardware needed to collect and especially store the data. More details of the programmed logger can be found at [56].

Flex sensor

There are certain requirements that a useful sensor has to fulfil. First it has to be small and light since it has to be built into a glove worn on the wrist and therefore should not annoy the user in his daily life and activities.

The second requirement deals with the needed current. The power consumption should be kept to a minimum because of the heavy weight of large batteries. This requirement is based on the choice of the data transmission method since there are methods that can not transmit data and power. The necessary power can be obtained for example from an USB cable connected to the logging device. This method would power the sensor and additionally transmitting the data but since the decision was made to use a Blue tooth connection for data transmitting and batteries are on the one hand large and on the other hand expensive the needed current supplying the sensor should be as little possible.

The third and most important requirement deals with measurement issues. The sensor should at least be able to measure the angle of the wrist and should not be influenced by environment factors like temperature, rain, noise, light and other disturbing influences.

There is one sensor that combines all above mentioned requirements, the flex sensor. Connected to power this tiny sensor is able to measure the angle of the wrist. If the user bends it the resistance changes. Since the sensor is very small it should not be too conspicuous in public. The sensor produced by Spectrasymbol [53] is very small (less than one millimetre thick), lightly,works in a range from -35 to 80 degree C. and can be used more than a million times according to the manufacturer. In addition the low cost of only 12 Euro is perfect for using it for the prototype. More information about the Flex sensor can be obtained from the homepage of the distributor Sparkfun [48]

Figure 6.2 shows the Flex sensor manufactured by Spectrasymbol.

Beside these advantages there are also two negative side effects of the used sensor. First the sensor can only be bent up to 90 degree which means that it is only useful at the back of the hand. In addition only the wrist of the angle is measured which means that it can not be used for interaction with the logging device.

During the design process the first ordered Flex Sensor sometimes refused to work properly. After some time of investigation it seemed that the electrical contacts of the sensor broke off as a result of being bent too often. The second ordered Sensor still works perfectly after being bent approximately 400 times.

To sum up the use of the Flex sensor manufactured by Spectrasymbol seems to be the best choice since it fits some important features from the specification list such as "As small as

Figure 6.2: The Flex sensor manufactured by Spectrasymbol.

possible", "As light as possible", "As unobtrusively as possible", "Not obstructive in daily life", "Wearable a long time" and finally "Logging wrist angle".

Sock

For the glove a simple sock was used. The end of the sock was cut off. To provide an aperture for the thumb the cut end of the sock on the right side was sewn together. To install the flex sensor a little pocket was sewn to the sock. To fix the sensor in the sewn pocket on the back of the hand cellotape was used. Small changes of the orientation of the Flex Sensor doesn't matter anyway, because the sensor in this case is still getting bent the same way. The used sock is made of a soft material and flexible enough to be used as a glove. In addition the combination of the used sock and the flex sensor ensures that the glove is very light.

Figure 6.3 shows the glove without the Flex sensor. The pocket is visible in the middle of the sock. Figure 6.4 shows the glove with the installed Flex sensor and Figure 6.5 shows the glove with the installed Flex sensor on the hand in action.

The use of an old sock again fits some important features of the specification list. "As light as possible", "As unobtrusively as possible", "Glove out of soft material", "Not obstructive in daily life" and especially "Wearable a long time".

Figure 6.3: The glove without Flex sensor.

Arduino Uno

The open source Arduino boards [6] can sense the environment by receiving input from many different sensor like the used Flex sensor. The on board micro controller can be easily programmed with the free of charge Arduino programming language and the Arduino development environment.

The small size of the Arduino Uno board and in addition the low cost of 22 Euro fulfil the requirements concerning the device not being too conspicuous and light.

The Arduino Uno board is used to measure the current resistance of the flex sensor. At this stage of development an USB-cable from a Laptop provides the necessary power. Later the board will be charged with a battery. The Blue Tooth chip is necessary to send the collected resistance data to a smart phone with Android operating system. More information about the Arduino Uno board set can be obtained from the Sparkfun homepage [45].

Figure 6.6 shows the Arduino Uno, the Blue tooth chip, the electronical board and some cables, the basic components of the spasm glove.

The Arduino board seems to be the heart of the used hardware. It is responsible for the most necessary tasks. Again the decision of using an Arduino board was made because it

Figure 6.4: The glove with installed Flex sensor.

fits most of the features from the specification list.

Android smart phone

Any android smart phone can be used to log the data received from the Flex Sensor and the Arduino board. For the testing procedure a Samsung Galaxy S [41] and a HTC Hero [25] were used. Additional informations can be obtained from the manufacturers homepages. Both with Android 2.1 installed on it. The use of an Android smart phone is necessary because of the logger which is programmed with Android. In addition the collected data from the sensor are delivered via the Blue Tooth chip to an Android application called Amarino which is used to communicate with the attached Blue Tooth Mate [46] device.

Figure 6.5: The glove with Flex sensor in action.

Software

Beside the described hardware the use of software components is necessary. The Arduino [6] micro-controller is needed to readout the data from the Flex sensor. The Blue tooth device is used for broadcasting this datasets. The Android smart phone receives the data via Blue tooth. From this step on five software components will be used:

1. Amarino.
2. The logging software.
3. Arduino programming environment.
4. Arduino micro-controller code = sketch.
5. A shell programme.

Amarino

Amarino is a little tool-kit to connect Android driven smart phones with Arduino micro-controllers via Blue tooth. With the help of Amarino the data from the Flex sensor, broad-casted by the Arduino micro- controller can be received and monitored by the Android driven smart phone. Amarino is a free of charge software and can be downloaded from [28].

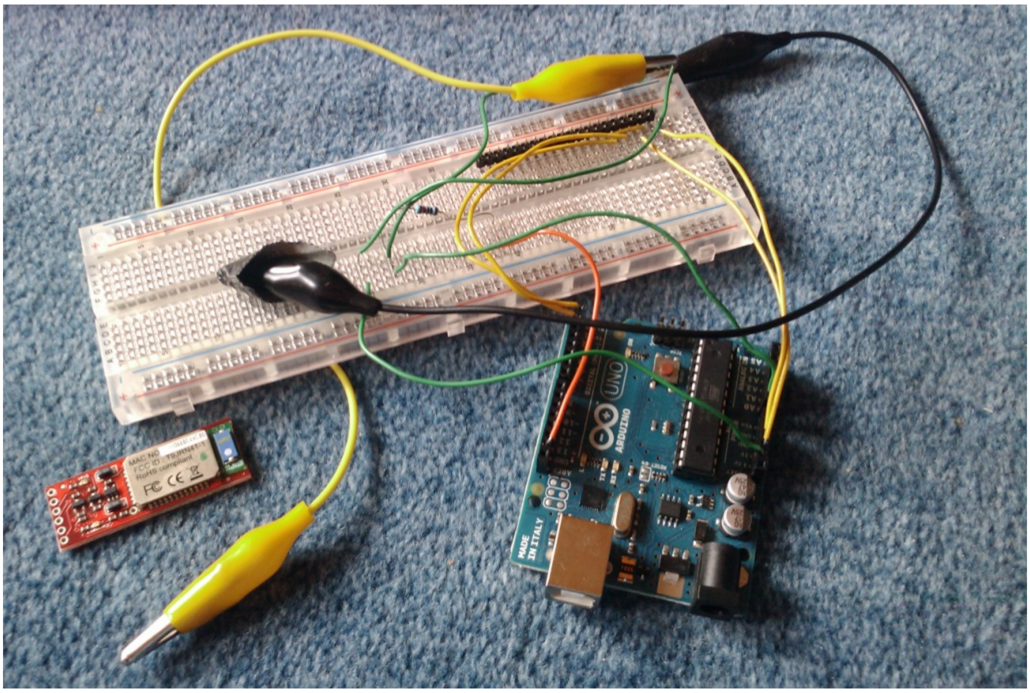

Figure 6.6: Ardunino Uno with Bluetooth Chip.

The loging software

The second software component is the logger. The logger is an Android written application that will be designed to grab the data sets from the Amarino tool- kit. In addition the logger is designed to make the data visible on the smart phone in a way the user can work with. This means that it is not only designed to log the collected data like when a spasm occurs but it also acts as an operating interface for the user. The user is alerted by the logger if a spasm occurs and with fast reactions on the spasm the user can collect achievements. Also some configuration issues like setting the volume level of the alerts or just muting the smart phone can be done by using the logger's interface. More information about the logger can be obtained from [56].

Arduino programming environment

The Arduino programming environment is used to upload the written micro- controller code to the Arduino board. The software is based on "Processing" and the code samples are called "sketches". The code is written into the programming window, compiled and then sent to the Arduino board over an micro USB cable. More information about the Arduino programming environment can be obtained from [6] where the software is also available for download.

Micro-controller code

The fourth necessary software component concerns the programming of the Arduino micro-controller. The necessary programme is very simple. The Arduino board is instructed to read the data from the Flex sensor at an analogue port. To achieve this only a few lines of code are necessary. The uploading of the code to the Arduino board is performed through an micro Universal Serial Bus cable with the help of the Arduino programming environment.

SSH/TelNet client

The fifth programme is a SSH/TelNet client to set the Baud rate of the Arduino micro-controller and the Blue tooth chip in order to enable communication with the Amarino software installed on the Android smart phone. For our purpose a SSH/TelNet client called "Putty" seems to be perfect. More information about the client can be found at [58].

After the design process of the spasm glove has been completed and all the necessary components have been bought the building of the prototype started.

6.2 Building the Proof-of-Concept prototype

This section provides an overview of how the hardware is attached and how Amarino and the logging software are working together with the Android smart phone and the Arduino board. Figure 6.7 shows the components of the first efficient prototype:

Laptop

A personal computer or just a Laptop is used to supply the Arduino board with the necessary electricity over an USB-cable. In addition the USB-cable is used to set the baud rate of the Blue tooth Mate chip and the Arduino micro-controller to 57600k. This is necessary to set up a connection between the Blue tooth chip, the Arduino micro-controller and Amarino installed on the Android smart phone. This step has to be done only once. The USB cable is also used to program the micro controller on the Arduino board. Later in the design process the used power supply over an USB cable will be replaced by the use of a small battery. Since the programming of the Arduino micro-controller chip has to be done every time the used micro controller code changes, the USB cable is still needed even when it is not needed as a power supplier any more.

Putty & Arduino programming environment & code

Putty

First Putty has to be downloaded and installed. It can be obtained from [58] and is free of charge. Putty is a SSH/TelNet client that is used to set the baud rate of the Blue tooth Mate chip to 57600k which is necessary to enable communication between Amarino installed on

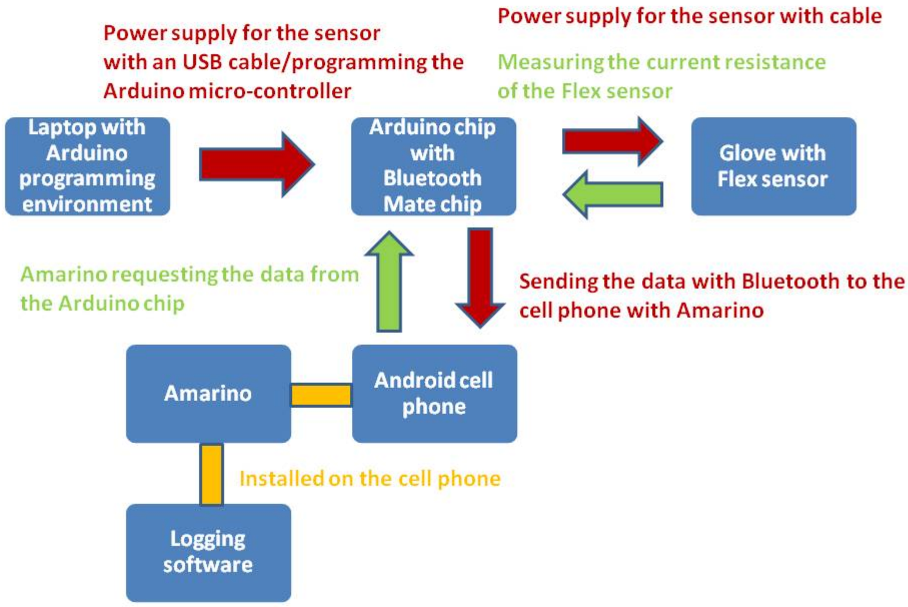

Figure 6.7: Composition of the components

the Android smart phone and the Blue tooth chip attached at the Arduino. This step has to be done only once since the Arduino board and the Blue tooth device remember the defined value even if the current is switched off. Unfortunately there is no feedback given if everything is configured correctly.

Arduino programming environment

The Arduino programming environment is used to program the Arduino micro controller for our purpose. The programme can be downloaded from [6]. After the downloading procedure has been finished the programme needs to be installed on the Laptop and finally launched. The Arduino board has to be connected with a micro USB cable with an USB port on the Laptop. The code is written into a so called "sketch window", compiled and uploaded to the micro controller with a button entitled "upload". If the sketch is uploaded the micro controller is ready to be used.

