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Smart Textiles Final Report

Ruben Beldé        Lara Hernández Cores       Daniël Lacko      Alberto Moñux Arenas      Alexander Ziegler
Figure 1 Moodboard Tai chi
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Figure 2 Scenario Tai Chi Middterm report

- Zhan Li Wu is 65 years old and has a very stressful job as a lawyer.
- He has so many problems related to the stress and his previous job.
- Has just retired but he never really developed any hobbies and now finds he has too much time on his hands.
- He can't get rid of the stress from his job and would really like to have a calmer life.

- He has been taking this class for two weeks now and he still has some difficulties with the basic moves.
- Smart t-shirt and pants with LEDs, vibrating elements, heart rate sensor and Bluetooth module.
- He wants to know if his training has the desired effect of making him calmer. Also he uses it to upload to an online Tai Chi community.
- Become more active. Become less stressful.
As a “smart textiles” team, we started with researching about our topic. Our first decision was that we wanted to develop something for elderly people. Based on this decision we started to do research in technology and in possible target groups of elderly age.

In the beginning of our project we did research about every possibility we could do with smart textiles and elderly care. We came up with two broad fields, “active elderly” and “dementia”. After deeper research and a trade off we decided to go for active elderly.

In this field we created 5 scenarios: extreme active elderly, heart attack, rehabilitation, locomotive problems and tai chi. After evaluation and discussions with companies like Verheart and Alcatel Lucent Bell labs we went for the Tai Chi scenario. In this report, we continue describing the different stages in the development of the suit and the development of the prototype.
1.2 TO START

In the midterm report we came to our final idea with the help of structural research and trade offs. We researched both human related and technical related issues and decided that we were going to focus on the fifth scenario: tai chi, this scenario was the most interesting of all because of the multidisciplinary of the project, it was the most social and gave the most opportunities.

In the next fases we divided the work: Daniel and Alex focussed on the technical verifiction of the project and made an electronics protoype for this. Alberto focussed on energy consumption and the components we need for the final prototype and battery. He also made the entire calculation and simulation of the battery circuit. Lara and Ruben dealt with the user related issues. These are related to the usability, ergonomics and the presentation of the product, but also about the integration of the electronics and the battery. Our goal was to combine our knowledge in order to find the best product which would be innovative in all of our study fields.

On the next pages we have some solutions for the part problems. They are divided in different categories and we will use a morphologic map to come to some final concepts we decided to create two different options and we will make a trade off to choose between them.
First specifications

1.3 Concept Design

1.3.1 Social
When using the product, social interaction with users improves
The product is wearable
The product is fashionable
The product can be used in public places or in a closed environment

1.3.2 Economically
The product focuses on a target group above 60 years old
The costs of the product will decrease, because, the industry invest a lot of money in the used technology

1.3.3 Technical
The product exists out of a suit and a tablet
The product must do measurements and give feedback
Feedback must be easily interpretable
Smart textiles are incorporated into the product
The interface is adapted for elderly
The suit comes in different sizes

1.3.4 Design drivers
Make elderly more active
Improve the health of elderly
Give the user feedback
Improve social contact
Create a product that can be used everywhere without the use of an external reference
Improve the knowledge of tai chi
Teaching the base of tai chi
Figure 4 Drawing
2.1 Clothes

Figure 5 Clothes
2.2 Social Solutions

Figure 6 Social

- Vibration
- Moving together
- Social interaction
- Tablet
- Colour
- Music
- Social
- Colour combination
- Brightness
- Images
Solutions

2.3 Output

Vibrating

Movement

Light activated on movement

Heart Rate Respiration Rate

Figure 7 Output
2.4 Measurements

Blood Pressure

Breath Rate

Heart Rate

GSR

Muscle Tension

ALL BODY

Breathing belt

Figure 8 Measurements
2.5 Tablet

- Catalogue of Tai Chi
- Social Networks
- Bluetooth
- Feedback
- Improvement
- Charts
- 3D Models
- How far from movement
- Size
- Colour
- Settings
- Music
- Voice guide

Figure 7 Measurements

Figure 9 Table
2.6 Closing clothing

Figure 10 Closing clothing
2.7 Sensors

Figure 11 Sensors placement

Figure 12 Drawing sensors
## 2.8 Usability

- Washability: by hand
- Temperature: 30°C
- Triangle
- Square
- Circle
- Figure 13: Washability

## 2.9 LED’s and OLEDs

- Different LED
- LED that can make more colours RGB-LED
- Sewed in the clothing
- Diffuser or not
- Flexible OLED surface
- Figure 14: Button
- Figure 15: Leds and OLEDs
2.10 Devices

2.11 Connectivity

Figure 16 Touch screen. Figure 17 Connection
3 Morphologic Map

Clothes

Close

Output

Measurements
**Morphologic Map**

**Usability**
- Conexions
- Place buttons

**Social**
- Moving together

**Tablet**
- Catalogue of Tai Chi
- Weather App
- How far from movement
- Colour combination
- Images

**Additional Elements**
- LED
- OLED
- Washability
- Place battery
- Bluetooth
- Zigbee
- Wireless
3.1 Concept 1

Motion capturing: high enough for personal use, information is relevant for giving a representation of the exercises on the tablet, but should not be extremely accurate.

Feedback: relevant for the user and his close environment (tai chi teacher, family, friends) focussed on positive and negative feedback.

Measurements: less measurements, not relevant for doctors, focussed on the user and the interpretation of the data.

Focus on elderly: more user friendly for elderly, keep it simple without the highly technical information.

Complexity: feedback during exercise is more important than measurements.

Power supply: low power consumption.

Tablet: interface simplified for elderly, bright colours and dark backgrounds.

Look: calm, relaxed, easy to wear.

Connection: combination of ZigBee, Bluetooth and wires.

Buttons: 1 basic button for control for easy use of control of the suit is on the tablet.
3.2 Concept 2

- **Motion capturing**: high accuracy for perfect motion capturing for professional use.
- **Feedback**: also relevant for doctors, higher reliability focused on measurements.
- **Measurements**: measurements are double checked on two places on the body; more accuracy, can be used as medical information, more different measurements in this concept like gsr and bloodpressure.
- **Focus on elderly**: more complexity in interpreting all the data.
- **Complexity**: technical higher challenge (battery is critical, connecting all the sensors, processing speed).
- **Power supply**: higher power consumption.
- **Tablet**: more measurements mean more functions on tablet, more difficult app.
- **Look**: calm, relaxed, easy to wear.
- **Connection**: Bluetooth and wires.
- **Buttons**: more control on the suit.
### 3.3 Trade-off

<table>
<thead>
<tr>
<th>Concept</th>
<th>Weight</th>
<th>Concept 1</th>
<th>Concept 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motion capturing</td>
<td>5</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Feedback</td>
<td>5</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Measurements</td>
<td>4</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Focus on elderly</td>
<td>5</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Complexity</td>
<td>5</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Power supply</td>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Tablet</td>
<td>5</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Look</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Connection</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Buttons</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 1: Trade off concepts

### 3.4 Conclusion

After completing the morphologic map we came out with two different concepts.

**Concept one** is focused on giving