It is important to disconnect the Blue tooth chip from the Arduino while the program is uploaded to the micro-controller because otherwise the communication between the two devices is not possible any more. If the code is uploaded to the micro-controller it remains on the storage module even if the current supplier is disconnected from the Arduino. The

opportunity to store the code without current is provided by the used Arduino boards [44], [45].

Micro-controller code

The code is used to read out the values from the analogue port A0 on the micro-controller. The flex sensor is connected with this port through a cable. To achieve this behaviour a simple sketch is used and uploaded to the micro controller.

The used code is quite simple. Two methods are needed to read out the analogue pin 0 and send the data from the Flex sensor over the Blue tooth chip to the Android smart phone and the Amarino software. A setup method is executed from the software automatically if the sketch is uploaded to the Arduino. The baud rate has to be the same value as the Blue tooth chip is configured to, otherwise the programme will not work. The second step in the setup method is to declare that the analogue port 0 has to be an input port and not an output port since the data from the Flex sensor should be read out at port 0.

In addition a loop method is used for receiving events, reading out the declared input pin and sending it to the Android smart-phone. In order to prevent the smart-phone from getting too busy a little delay is added. More information about the used code can be obtained from [56] .

Arduino sensor circuit

The Arduino board with an attached Blue tooth Mate chip is used for measuring the data from the flex sensor. At this step of design simple cables are used to supply the sensor with power and to measure the data from the sensor. Figure 6.8 shows the wired connection between the Arduino board, the Blue tooth chip and the Flex sensor in detail.

To establish a connection between the Arduino Uno and the Blue Tooth Mate chip four cables are used. Two white cables, a blue one and a brown one. One white cable connects the send connector of the Blue tooth chip (Tx-0) with the receive connector of the Arduino Uno (Rx<-0). The second one connects the send connector of the Arduino Uno (Tx->1) with the receive connector of the Blue tooth chip (Rx-1). Since the communication between the Arduino board and the logging device is designed to use a Blue tooth connection the send and receive connection between the Arduino board and the Blue tooth chip is only used to make a communication between the two chips possible. The brown cable is used to supply the Blue tooth chip with the necessary power. It establishes a 3.3 volt connection between the two chips. One side of the cable is plugged into the 3.3 volts connector (3.3V) of the Arduino Uno the other side is plugged into the VCC connector (VCC) of the Blue tooth chip. The blue cable is used for the grounding of the two chips. Both endings of the blue cable are plugged into the ground connectors (GND)of each chip.

For the first prototype a board made of plastic and metallic pathways is used to connect the Flex sensor with the Arduino board. Figure 6.8 shows this board. Again two white cables and one green cable are used to establish a connection between the Arduino Uno and the Flex sensor. The first white cable is used to supply the board with the necessary power. One end is plugged into the 3.3 volts connector (3.3V) of the Arduino board the other one into the board. The second white cable is used to measure the current resistance of the Flex sensor. One end of the cable is plugged into the A0 serial port (A0) of the Arduino board to receive data from the Flex Sensor, the second end is plugged into the board. The green cable is again used for the grounding. One end is plugged into the ground connector of the Arduino board (GND) the other end is plugged into the board.

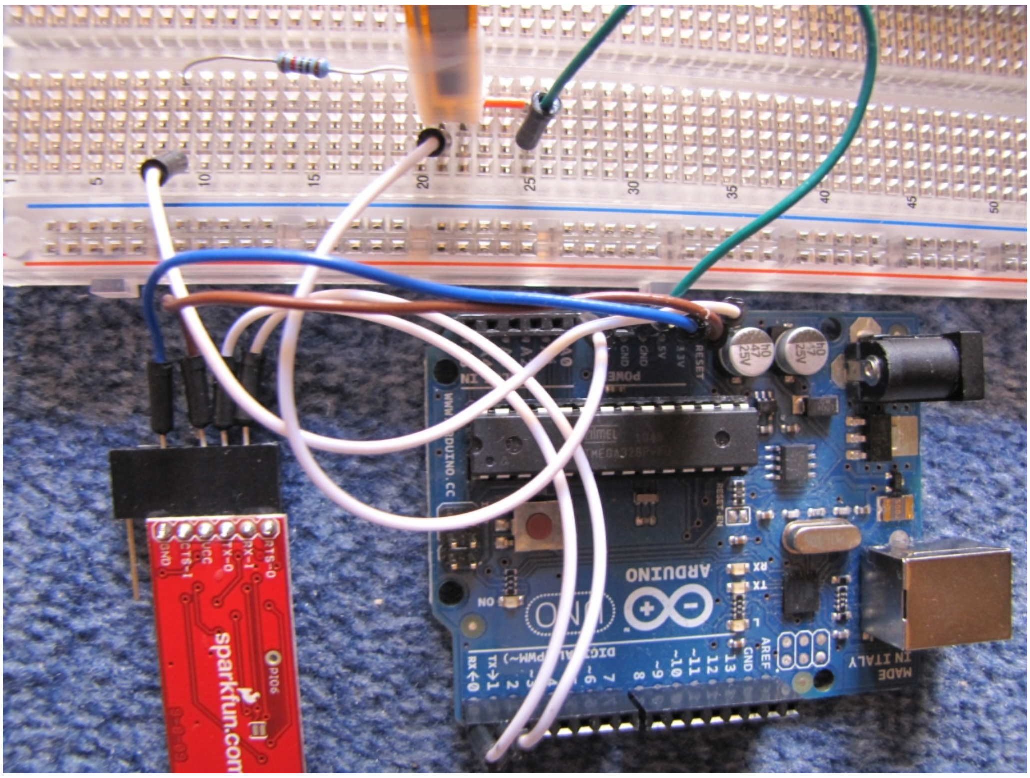

Figure 6.8: Wired connection between the Arduino Uno, the Blue tooth chip and the Flex sensor.

In addition to the Flex sensor and the cables of the Arduino board a resistor is plugged into the electrical board. It is used to protect the Flex sensor of overheating troubles. As displayed in Figure 6.8 the white 3.3 volt cable is plugged into the board. Through the electrical pathway on the board the white cable is plugged in the electricity is conducted to the resistor. As the electricity passes the resistor and reaches another electrical pathway it supplies the input side of the Flex sensor with electrical power. After the input side of the sensor but still on the same electrical pathway the electrical resistance is measured with

the white cable plugged into the A0 connector of the Arduino Uno. As the power traverses the Flex sensor a small orange cable is used to ground the electrical diagramm. It connects the electronic pathway of the exit pin of the flex sensor with the electronic pathway of the grounding cable of the Arduino Uno.

Amarino and the logging software

On the hard drive of the Android smart phone an application called Amarino will be installed. Amarino is free of charge and can be downloaded from [28]. From the download page a file named "Amarino2.apk" can be obtained. With the help of an installed file manager on the Android smart phone this file can be installed easily. This little tool is used for receiving the data from the Blue tooth chip. In addition it is also possible to monitor the received data. Once the application is installed and the Arduino board with the Blue tooth device is activated Amarino has to be attached to the Blue tooth Mate chip. First of all Blue tooth has to be activated on the smart phone. Then the Amarino application has to be started. By using the button "Add BT device" the application starts scanning for new Blue tooth connections. If the Blue tooth Mate chip has been found it is possible to attach it by using the button "Connect". Once it is connected the received data can be monitored by using the button "Monitoring".

The logging software is an application written in Android. The installation of the application is the quite simple. Just like the Amarino tool the Android apk file is installed by using a file manager programme. It is used for reading in the data from the Amarino application and displaying it useful on the smart phone's display. In addition this software is responsible to provide feedback for the user. More details about the logging software can be found at [56].

The first working Proof-of-Concept prototype

After the Arduino Uno, the Flex sensor and the Bluetooth chip have been wired and Amarino and the logging software have been installed on the smart phone the Flex sensor has been removed from the electronic board. For the first tests with the selected hardware the Flex sensor was installed on the sock. Two additional cables, a yellow one and a black one, were plugged into the electronic board at the same places the input pin and the exit pin of the Flex sensor were plugged in before. The other endings of the cables are equipped with clips that can be connected with the input pin and the exit pin of the Flex sensor. The yellow cable is used for the input pin of the Flex sensor and the black cable is used for the exit pin of the Flex sensor.

During the test an unspecified error occurred. The communication between the Blue tooth chip and Amarino worked perfectly even if the baud rate was not changed. Although it was not possible to receive data from the Arduino. Once the Blue tooth chip was changed and configured like the old one before everything worked perfect and the created application received data from the device.

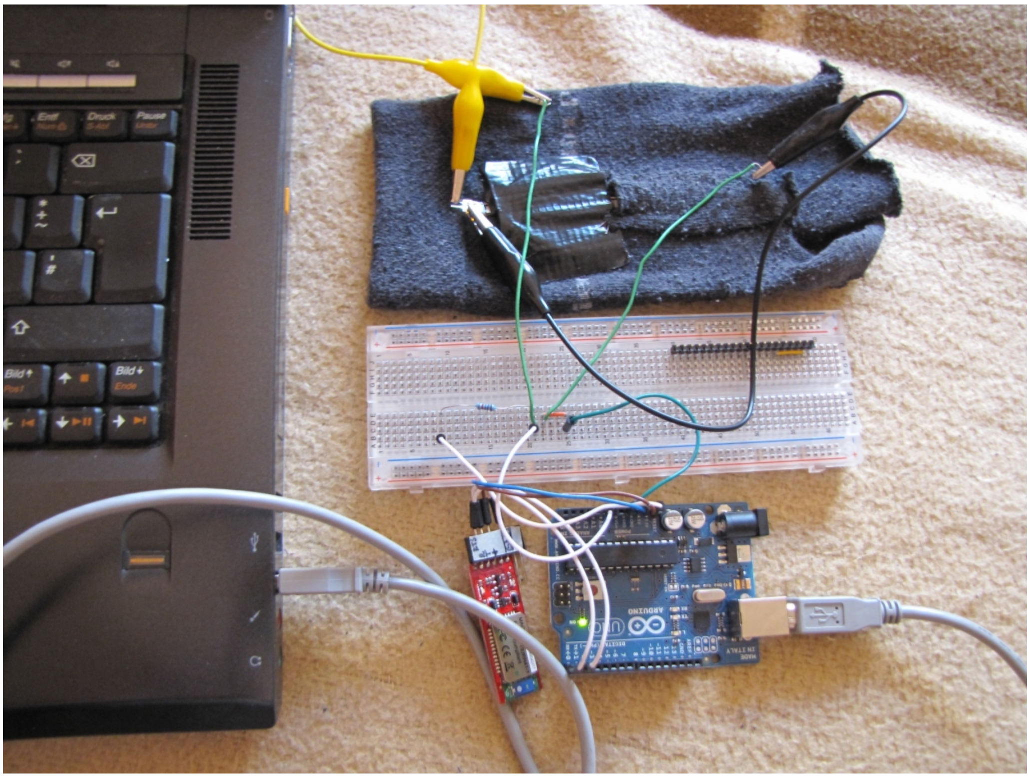

Figure 6.9: The first working prototype

Figure 6.9 displays the first full working prototype with all the mentioned hard and software above including the laptop used for supplying the system with the necessary electricity over an Universal Serial Bus cable.

6.3 Enhancing the Proof-of-Concept prototype

After the first Proof-of-Concept prototype has been built it has been tested by ourselves, friends and members of our family to ensure the functionality of the used components. Figure 6.9 shows the Proof-of-Concept prototype at this stage of development. To use the Proof-of-Concept prototype in everyday life and to evolve it to a real useable prototype it was necessary to develop several improvements for the Proof-of-Concept prototype. The laptop, responsible for supplying the Arduino board with the necessary electricity has to be removed in order to use the device in public. A small battery seems to be perfect for this purpose. Due to the fact that this battery has to be charged from time to time a simple charging unit has to be found. Also a so called Step-up-boost to enhance the delivered current is needed since the selected small battery is not able to power the Arduino board because the delivered current is to weak. In addition the electronic board has to be removed to reduce the weight and the size of device. It is also necessary to build a case for the used hardware to secure that it cannot be damaged or even destroyed while it is in use. To design

this case as small and inconspicuous as possible it is necessary to use a smaller Arduino board. Using a smaller Arduino board results in lacking a on board micro Universal Serial Bus adapter which is needed to load the measuring programme to the board. To ensure that the used cables do not lose contact with the circuit boards of the used hardware they will be soldered on the hardware chips. Lastly the used hardware gets integrated into the constructed case.

In the following section all improvements of the device will be explained. The goal of fulfilling most of the features from the specification list make this step necessary. The features "As small as possible", "As light as possible", "As unobtrusively as possible", "Not obstructive in daily life" and especially "Wearable a long time" are going to be improved throughout the following subsections.

Self made Flex sensor

During the investigations of finding a useful sensor that completely fits the needs of the device a project entitled "Fabric bend sensor" has been discovered. This self made flex sensor acts in the same way like the bought Flex sensor but since it is handmade it can be formed to perfectly fit our needs. The construction manual can be found at [42]. Basically the self made flex sensor consists of a neoprene cover, a conductive thread an anti static foil called Velostat and two little pieces of conductive fabric.

To build this sensor two tiles of neoprene are needed in exactly the same size. After cutting out two neoprene pieces two pieces of conductive thread are placed on each end of the neoprene pieces. After that step the conductive thread is stitched along on each neoprene tile until the conductive fabrics are reached. Stitching the conductive thread trough the conductive fabric ensures a good contact between them. The next step includes the anti static foil which is placed between the neoprene tiles. The two neoprene pieces can now be sewn together with normal thread.

If the sensor gets bent the anti static foil changes its resistance depending on the pressure. Since the self made sensor is out of soft materials it can be bent more than the bought one. Due to this it can be placed on the front side of the hand where it can be much smaller.

Figure 6.10 shows the two pieces of neoprene with the stitched in conductive thread on the left side. The right side shows the finished self made flex sensor.

Although the selfmade flex sensor seemed to be perfect for our needs it was impossible to build it. After hours of investigation with the help of the world wide web, telephone conversations and many e-mails it was not possible to purchase the necessary anti static foil "Velostat" or any other material with similar characteristics. The attempts with other materials failed because of missing conductive and bendable abilities and our selfmade flex

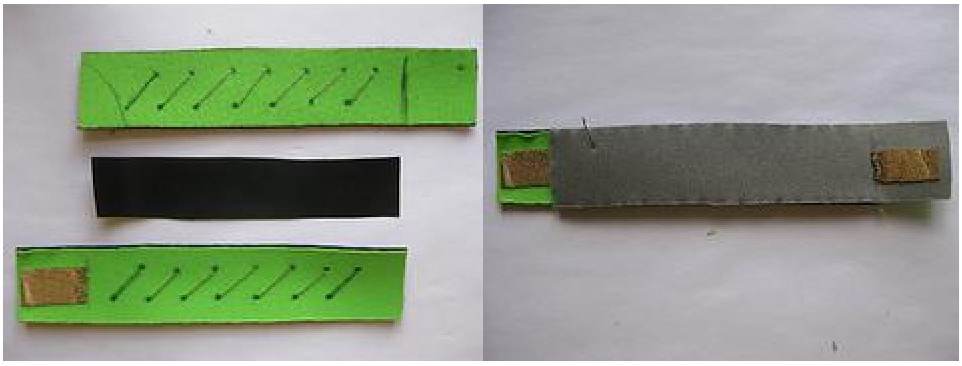

Figure 6.10: Selfmade Flex Sensor [42]

sensors refused to work in a satisfying way. Due to that the decision was made to use the flex sensor manufactured by Spectrasymbol [53].

Smaller Arduino board - Arduino Pro

To reduce weight and being able to design a smaller case for the used hardware another Arduino board called Arduino Pro [6], [44] has been chosen. The used Arduino Uno is 75 millimetres long, 52 millimetres wide and 12 millimetres high. The Arduino Pro's dimensions are 52 millimetres x 52 millimetres x 7 millimetres which means that the length of the used boards can be reduced by 31 percent. The height can be reduced by 42 percent. The used connectors of the Arduino Uno are available in exactly the same way on the Arduino Pro too. The cable system of the Arduino Pro including the external battery will be explained in the subsection "Soldering". The Arduino Pro is available in a 3.3 V/8 MHz or in a 5 V/16 MHz version. Both versions are available for $ 19,95. Due to the fact that 16 MHz are twice as fast as 8 MHz the 16 MHz version has been purchased.

The biggest advantage of the Arduino Pro is the possibility to use an external battery for supplying the board with the necessary electricity. Since the Laptop as a power provider should be removed to use the glove in public it is essential to use an external battery for this purpose. Figure 6.11 shows the two Arduino boards. On the left side the old Arduino Uno and on the right side the as from now on used Arduino Pro. More informations about the Arduino Pro can be found at [44].

FTDI adapter

To gain the possibility to build the case as small as possible a smaller Arduino board, the Arduino Pro, has been chosen. A small disadvantage of this board is the missing Universal Serial Bus connector. Due to the necessary programming of the Arduino Pro an USB connector is important for the project. After some research a simple FTDI adapter called FTDI BASIC manufactured by Sparkfun [49] has been found. The adapter can be easily

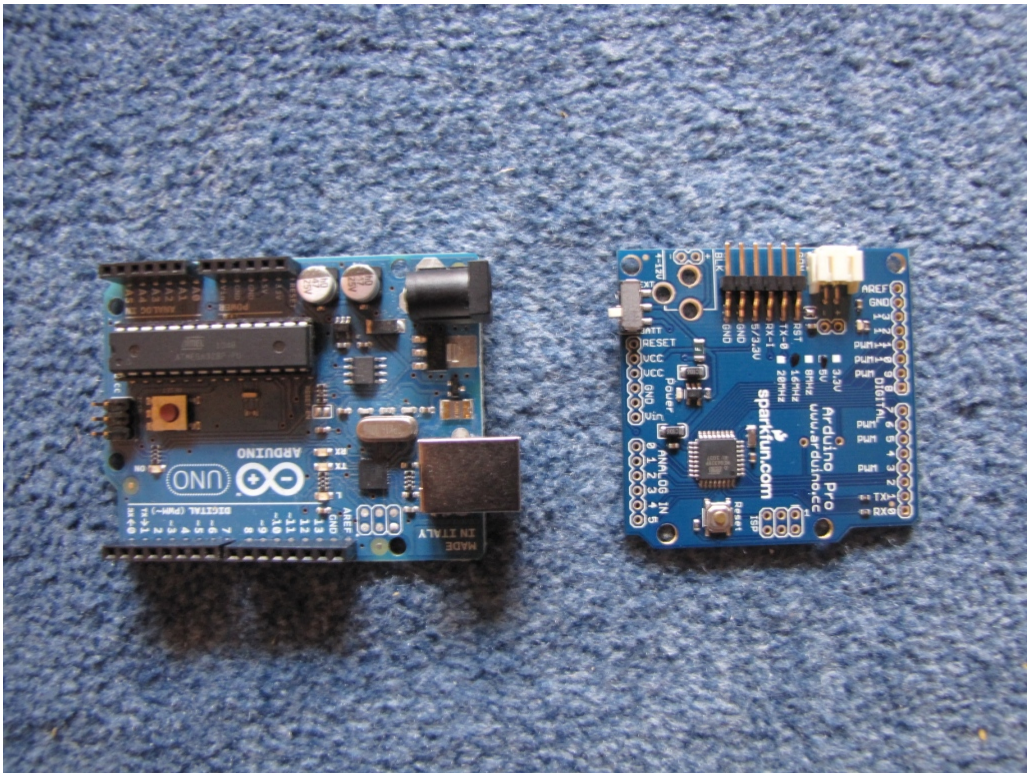

Figure 6.11: Comparison of the two Arduino boards

plugged on the Arduino board and allows to establish a connection between a Laptop and the Arduino board in order to load up the software to the Arduino board. The device is also available in a 3.3 V or in a 5 V version. Due to the 5 V Arduino Pro board the 5 V adapter version has been purchased. If the FTDI adapter is going to be soldered directly on the board or if it will be simply plugged to it is going to be decided after the case has been built.

The FTDI adapter is 23 millimetres long x 16 millimetres wide and 7 millimetres high. Figure 6.12 shows the FTDI BASIC adapter distributed by Sparkfun.

Battery

Since the spasm glove is designed to be used in public it is necessary to use a current supply that can be easily carried around. Due to this the power supply for the Arduino board and the flex sensor over an USB cable has to be removed. A small flat and light battery seems to be perfect for this issue. For the device a 2000 mAh Lithium Ion battery with 3,7 volts was purchased from [50] where also detailed references can be obtained. The chosen battery is 60 millimetres long, 52 millimetres wide and 4 millimetres high. Beside of the LI-Ion

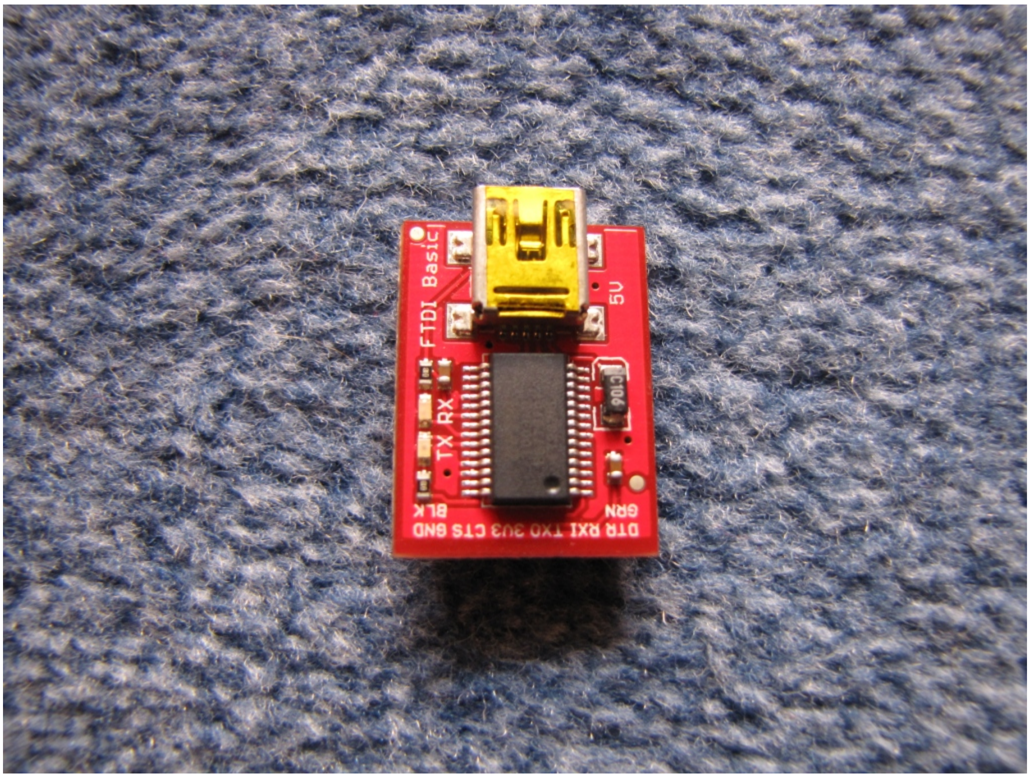

Figure 6.12: FTDI adapter by Sparkfun

battery a Step-up-boost and a charging unit are used. Figure 6.13 shows the working scheme of the battery package.

The Arduino Pro board requires 5 volts in order to guarantee proper functioning. Because the used battery delivers only 3,7 volts a so called Step-up-boost is needed to gain 5 volts from the battery. A Step-up-boost is a tiny little converter with an output DC voltage higher than its input DC voltage. It contains out of at least two semiconductor switches which are normally a diode and a transistor. In addition an energy storage element is used to boost up the output value. To reduce output voltage ripple filters out of capacitors are added to the output [2].

The purchased Step-up-boost is manufactured by Bodhilabs. This manufacturer [11] is specialised in providing current suppliers for mobile devices such as the Arduino boards. The chip is 20 millimetres long, 20 millimetres wide, 3 millimetres high and can be purchased at [51].

As the battery needs to be charged from time to time it is necessary to install an USB charger between the battery and the Step-up-boost. This device is necessary to charge

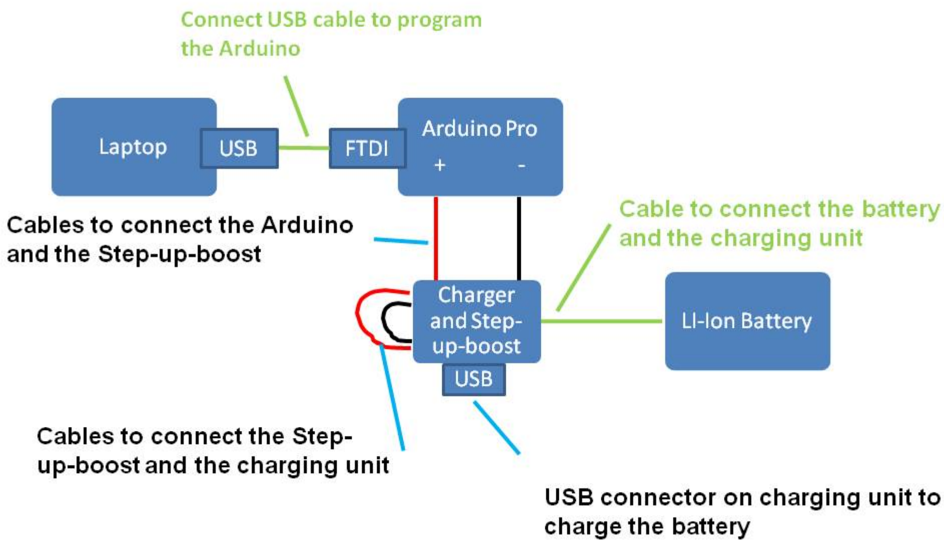

Figure 6.13: The working scheme of the battery package

the battery of the spasm glove when it is empty. The purchased charger is distributed Sparkfun. It is designed to charge 3.7 volt LI-Ion batteries with a rate of 500 mA or 100 mA per hour. Over a micro-USB connector on the board of the charging device the electricity can be taken from any USB device to charge the battery of the spasm glove. The chip is 27 millimetres long, 27 millimetres wide and 8 millimetres high. It includes a charging circuit, a status LED, selectable solder jumper for 500 or 100 mA charging current, an external LED footprint, a micro-USB input and mounting holes. More information about the used charging unit can be obtained from [47].

Figure 6.14 shows the whole Li-Ion battery [50] (left side of the picture)construction including the Step-up- boost chip [51] (middle of the picture) and the micro-USB LiPo charger unit [47] (right side of the picture).

The case

The case is used to protect the selected hardware when the user is in public. The electronic devices are very sensitive and have to be protected from rain, vibrations and other influences that can damage the device.

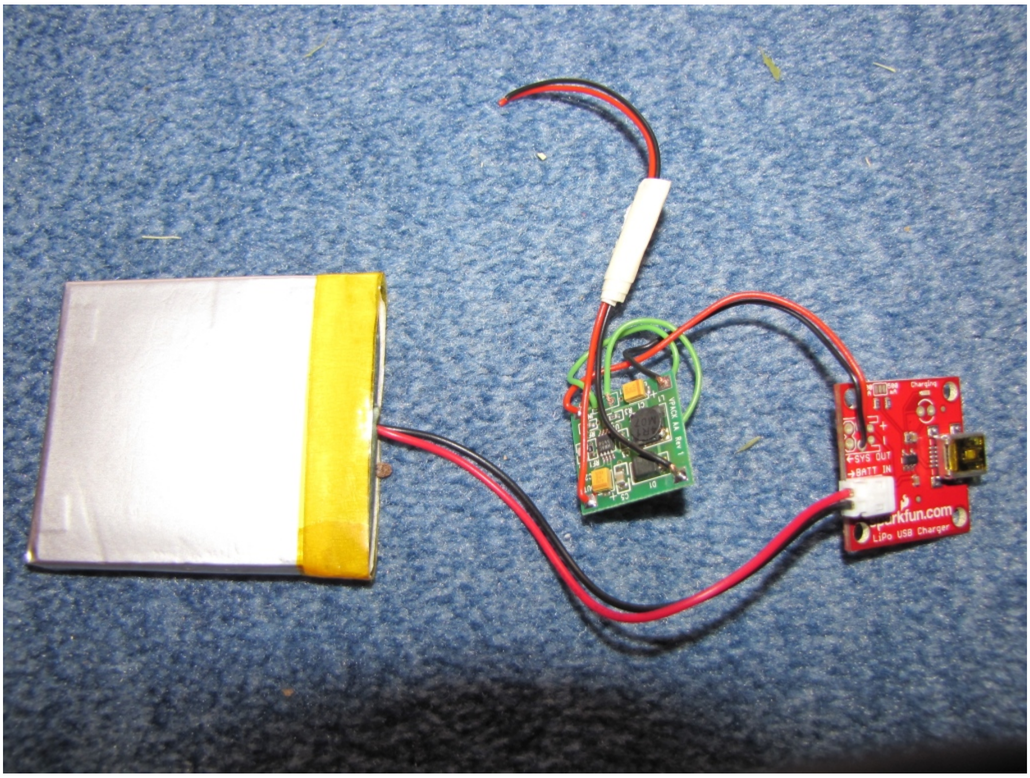

Figure 6.14: The battery construction including the Step-up-boost and the micro USB charger

Again the main goal of building the case is to design it as small and light as possible. The first idea was to build it out of Styrofoam which is very light and resistant against rain. After the case was build out of Styrofoam some disadvantages occurred. First it is not possible to screw the Arduino board on Styrofoam. This problem could be solved by using duct tape. The main problem was to make outlets for the cables. Once the holes were drilled the Styrofoam broke off.

The second idea, using wood, seems to be perfect for the case. The used wood plates are only 5 millimetres thick. Small pieces of wood were cut out of the big plate and nailed together. The resulting case is 115 millimetres long and and 70 millimetres wide and very light. It is swathed by duct tape to make it more resistant against rain. To open the case the two rubber bands have to be removed. After this the top wood plate of the case is ready to be removed.

Figure 6.15 shows the case made out of wood. One the left side the case is closed and on the right side of the picture the box is open.

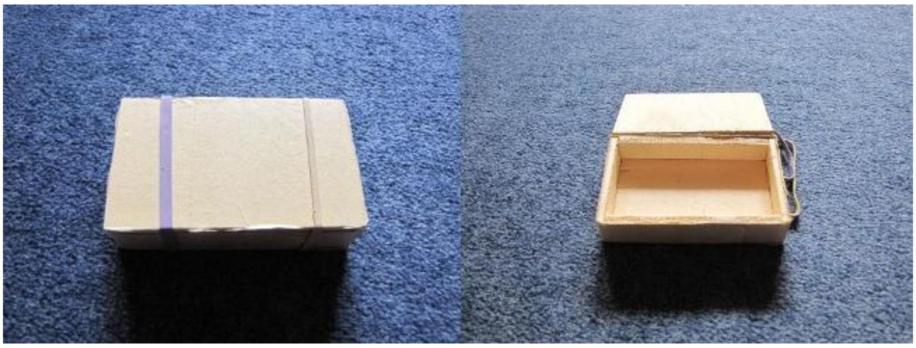

Figure 6.15: The created case made out of wood

Soldering

To make the used electronic devices resistant against occurring vibrations the used cables get soldered. Some cables are removed due to the electronic board which isn't used any more at this stage of development. This section provides an overview about how the cable system is soldered and made ready for the mounting into the case.

Soldering the battery

The battery consists of three main parts. First the battery which is responsible for supplying the Arduino board with the necessary power. Second the battery charger and third the Step-up-boost for creating the needed 5 volt DC output to supply the Arduino with current. The used battery charger is delivered with a single JST-type connector which is soldered on the battery in connector (->BATT IN) on the charger chip. The LI-Ion battery is already equipped with two cables soldered to the counterpart of this JST connector. The last step of connecting the charging board with the battery is to link the battery cable adaptor with the already soldered JST-type connector of the charger.

To connect the charger with the Step-up-boost again two cables are used. A red one for the positive pole and a black one for the negative pole. The red one is soldered to the system out connector (+ <-SYS OUT) on the charger chip and the black one to the system out connector (- <-SYS OUT). The other endings of the two cables are simply soldered to the in connectors of the Step-up-boost chip (IN+ and IN-). Again a red and a black cable are used to connect the Step-up-boost with the Arduino board. The two cables are soldered to the out connectors of the Step-up-boost (OUT+ and OUT-). The other endings are soldered to the Arduino board. This step will be explained in the following section.

After the battery, the charging unit and the Step-up-boost have been soldered together, the charger and the Step-up-boost have been stuck together with the help of duct tape. During this it was important to let the micro-USB connector open so that the battery can be charged. Figure 6.16 shows the ready to use battery pack.

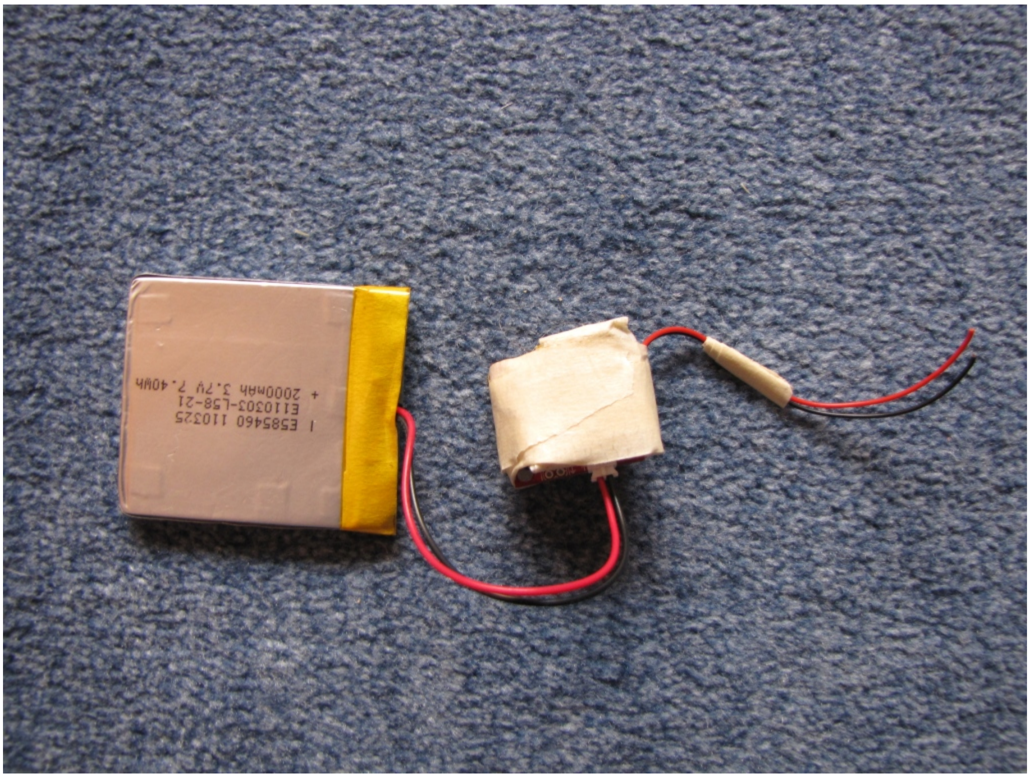

Figure 6.16: The ready to use battery package.

Connecting the battery with the Arduino board

Being able to use the spasm glove and detecting occurring spasms not only at home but also in public is one of the most important milestones of the project. The existing current supply of the first Prototype over an USB cable between a Laptop and the Arduino board is not sufficient because this reason the already described battery package has been invented. This section describes how the battery is connected with the Arduino board and which steps are necessary to ensure 100 percent functionality.

As already explained in the "Soldering the battery" section two cables, a red one and a black one, standing for the positive and the negative pole are already soldered to the Step-up-boost. The other endings are simply soldered to the positive and negative connectors (+ and -) of the Arduino board.

The Arduino Pro board is equipped with a white battery connector on which the stand alone LI-Ion battery can be connected directly. Since the use of a charging unit and the Step-up-boost is necessary for the project this connector is useless for our purpose. Behind the white battery connector there are two connectors for the use of simple cables to which our cables are soldered to. After soldering the cables of the Step-up-boost to the Arduino

board the equipment has been tested. After measuring the current with a measurement device the proof was given that there was no current on the Arduino board although the battery was fully charged and the Step-up- boost cables have been soldered correctly to the Arduino board. After reading the manual of the Arduino Pro board the solution has been found [44].

On the Arduino Pro board there is a small jumper, determining whether the current is delivered by a battery connector or an external method like a charging unit. In order to guarantee full functionality with the soldered cables method the jumper needs to be set to the external value (EXT) and not to the battery (BATT) value. After this step the current was measurable on the hole chip set and the battery package has been successful connected to the Arduino board.

The Arduino board and the flex sensor

The electronic board of the first prototype has to be removed out of mobility reasons and to fit into the wooden case which is already described above. Due to this the wiring of the Arduino board and the flex sensor changed significantly.

At first the described FTDI adapter has to be installed. On the Arduino board there is already a connector for the FTDI adapter. The first idea was to connect the adapter and the connector with the help of cables which sounds good first because this idea allows to place the adapter in the middle of the Arduino board and so the case could be made smaller but on the other hand the FTDI adapter has to be near an ending of the case in order to be reached by a micro USB cable to load the software to the board. This is important because the case doesn't have to be opened in order to connect the FTDI adapter with a laptop. Through a hole in the case the micro USB cable can be easily plugged into the adapter if it is placed near a side of the case and not in the middle of the Arduino board. Out of this consideration the FTDI adapter is simply plugged into the on- board connector of the Arduino board. Soldering it to the connector is not necessary because the connection is very tough.

Just plugging the FTDI chip into the Arduino and not fixing it in the middle of the Arduino to be reached by a micro USB cable causes another Problem. In that case the FTDI chip juts out the Arduino and the case has to be bigger as it needs to be if the FTDI adapter is placed in the middle of the Arduino. However the advantages of simply plugging it into the connector are even bigger:

1. The FTDI can be reached with an USB cable through a hole in the case without opening it.

2. Plugging the FTDI adapter into the connector makes the combination more stable than using cables.

3. The FTDI adapter cannot be pushed away with the micro USB cable if it is plugged in and the Arduino board is anchored in the case.

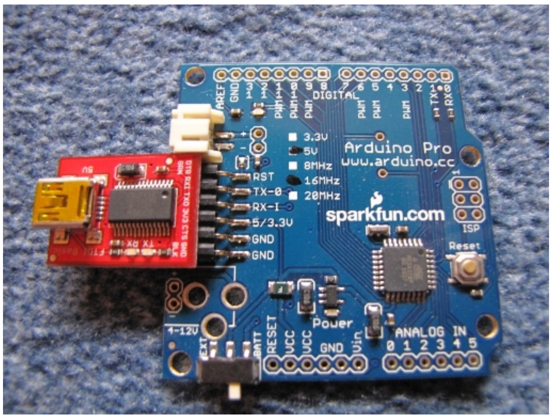

Figure 6.17: The Arduino Pro board with the plugged in FTDI adapter.

Out of this reasons the decision was made to simply plug the FTDI adapter into the on board connector of the Arduino board. Figure 6.17 shows the Arduino Pro and the plugged in FTDI adapter on the left side of the Arduino board.

After installing the FTDI adapter the Blue tooth chip is attached. The procedure is just the same way like it was at the first prototype but the cables are being soldered now on the Blue tooth chip and the Arduino. Again two white ones, a blue one and a brown cable are used. One white cable connects the send connector of the Blue tooth chip (Tx-0) with the receive connector of the Arduino Pro (Rx<-0). The second one connects the send connector of the Arduino Pro (Tx->1) with the receive connector of the Blue tooth chip (Rx-1).

The brown cable is used to supply the Blue tooth chip with the necessary power. One side of the cable is soldered with the current connector (VCC) of the Arduino Pro the other side is soldered with the VCC connector(VCC) of the Blue tooth chip. The blue cable is used for the grounding of the two chips. Both endings of the blue cable are soldered with the ground connectors (GND)of each chip.

Since the electronic board had to be removed the soldered connection between the Arduino and the Flex sensor differs from the old connection of the first prototype. The first white cable is soldered with the current connector (VCC) of the Arduino Pro and the other ending of it is soldered with an electrical resistor. The other side of the resistor is soldered to another cable. This cable is soldered to the input pin of the Flex sensor to provide current and the measuring cable. The other ending of the measuring cable is soldered to the analogue input connector (ANALOG IN 0)on the Arduino Pro board. The output pin of the

Flex sensor is soldered to a cable which is again soldered to the ground connector (GND) of the Arduino Pro board.

Since the Flex sensor is positioned and installed in a glove on the back of the hand and the case with the electronics is strapped down on the upper arm the cables which connect the Flex sensor with the Arduino have to be long enough. The current cable that connects the current output and the resistor will be placed inside the case. The resistor will also be placed into the case in order to avoid that this sensitive component gets damaged. In addition the measurement cable can be placed into the case because the point of measurement is directly after the resistor on the current cable and therefore the measurement cable can be soldered directly anywhere on the current cable. The cables that have to be long enough for reaching the Flex sensor are:

1. The current cable that connects the resistor with the input pin of the Flex sensor.
2. The grounding cable that connects the output pin of the Flex sensor with the ground connector of the Arduino Pro.

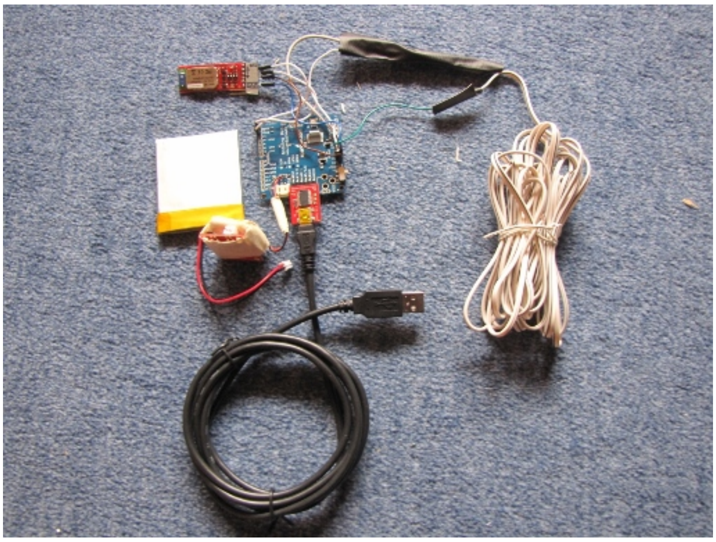

Figure 6.18: The finished soldered equipment that is going to be attached to the case.

All of the other used cables are inside the case. Figure 6.18 shows the finished soldered electronic equipment that will be assembled into the case.

Combining the electronic devices with the case

The last step of enhancing the prototype is to integrate the complete hardware into the already described case. This case is equipped with several holes, simply drilled with a

carpenter's brace, which are used to plug in the necessary cables. The three holes are used for:

1. The FTDI adapter to program the Arduino Pro with the help of an micro Universal Serial Bus cable.

2. The charging unit adapter to charge the LI-Ion battery with an micro Universal Serial Bus cable.

3. The cables that connect the Flex sensor with the Arduino board.

The first step of integrating the hardware into the case is to find a suitable place for the battery. One of the edges of the case seems to be perfect for this purpose. With the help of double faced adhesive tape the battery is glued on the bottom plate of the case.

The second step of integrating the hardware contains fixing the Step-up-boost and the charging unit in front of the hole for the micro Universal Serial Bus cable. This package is fixed on the bottom plate of the case with the help of two screws in order to prevent the package from being pushed away if the micro USB cable is plugged in. After the charging unit and the Step-up- boost have been screwed down the battery cable is plugged into the adapter of the charging unit to provide the hole system with the necessary power.

After the Step-up-boost and the charging unit have been installed on the bottom plate of the case the Arduino Pro board with the FTDI adapter is placed on the already installed battery. The FTDI adapter is eased into the envisaged hole. Fixing the board with screws is not necessary since the remaining free place in the case is now stuffed with the Blue tooth chip and the residual cables which prevent the Arduino board from being pushed away if the micro Universal Serial Bus cable is plugged in to upload the necessary software to the chip.

The last step of integrating the hardware into the case is to plug in the Blue tooth chip. The free remaining place in the case is used to accommodate the Blue tooth chip. Due to the very small case a part of the Blue tooth chip overlaps the Arduino Pro board. To isolate the overlapping part of the Blue tooth chip duct tape is used.

The measuring cable is also obstructed in the case. The long current cable and the necessary grounding cable leave the case through a hole and are ready to be soldered with the input and the exit pin of the Flex sensor. This last remaining step of soldering is done after the evaluation process when the position of the case on the body is determined because the length of the current and the grounding cable connecting the glove and the case depends on the position of the case on the body.

To fix the case with the integrated hardware somewhere on the body a belt clip is used. This belt clip is screwed on the case and can be fixed on a belt which results in wearing the case near the pelvis. Another possibility is to wear a flexible armlet on the upper arm on which the belt clip can be fixed.

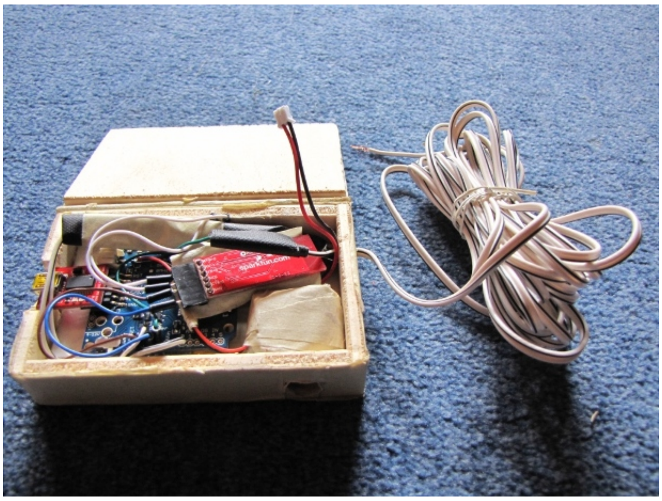

Figure 6.19: The finished case with the integrated hardware.

Figure 6.19 shows the case with the integrated hardware. On the left side of the case the FTDI adapter is visible. On the front side of the case the outlet for the micro USB is positioned which is used for charging the battery. On the right side of the case the current and measuring cable for the Flex sensor are visible.

The last step of integrating the hardware into the case and making the device suitable for the evaluation procedure contains the connection of the flex sensor with the current and the grounding cable. For this purpose two yellow cables have been soldered to the in- and output pin of the flex sensor. The other endings of these cables have been soldered to a cable clamp which connects the yellow cables with the current and the grounding cable. Figure 6.20 shows the soldered connection of the flex sensor with the current and the grounding cable.

Occurred Problems

After the prototype has been completed and tested over several days an error occurred. The used Li-Ion battery seemed to be empty although it was charged. Investigations showed that the battery smelled in a very bad way. A new battery from the same type was purchased and everything seemed to be fine again but soon the battery showed the same behaviour like the old one except of the bad odour. To overcome this problem a new current supplying method had to be found.

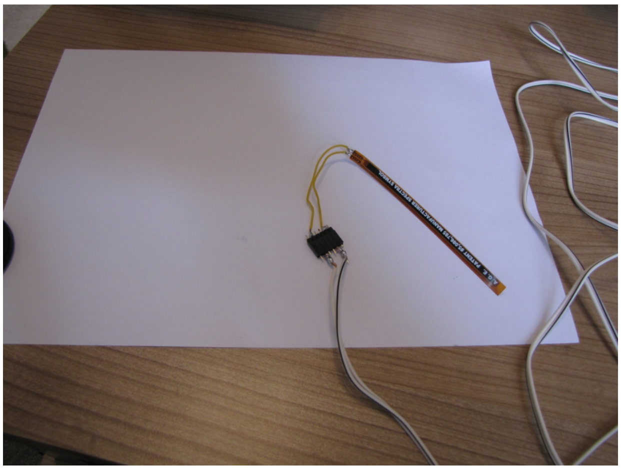

Figure 6.20: The connection between the flex sensor and the current/grounding cable.

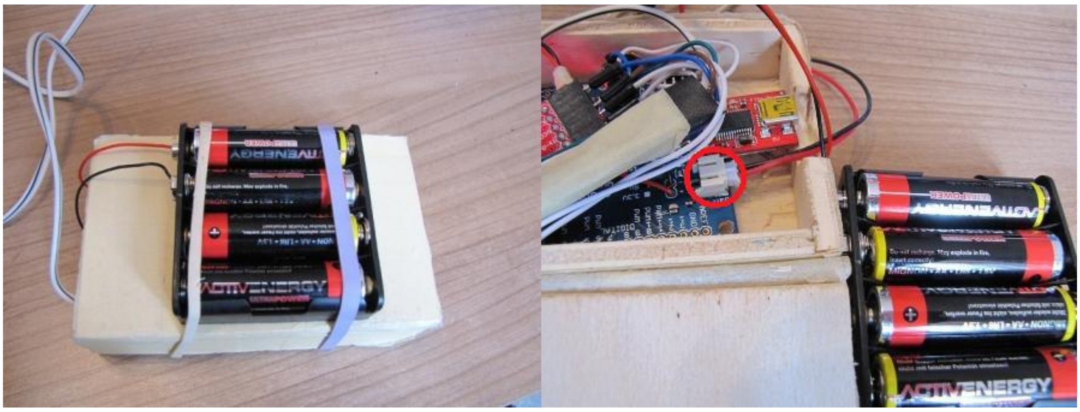

Figure 6.21: The new battery solution. On the left side of the picture the battery package placed onto the device case is visible. On the right side the connection of the battery case and the Arduino Pro is displayed.

To gain the possibility of testing the device with T. a battery case has been purchased. This case can be equipped with four 1.4 volt AA batteries and is able to provide the Arduino with the necessary 5 volts. To get the new battery functionally a black and a white cable were soldered to the connectors of the battery case. In addition a battery connector was soldered to the other endings of these cables. The connector can be easily plugged to the battery connector of the Arduino Pro. In order to get the prototype working with this battery solution the jumper of the Arduino Pro board needed to be set to battery [BATT] and not to external [EXT] mode. The new used cables are placed in the hole for the FTDI adapter which makes a new hole useless. Figure 6.21 shows the new used battery package.

Through this solution the extend of the device is bigger than using an intern Li-Ion battery. Unfortunately it was not possible to purchase a third Li-Ion battery through financial limitations of the Technical University of Vienna. The approach of using an external battery package makes the already integrated battery charger and the Step-up-boost useless because the battery case delivers enough volts to power the Arduino Pro and empty batteries can easily be switched. Since the approach of using an intern Li-Ion battery which is significantly smaller fits the needs of T. more than the current external version both, the charging unit and the step up boost remain in the case to gain the possibility of using the intern version maybe at a future date.

CHAPTER 7

Evaluation of the prototype

7.1 Pre-evaluation

Figure 7.1: Pre - evaluation pictures prepared for T.

Since the device has been designed with the help of a person suffering from cerebral palsy and therefore the design process was user centred it was necessary to gain some feedback. The main test person, T., agreed to help us through the whole design process. To ensure that the designed and built device fits the needs of T. some pictures of the prototype have been taken. These pictures were mailed to T. together with a detailed description of how to

use the glove to get feedback and to hear his opinion about the prototype before the device can be tested in Germany or Austria with T.'s attendance. Figure 7.1 shows the pictures of the prototype mailed to T. The top row shows the glove positioned on the hand. The bottom row shows the the measuring cable and the case. The right picture in the bottom row shows the pathway of the measuring cable which is partly under the shirt.

7.2 Feedback from the pre-evaluation

The received feedback from T. was positive. He mentioned that the device fits his needs at this stage of development. He was satisfied with the design and the software and agreed to test the device in Germany. For that reason we talked with our supervisor Univ. Ass. Mag.rer.soc.oec. Dipl.-Ing. Florian Güldenpfennig who agreed to visit T. on a trip to his home town in Germany. A smart phone from the Technical University Vienna was taken and the necessary software was installed. Together with the necessary hardware the prototype of the spasm glove was sent to Germany and tested with T. under ward of Univ. Ass. Mag.rer.soc.oec. Dipl.-Ing. Florian Güldenpfennig a few hours long. In addition an evaluation plan was used to gain as much information as possible from that meeting. The evaluation plan is presented in the following section.

7.3 Evaluation plan

The evaluation plan includes all the necessary information for evaluating the device. Since the evaluation can be split into a mechanical and a software part the following tasks and data are necessary to evaluate:

- Hardware:
  - Tasks:
    - Learn to mount the device.
    - Learn to handle/operate the device.
    - Use the glove a few hours under supervision.
    - If no problems occur possibly use the glove unattended.
  - Data:
    - Conspicuousness
    - Comfort
    - Weight
    - Size
    - Design
    - Robustness
    - Effect
    - Correct recognition

    * Usefulness
    * Applicability

- Software:
  - Tasks:
    * Learn to calibrate the device.
    * Learn to handle the User interface of the device.
    * Use the glove a few hours under supervision.
    * If no problems occur possibly use the glove unattended.
  - Data:
    * Design
    * Usability
    * Effect
    * Correct recognition
    * Usefulness
    * Applicability

Collecting this data with the help of T. will help us to reveal weak spots of the spasm glove. The gained information can be used for improving the glove to fit T.'s and other's needs.

7.4 Findings of the pilot study

Overview

To gain as much information about the functionality of the spasm glove as possible the device was tested with T. under ward of our supervisor Univ. Ass. Mag.rer.soc.oec. Dipl.-Ing. Florian Güldenpfennig in Germany. T. used the device a few hours long and the findings of this evaluation are presented in the following sections. Unfortunately we could not attend the meeting of Univ. Ass. Mag.rer.soc.oec. Dipl.-Ing. Florian Güldenpfennig and T. which made it necessary to arrange a meeting with our supervisor in order to talk about the evaluation with T.. In order to talk with T. personally we arranged another interview with him which was conducted over Skype and audio recorded again.

Meeting with our supervisor

After Univ. Ass. Mag.rer.soc.oec. Dipl.-Ing. Florian Güldenpfennig returned from his trip to Germany we arranged a meeting with him to talk about the evaluation with T..

The evaluation with T. consisted of three main steps. First of all the device was explained to T. which included a basic introduction of the hardware as well as of the software. T. learned how to attach the device and how to calibrate it. In addition he had to learn how the user interface of the device works in order to control the device alone.

During the second step T. had to wear the device a few hours under supervision. This was necessary to adopt the hardware and software to the needs of the user and to gain a first feedback.

The last step included the use of the device on his own without being under supervision. This step was necessary to see if the user was able to work and train with the device on his own.

Hardware

Validating the hardware and talking about other evaluation criteria like robustness, effect, correct recognition, usefulness and applicability T. mentioned that the hardware never refused to work, his spasms were correctly recognized by the system and after a few hours of using the device the spasms occurred rarer than using it before.

It is small enough and does not hinder him in his daily life. In addition it is very light, unobtrusive enough and the comfort of wearing it is very high since the glove was made out of an elastic sock. He likes the cut of ending of the sock which enables T. to use his fingers without being hindered by the fabric.

Software

While validating the software components of the spasm glove such as the logger and the feedback device, unfortunately some problems occurred in the long-term monitoring scenario with T.. Amarino crashes, compatibility problems with different smart phone manufacturers like Samsung and HTC and small errors in the leveling system of the logger have been discovered during the evaluation. More details about the software evaluation can be found at [56].

Functionality of the device

Although some problems during the usage occurred the device worked fine and was easy to handle. The prototype of the spasm glove was tested by T. for several hours and he was able to use the device on its own without help from his parents or any other person. The provided feedback from the device helped T. to relax and concentrate on occurring spasms. As a result he was able to react to the spasms in a more satisfying way than before because he was able to dissolve the spasm much more faster than without using the device. In addition to faster resolvable spasms, even less spasms occurred due to the more relaxed mood of the patient.

To sum up, according to T., the use of the spasm glove seemed to be very useful. Beside some stability issues of the software, the device worked fine, detected all occurring spasms and alerted the user. Through the implemented logger and the included motivational and achievement system the user was more relaxed and could react to occurred spasms in a

more suitable way than without using the device. In addition first signs of an occurring neuroplacstic effect, such as suffering from less and even less intensive spasms could be observed.

Evaluation interview with T.

To gain as much information as possible and to reveal possible missed statements that T. made at his meeting with our supervisor we conducted a second interview with T. to talk personally with him about the evaluation. During this interview some new points of view and possible improvements were revealed. The following sections describe new information we gained from the evaluation interview with T.:

Hardware

As far as the used hardware is concerned, T. mentioned that it was very simple to mount and learn how to use the device. He was very happy with the hardware of the device with exception of two single points.

Regarding the design of the spasm glove T. explained that the approach using a sock as a glove is functional but he mentioned that it looks quite cheesy. In addition he was unhappy with the approach of using a case for the hardware and the long cables which are necessary to connect the Arduino board with the Flex sensor.

T. suggested to design a new glove and to build the hardware directly into the glove right beside the flex sensor. According to T. this new design approach will result in an even smaller size and weight of the device because the case can be dropped. Also the comfort in daily life and the conspicuousness of the device can be improved by placing the hardware directly on the glove.

Software

Beside new information regarding the hardware also some new improvements for the software of the device have been discovered during the evaluation interview with T..

No events were raised by accident, the achievement system did not work as planned, the leveling system worked pretty well and the user interface was perfectly designed to fit T.'s needs. Another interesting point was that the user wants to have statistics about his progress. More information about the software evaluation interview conducted with T. can be found at [56].

Functionality of the device

T. mentioned that the device is very useful for him and can be used as a training device for reducing occurring spasms. On the one hand the device forced him to relax which

had a significant impact on the strength and duration of occurred spasm. On the other hand after the device had been used a few hours the frequency of occurred spasms was even lower than at the beginning of the evaluation. The analysis of the logged spasm data confirmed his statements.

Due to T.'s assertions the main remaining problems for him are the case, the cheesy sock,the long current and measurement cables which disturb him in daily life and the bugs in the logging software. These mentioned problems as far as hardware and design issues are affected are solved and described in the next section of this master thesis entitled "Redesign of the prototype". Information about solving problems regarding the logger, the motivational system and the achievment system can be obtained from [56]. Problems like Amarino crashes and stability issues between different smart phone manufacturers can not be solved by us due to the lack of a smart phone produced by each manufacturer.

7.5 Redesign of the prototype

The glove

After T.'s statement that the used sock looks cheesy one metre of black elastic fabric was purchased. With the help of a sewing machine a simple glove was produced. Again a little pocket for the flex sensor was sewn to the glove. In addition a bigger pocket for the hardware was sewn beside the flex sensor. This pocket takes over the functionality of the case:

1. Holding and protecting the hardware.
2. Reducing the size of the hardware to an absolute minimum.

The hardware holding pocket is equipped with a Velcro fastener which allows the user to open and close it. The Velcro fastener prevents the hardware from dropping out. Figure 7.2 shows the new glove with an already installed flex sensor in the small pocket and an empty big pocket.

Combining the glove and the hardware

Due to the omission of the case the current cable and the measuring cable have to be shortened and new black cables are installed on the Arduino board. These black cables are nearly invisible on the black fabric of the new constructed glove.

Beside the use of a pocket on the glove nothing else changed. The hardware still consists of the same components including the Arduino Pro, the Li-Ion battery, the FTDI adapter, the charging unit, the Bluetooth Mate chip and the step up boost. These components are belted together with a rubber band and simply stuck into the dedicated pocket. Figure 7.3

Figure 7.2: The new glove made out of elastic fabric.

Figure 7.3: The bundled hardware on the left side and the ready to use glove with the integrated components on the right side of the picture.

shows the bundled hardware on the left side and the ready to use glove with the integrated components on the right side.

CHAPTER 8

Discussion

This chapter summarizes the outcome of this master thesis and the results are compared to the initial work. In addition findings are presented which show that the device could not be implemented as planned.

8.1 The fundamental design of the spasm glove

According to T. the perfect prototype for him has to fit three main characteristics. The device has to be small, light and should not disturb him in daily life. During the design process the first prototype of the spasm glove consisted of an old sock with an attached flex sensor. The necessary hardware to make the prototype functional was built into a wooden case and cables were used to establish a connection with the flex sensor. This approach corresponded the requirements of T. but although he was satisfied with the functionality of the device he argued that a new glove with integrated hardware would be even better for him because of the disturbing long cables connecting the case on the belt with the flex sensor attached to the glove.

Another patient suffering from cerebral palsy who did not want to appear or be a part of this master thesis but agreed to decide himself between the two versions argued that the first version would be better for him because he is feared that the second approach with the integrated hardware directly on the glove would disturb him more than the first version. Unfortunately this patient was not willing to be interviewed and taken into consideration for the design of the device.

The resulting spasm glove was designed and built for the needs of T. and his personal taste but these two different opinions showed that many different people prefer different solutions which are most comfortable for each of them.

8.2 The feedback device and the logger

Beside the spasm detection device and the corresponding hardware there are two additional key components belonging to the spasm glove. The feedback device and the logger. The interviews with T., his father and a therapist showed that placing the feedback device directly on the wrist or on the forearm would cause some problems. Cerebral Palsy can be caused by various causes. Some of these causes are responsible for the disability of not being able to feel any pain at those areas of the human body. In this cases the placement of a vibrating device on those areas is impossible even if the literature [13] states that the forearm or the wrist are the best places for the perception of vibrating signals. Out of this reason the decision was made to use a smart phone as feedback device. According to several patients with different abilities of feeling pain the smart phone used as vibrating device can be placed at different positions if the evaluation shows that a chosen place is bad for the current user.

Beside the already implemented features of the feedback device another point of the specification list, "Alert relatives too", would be useful. By broadcasting the alert of an occurring spasm to multiple smart phones, for example the smart phones of the parents, they would be alerted too if their son has a spasm. In this case they could react even faster and help their son trying to relax.

The logger is one of the key components of the spasm glove. Responsible for logging information that can be used for supporting an additional therapy, the logger automatically collects various sets of data such as the duration of an event. Spasms often occur if people suffering from cerebral palsy are excited or nervous. The mood of a patient is mostly responsible for occurring spasms so beside these automatically collected items the user should have the possibility to enter a reason or a frame of mind for each spasm which might be interesting for therapists or the user himself. Of course affected people often suffer from impaired writing skills which makes it difficult to define a specific reason on the smart phone by writing. To overcome this serious problem there are some possibilities which include speech recognition, input via text-box or input via "mood images".

Although Android supports speech recognition [31] the main disadvantage is the use of it while being in public which may annoys other people. A text-box would not harm any other people but as mentioned above writing can be difficult for affected people. The perfect middle course of these two approaches seems to be the use of "mood images". Various pictures of moods can be displayed on the smart phone and with one single click the user can define his current state of mind. This method does not disturb any other peoples in his environment nor is it necessary to write down a specific reason. Although input possibilities are not implemented in the prototype advanced input possibilities should be treated in possible future work.

8.3 Data transmission

At the beginning of investigations three main possibilities of transmitting the data from the Arduino board to the logging device have been discovered:

- USB connection
- Wireless LAN
- Blue tooth

The used blue tooth connection turned out to be the best choice. Although an USB-connection can be used to power the system which makes the use of a battery including the charging unit and the step-up boost needless and therefore the device would be even smaller it turned out that an additional USB cable would disturb the user in his daily life. The first approach of the spasm glove was equipped with a case containing the necessary hardware. This case was fixed on a belt and with the help of two long cables the Arduino was connected with the flex sensor attached to the glove. As T. evaluated the device he mentioned that this solution worked perfectly on the on hand but on the other hand the long cables disturbed him. In contrast to the connection between the case and the flex sensor, which are both fixed on a belt or the hand and therefore non moveable, the connection between the Arduino board and the smart phone with an USB cable would be even more disturbing for T. because the smart phone can be placed everywhere and has no fixed point of attachment. The approach using wireless LAN described during the design process [37] is not suitable for the spasm glove since it lacks the opportunity to establish a connection between the smart phone and the Arduino board.

Unlike the blue tooth connection which is stable and works perfect Amarino, responsible for the receiving the data on the smart phone, can be unstable when used over a long period. Unfortunately these stability problems cause some crashes from time to time and the only way to continue the spasm measurement is to restart the program.

8.4 The underlying hardware

The main purpose of building a prototype of the spasm glove was to develop a tool which is able to help people suffering from spasms in their arms. Through the help of neuroplasticity a reduction of occurring spams should be achieved. Through conducted interviews with T., his father and a therapist the requirements for the design were quickly resolved. The device has to be small, light, inconspicuous and not to expensive.

The flex sensor [53] is the heart of the spasm glove. Responsible for detecting occurring spasms it was necessary to find a solution which guarantees a stable working setup. The flex sensor manufactured by Spectrasymbol works in a satisfying way. It is able to detect spasms and is robust. Unfortunately some of the used sensors refused to work after a

period of usage due to the loss of conductive paint on the connector pins. This seems to be a problem of some flex sensors evoked through production issues. Another disadvantage of the flex sensor is the small range of possible values which are delivered by the sensor. Due to that the measurement of the angle of the wrist is more difficult. The self made flex sensor mentioned above would provide a solution for these problems but could not be built because of the missing and not purchasable components in Europe. The other introduced sensors were either too expensive or too big to be used so the flex sensor by Spectrasymbol was the best choice to fit T.'s needs.

The Arduino board and the Blue tooth module were purchased and used for building a first Proof-of-Concept prototype to guarantee the functionality of the designed spasm glove. During the enhancement step of the design process a smaller Arduino board was purchased. This step, on the one hand, made the use of an FTDI adapter necessary but on the other hand reduced the size of the device significantly. In addition there are on the one hand even smaller Arduino and Blue tooth chips available on the market [6] but on the other hand the size of the hardware package depends on the size of the Li-Ion battery which is the biggest component of the used hardware. If the battery is smaller it makes sense to buy smaller Arduino and Blue tooth chips in order to build an even smaller device.

The use of a battery was necessary since we decided to use a Blue tooth connection instead of an USB cable. The used Li-Ion batteries are small and cheap but refused to work proper after some time. The reason for that behaviour is not clear and could not be found out. The solution with an above explained external battery case works out fine but is to big for a regular use instead of the intern Li-Ion battery and should only be considered as a workaround. In addition the battery needs to be charged from time to time. For that case the charging unit has been installed which can not be used for the external battery case. There are many other Li-Ion batteries available on the market which are even smaller. Future work should contain the search for a matching battery solution.

8.5 The functionality of the spasm glove

The functionality of the spasm glove is given. After the redesign of the glove T. was satisfied with both, the design and the logging interface on the smart phone. A reduction of occurring spasms after a few hours of practice was noticed and validated by T. himself and the collected data.

Unfortunately some stability problems occurred. From time to time Amarino refuses to work proper. There seems to be a bug in the distributed version which causes the program to crash. Without the use of Amarino the logging software can not operate any more which makes the device useless. The problem can be solved by restarting Amarino but of course this is a serious problem and can not be ignored at possible future work. Maybe coming versions of the Amarino tool kit [28] can solve this problem.

In addition there are stability problems with cell phones from different manufacturers. The software has been developed on a Samsung Galaxy S cell phone and worked without any problems. For the evaluation with T. we used a HTC smart phone and installed the application on the hard drive. When we checked the software we noticed that there was an error caused by parsing dates on the HTC smart phone. Such errors are produced by differences in the Android system of Samsung and HTC. Although this special bug has been removed the functionality of the software can not be warranted for all different labels of smart phone.

An important point of making the device successful deals with the customization of the software. It is implausible that the physical limitations and skills of affected people are the same for each person. For that case some customizations in the logging software for each user have to be done to adapt the device to the patients personal needs.

To sum up on the one hand the device seems to be suitable as an additional training tool which T. appreciates and also can be observed by reference to the collected data. On the other hand there are some points which have to be fixed in possible future work to make the device more flexible for all affected people. The glove for example is designed especially for T.'s needs. As the case with the other not cooperating patient shows the personal taste and design issues can differ from person to person. Unfortunately it was not possible to find more affected people which were willing to contribute. The more people had cooperated, the more opinions had been incorporated into the design which had made the design much more general and not specialised for one person. In addition we can not guarantee that the device works with all different manufacturers since the Android system changes slightly from smart phone to smart phone.

8.6 The spasm glove and neuroplasticity

During the design process of the device we explained the term "Neuroplasticity" to T. in order to make him understand which goals have to be achieved by our work. During the evaluation process we talked with T. about the usefulness of our device regarding neuroplasticity. T. mentioned that the device was able to reduce occurring spasms over time. His statements were confirmed by the collected and analysed data sets.

As described in the section "Neuroplasticity" there are four kinds of neuroplasticity [60]. "Reactive plasticity" , which mostly appears after a transient exposition to a significant stimulus and can be seen as a reaction of the human brain to an event, could be observed during the evaluation with T.. Soon after T. got in contact with the device he was able to control it and soon he knew what he had to do to dissolve an occurring spasm.

Also the second kind of neuroplasticity entitled "Adaptation plasticity" [60] occurred during the evaluation phase. Due to the over a long time repeated stimulus of the device a

significant change in the appearance of occurred spasms could be achieved. The spasms were less intense, occurred less often, did not last so long and could be better resolved compared to the situation before using the device.

Although short-term plasticity successes could be achieved the main goal of achieving a "Reparation plasticity" [60] could not be observed. A totally disappearance of spasms could no be achieved. Possible reasons for that are the lack of time for conducting a long term study with T. and his training successes, the possible to weak stimuli offered by the device or the universal disability of the device to achieve 100 percent of recovery.

8.7 The spasm glove as assisitive and rehabilitation device

Although the goal of achieving a reparation plasticity [60] could not be reached, the spasm glove is suitable for being used as an assistive or a rehabilitation device.

According to [66], rehabilitation and assistive devices are developed to overcome certain impairments to a mostly limited extinct. By the use of the spasm glove the patient gets forced to be more relaxed, which results in much less occurring spasms. In addition occurring spasms become less intense over time and are much more easier to dissolve due to the training with the spasm glove.

Because of these achievable changes of the medical condition due to a permanent training with the device, the spasm glove can be considered as a suitable rehabilitaion and assistive device.

CHAPTER 9

Conclusion

During this joint master thesis a device was developed, that is able to detect occurring spasms. In addition it alerts the user of an occurring spasm, provides feedback and tries to establish a neuroplastic effect inside the brain of the user to achieve permanent improvements of the medical condition of the patient. This part of the joint master thesis focuses on the hardware which is needed to build such a device.

The implementation of the device was done in an iterative process, which included different people after each step. At the end the device was tested with the help of T. who suffers from spasms. T. finally stated that the device works well for him but in addition he offered some additional possibilities, which can be implemented to enhance the device. Due to T.'s statements from the evaluation the device can be considered as a helpful training tool. Although the functionality of the spasm glove is already given there are some points of enhancement which can be examined in possible future work. These improvement approaches will on the one hand customize the spasm glove for each user and on the other hand improve the amount of useable data sets. In addition the hardware will be optimized to make the spasm glove as satisfying as possible. This suggestions are described in the following sections.

In addition the answers of the at the beginning of this master thesis formulated research questions are presented.

9.1 Answers of the research questions

At the beginning of this master thesis three basis research questions for the project have been formulated:

1. Is it possible to design and implement a device which is able to detect occurring spasms in the wrist?

2. Are the logged information useful to support an additional physical therapy or to fit any other needs of analysis?
3. Is it possible to reduce occurring spasms and achieve a neuroplastic effect inside the brain by a permanent training with the device?

The answer for the first question is quite simple. It is possible by the usage of the following components:

- A suitable glove.
- The flex sensor to detect the angle of the wrist.
- The Arduino board.
- A battery to power the electronic hardware.
- A Blue tooth chip used to transmit the collected data.
- An Android smart phone responsible for hosting three main software components:
  - The logger, responsible for logging useful data sets.
  - The motivational system, responsible for motivating and rewarding the user.
  - The feedback system, responsible for alerting the user if a spasm occurs.

The second question can be answered by observing the motivational system and the progress a patient achieves. The logged information are useful in many different ways. First of all the patient is able to see improvements of his medical condition which additionally will motivate him. In addition the collected data sets can be used to have a proof what happens if the patient is not in therapy. The patient's parents, other relatives or just friends can compare the information gained from sessions under their surveillance with the information gained when T. is meeting others. The collected data sets can be used to find behavioral disorders which might cause spasms and reveal activities the patient is performing while a spasm occurs. At last, logging information is nowadays very important for health insurances. With the collected data a prove can be given that new therapies are necessary and have to be paid by health insurances.

Finally the third questions can be answered quite simple too. Yes, with the current prototype of the spasm glove it is possible to reduce occurring spasms and achieve a neuroplastic effect inside the brain of the user by a permanent training with the device.

"Reactive plasticity" and "Adaption plasticity" [60] could be observed during the evaluation. Our main participant, T., mentioned that the spasms were less intense, occurred less often, did not last so long and could be better resolved compared to the situation before using the device. His statements were confirmed by the collected and analysed data sets.

To sum up this section the evaluation of the developed prototype showed that the prototype had some little flaws but it worked as expected and supports T. in his daily life.

9.2 Degree of possible neuroplastic effects

During the evaluation phase "Reactive plasticity" and "Adaption plasticity" [60] could be observed. The occurred spasms were less intense, occurred less often, did not last so long and could be better resolved compared to the situation before using the device. This statements were confirmed by the collected and analysed data sets.

Although the frequency of occurred spasms could be decreased, there were still spasms. The last and most powerful degree of neuroplasticity, "Reparation plasticity" [60], could not be achieved out of the following possible reasons:

- The lack of time for conducting a long term study with T. to observe and evaluate his training successes.
- The possible to weak stimuli offered by the device.
- The universal disability of the device to achieve 100 percent of recovery.

The execution of a long term study would be necessary to see if "Reparation plasticity" is achievable. If "Reparation plasticity" will not occur until one or maybe two years the current provided stimuli could be to weak. In this case the possible improvements described in the following sections could be useful to achieve a better stimuli.

Another possibility of not reaching the "Reparation plasticity" process could be the universal disability of the device to achieve 100 percent of recovery. In this case the device could only be used to improve affected functions, but it will not be able to recover damaged functions to an extinct of 100 percent.

Possible future work should include the question of if the "Reparation plasticity" degree is reachable by conducting a long term study. If not, several in the following sections described modifications can be useful.

9.3 Customization

The spasm glove was designed and developed with the help of T. who told us his personal requirements for the product. Of course additional information were gained from other interviews too but unfortunately T. was the only affected person who was willing to cooperate. Due to that the design, hardware and software are specialised for T.'s taste. In order to build a device which is most useful for a bigger range of affected people more people who are willing to cooperate and finally redesign the product have to be found.

If these people can be located some important issues of the spasm glove can be redesigned or customized for each patient:

- The basic design which deals with the question where specific hardware components have to be located.
- Missing features, hardware and software that were not considered yet through missing input from more affected people.
- The software has to be adopted for each user. This step includes the input techniques, achievements, levelling system, difficult level, the feedback and the general user interface. More information about necessary customizations can be obtained from [56].

Regarding the software a possible step of making the software more individual for each person could be the use of selectable setup files which for example can be used to simply change the user interface or the difficult level. Another possibility is to change the code of the software for each person to adjust the program for personal needs.

As far as the basic design is concerned it could be possible to develop a modular hardware system that can be attached and fixed at different positions true to the taste of the user. If the hardware is fixed at a certain position it can be connected with simple cables.

9.4 Optimization of the hardware

Although the selected hardware already fit the three basic requirements of being small,light and inconspicuous there are some possibilities to optimize the hardware.

Arduino and Blue tooth chip

In comparison with the used Arduino Pro there are even smaller Arduino boards available on the market. The Arduino Mini, the Arduino Nano or the Arduino Pro Mini are basically eligible for the project and can be taken under consideration. The main disadvantage of these smaller boards are less existing connectivity options. The possibility of using one of these boards has to be examined in future work. Beside the possible use of a smaller Arduino board there are also some smaller blue tooth chips which could be used.

FTDI adapter

The used FTDI adapter can be dropped once the program which readouts the electrical resistance of the flex sensor is uploaded to the Arduino board. Due to the current use of the Arduino Pro board and the resulting bigger pocket on the glove the remaining place of the pocket can be filled with the FTDI adapter. If one of the above mentioned smaller boards is suitable the pocket can be made smaller and the FTDI adapter can be dropped since the Arduino boards have the possibility to store the necessary code without current supply.

The battery

The most necessary point of optimization contains the current supply over a battery. The used approach contains an Li-Ion battery including a step up boost to gain 5 volts and a charging unit to charge an empty battery. This approach works fine for a few days but after this period the battery starts to reek and does not work any more. Two batteries of the same kind have been tested. As an alternative solution we used an external battery cage which is far too big on the one hand and on the other hand makes the charging unit and the step up boost needless since the batteries can not be charged while they are placed in the external case. The search for a new Li-ion battery is another step of optimizing the hardware. A battery with the same extent or even smaller as one of the above mentioned tiny Arduino boards would be perfect for making the sewn pocket on the glove as petite as possible.

Sensor for detecting spasms

Also the flex sensor provides enough space to be optimized. Although the functionality of the flex sensor manufactured by Spectrasymbol is given the low range of possible measured values makes it difficult to calibrate and log occurring spasms. The already introduced self made flex sensor from [42] is able to increase the possible range of measurable wrist angles. With the help of this sensor it would be possible not only to detect whether the wrist is bend or not but also the angle of the flexion would be measurable. This additional data can be used to improve the logging software and provide even more useful therapeutic information.

9.5 Analysis of the collected data

The collected data from the spasm logging device on the smart phone is currently saved into a simple text file. To gain important and useful information the user or the therapist has to open the file located on the hard drive of the phone. Due to that the feature "Logged information as basis for analysis" from the described specification list is implemented.

The records are more difficult to interpret the larger the file becomes. For that reason an information visualization tool seems to be the best choice. Using such a tool would be perfect for converting text-based data sets into many different charts which are more easier to interpret for:

- The user himself:
  If the user is able to easily access and visualize the logged data over an visualization tool he might be able to draw conclusions. This might help the user to avoid critical situations.

- The therapist:
  Through the help of the collected data visualized with an effective tool therapists will be able to create a individual training program for each patient.

- Relatives:
  Even relatives of a patient can study the data with a visualization tool more powerful which again might helps to avoid critical situations.
- Health insurances:
  Nowadays the logging of information is very important for health insurances. With the collected data a prove can be given that new therapies are necessary and have to be paid by the health insurances. With a visualization tool processed data can be checked faster than text-based information.

9.6 Possible additional hardware

Servo motors

Currently the glove is able to measure and detect and occurring spasm. Warned through an audio or vibrating signal the user has to react to the spasm and in case of resolving it he earns an achievement. Through the conducted interview with the therapist we discovered another future possibility of enhancing the spasm glove.

If the user is not able to loosen the spasm on his own little servo motors could be used to bring the finger and the wrist back to a natural pose. The advantage of this additional approach is that the device can also react on spasms in a mechanical way, if the patient is not able to get rid of the spasm on his own. In this case the device could stretch the fingers automatically which may helps the user to relax faster than trying to loosen the spasm own his own for a long time. The feature "React to spasms in a mechanical way" from the described specification list will be fulfilled within this solution.

One Disadvantage of this approach might be the increased weight of the spasm glove. The servo motors have to be placed near the fingers and the wrist to stretch them if the user is not able to himself. Therefore the increased weight of the spasm glove could be a serious problem for people suffering from spasms. Another disadvantage seems to be the necessary current supply for the servo motors. A simple Li-Ion battery like used in our approach would not be able to power six or seven servo motors. Again a larger battery or even one battery for each servo motor have to be used.

Another possibility of supplying the servo motors with power would be the use of an electrical cord but since it has to be plugged into a receptacle it will handicap the user. Using an electrical cord is not possible while being in public and in addition the user can not move around completely free even at home.

Additional sensors

Another approach of adding some useful additional hardware to the current prototype of the spasm glove would be the use of further sensors. The logging software is designed to

log the data automatically. Since it is very hard for affected people to ad a reason for the occurred spasm by writing it into a text-box via smart phone some other input technologies would be important. Beside the use of "mood images" or speech recognition the use of additional sensors can be useful.

Modern smart phones are equipped with many internal sensors. Together with an enhancement of the flex sensor these sensors would be able to detect simple daily activities on their own without requiring the users manual input of what he is currently doing. These activities can be logged and added to the data sets which provide more data to analyse for the therapist.

Biofeedback can be used to improve health or performance since physiological changes often occur in conjunction with changes to thoughts, emotions and behaviour. Therefore additional biofeedback sensors can be useful to log a possible reason for an occurring spasm automatically and without the user's manual input.

In addition the spasm glove could be equipped with motion sensors which could be used for gesture recognition. With simple gestures the user could be able to control the spasm glove without the need of interacting with the logging software on the smart phone.

All these kinds of additional sensors share two main problems. One the one hand they would enhance the amount and especially the quality of the collected data and therefore the use for an additional therapy. With the help of the gathered information links between moods, activities, situations and ocurring spasms could be found more easily. On the other hand the main goal of the device should be the small size. Additional sensors need space which results in a bigger and even heavier device. In addition these sensors need to be supplied with electrical power which could not be delivered by the current Li-Ion battery.

Status indicators and switches

The prototype of the spasm glove is not equipped with any status indicators which are useful to inform the user of the current state of the device. To provide more feedback for the user the following status indicators could be used:

- State of charge display:
  To gain information whether the battery is fully loaded or needs to be recharged.

- On/Off button:
  At the moment the spasm glove is powered up by plugging the cable of the battery into the Arduino board. For that procedure the hardware has to be hauled of the glove's pocket. A switch between the battery and the Arduino board, placed outside the pocket to be easily reached would solve this problem.

- On/Off indicator:
  Even if a switch is mounted, it is not possible to see if the device is turned on or not without removing the hardware from the pocket.

- Integrated display:
  Beside the use of a smart phone as a feedback and logging device the use of an additional small display directly on the glove as an general status indicator would be useful. Since the user has to have a look on the smartphone to gain information, an additional display placed on the glove would be perfect because it is always in the user's field of view. A touch screen could be even used for controlling the smart phone and therefore the feedback and the logging device.

Broadcasting the alert to multiple smart phones

As already mentioned in the chapter "Summary" it would be useful to alert more persons than only the user of the spasm glove. For this possibility there are basically two different approaches:

- The use of additional Blue tooth modules.
- The use of the Short Message Service.

The use of additional Blue tooth modules is easy to implement since there only have to be additional Blue tooth chips attached to the Arduino. The main disadvantage of this approach is that the additional receiver has to stay in the range of the second Blue tooth chip. Another disadvantage is that the number of additional receivers is limited to the number of additional attachable Blue tooth chips to the Arduino board.

The second approach is more complicated. If a spasm occurs and the user is alerted over the Blue tooth connection by the smart phone, the smart phone itself can be programmed to use the Short Message Service and alert the relatives or friends.

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Part II

Appendix

APPENDIX A

Guideline for the interview with an affected person

"We would like to record the interview. We will use the recording as a backup for our notes to make sure that we don't miss anything important. Is that acceptable for you?"

...Explanation of our project...

"Please tell us something about a typical week in your life. Report free of your life, whatever you want:"

More precisely:

- How do these influences express themselves?
- How strong are they?
- What kind of impacts are there?
- When do the spasms / cramps (especially in the hand area) occur?
- How often do you experience the cramps?
- Can you do something to relax the muscles again?
- What kind of strategies have you developed to compensate your limitations?

"What is the role of relatives and friends in your life?"

"Are there currently treatments, therapies or any other kind of assistance?"

More precisely:

- Who performs this?
- How many times must this be done?
- How they affect the daily routine?
- Are there any deteriorations or improvements within your disability?
- Are there any goals within your therapy you set yourself?

"Are there any expectations or requirements for the product?"

More precisely:

- Do you have own ideas for the product?
- What should be achieved? Talking about the spasms in your hand, how do they express themselves?
- What do you expect from the product?
- Can you imagine wearing a glove?
- Imagine a situation in which you wear the glove, what should be taken in the design?
- What should be possible while wearing the glove, what could be dispensed with? (Dexterity, mobility of the wrist)
- What conditions in terms of size, weight and design of the glove do you expect?

"What kind of feedback is required?"

More precisely:

- There are different types of feedback: audio, tactile. Which requirements have to be fulfilled in order to provide a suitable feedback? (Fault, visibility)
- When and how strong feedback should be given?
- When it is not appropriate to provide feedback? (For example at the cinema, take breaks from training)?

"Can you see an advantage in logging the collected information? Who might be interested in this information and why?"

More precisely:

- How accurate the information should be logged?
- How often should be recorded?
- What kind of information should be logged?
- Is it possible to use the logged information for therapies or treatments?
- Which kind of data would you like to see? How should the data be represented?
- What would you like to do with the collected information?

"How far is the willingness to cooperate? (On further interviews, participation in testing procedure)"

More precisely:

- Is it possible, to arrange an interview with members of your family?
- Is it possible to conduct an interview with a therapist?
- Can we contact you again if we have added two or three design drafts?

APPENDIX **B**

Guideline for the interview with a relative of an affected person

"We would like to record the interview. We will use the recording as a backup for our notes to make sure that we don't miss anything important. Is that acceptable for you?"

...Explanation of our project...

"Please tell us something about a typical week in your life, especially as it relates to T. Report free of your life, whatever you want:"

More precisely:

- How do you think about your relationship with T. ?
- How do you assist T. in his daily life?
- What works well? What routines and procedures do you have well in place?
- What things do not work so well? What are the areas that you think could be better supported or that could be made easier for you and/or for T. ?

"What is the role of relatives and friends in T. life?"

More precisely:

- Is the whole family involved in assisting T.?
- Who else is involved in T.'s life? What roles do they play?

"Are there any expectations or requirements for the product?"

More precisely:

- What is your general attitude towards technology? Chance or risk??
- How do you experience assistance technology?
- Would you help to maintain the product? What would be important with respect to maintainane?
- Do you have own ideas for the product/prototype?
- What should be achieved? What do you expect from the product?
- Do you think T. is going to wear a glove?

"What kind of feedback is required?"

More precisely:

- There are different types of feedback: audio, tactile. Which requirements have to be fulfilled in order to provide a suitable feedback? (Fault, visibility)
- When and how strong feedback should be given?
- When it is not appropriate to provide feedback? (For example at the cinema, take breaks from training)?

"Can you see an advantage in logging the collected information? Who might be interested in this information and why?"

More precisely:

- How accurate the information should be logged?
- How often should be recorded?
- What kind of information should be logged?
- Is it possible to use the logged information for therapies or treatments?
- Which kind of data would you like to see? How should the data be represented?
- What would you like to do with the collected information?

"How far is the willingness to cooperate? (On further interviews, participation in testing procedure)"

More precisely:

- Is it possible to conduct an interview with a therapist?
- Can we contact you again if we have added two or three design drafts?

APPENDIX C

Guideline for the interview with a therapist

"We would like to record the interview. We will use the recording as a backup for our notes to make sure that we don't miss anything important. Is that acceptable for you?"

...Explanation of our project...

"Please tell us something about a typical week in your work as a therapist, especially as it relates to your work with people suffering from cerebral palsy. Report free of your work, whatever you want:"

More precisely:

- What are the challenges in working with people suffering from cerebral palsy?
- What are the problems people suffering from cerebral palsy are concerned with?
- What methods of treatment are currently available?
- What works well? What routines and procedures do you have well in place?
- What things do not work so well? What are the areas that you think could be better supported or that could be made easier for you and/or people suffering from cerebral palsy.

"Are there any expectations or requirements for the product?"

More precisely:

- What is your general attitude towards technology? Chance or risk??
- How do you experience assistance technology?
- Would you help to maintain the product? What would be important with respect to maintainane?
- Do you have own ideas for the product/prototype?
- What should be achieved? What do you expect from the product?
- Do you think affected people are going to wear a glove?

"What kind of feedback is required?"

More precisely:

- There are different types of feedback: audio, tactile. Which requirements have to be fulfilled in order to provide a suitable feedback? (Fault, visibility)
- When and how strong feedback should be given?
- When it is not appropriate to provide feedback? (For example at the cinema, take breaks from training)?

"Can you see an advantage in logging the collected information? Who might be interested in this information and why?"

More precisely:

- How accurate the information should be logged?
- How often should be recorded?
- What kind of information should be logged?
- Is it possible to use the logged information for therapies or treatments?
- Which kind of data would you like to see? How should the data be represented?
- What would you like to do with the collected information?

"How far is the willingness to cooperate? (On further interviews, participation in testing procedure)"

More precisely:

- Can we contact you again if we have added two or three design drafts?

APPENDIX D

Guideline for the evaluation interview with an affected person

"We would like to record the interview. We will use the recording as a backup for our notes to make sure that we don't miss anything important. Is that acceptable for you?"

"Please tell us something about the evaluation of the device. Report free of the testing procedure, whatever you want:"

Generally - more precisely:

- Did any problems occur while mounting the device?
- Did you mount the device on your own?
- How long did you use the device under supervision?
- How long did you use the device unattended?
- How long did it take you to understand how the device operate or how to operate it?
- How long did it take to calibrate the device correctly?
- How long did it take to understand the User interface of the device?

"Regarding the hardware or the spasm glove with the smart phone". Are you satisfied with the appearance and function of the current prototype?

Hardware - more precisely:

- Conspicuousness?
- Comfort?
- Weight?
- Size?
- Design?
- Robustness?
- Effect?
- Correct recognition?
- Usefulness?
- Applicability?

"Regarding the software installed on the smart phone". Are you satisfied with the appearance and function of the user interface?

Software - more precisely:

- Design?
- Usability?
- Effect?
- Correct recognition?
- Usefulness?
- Applicability?

"We want to thank you for the conducted interviews and your willingness to cooperate."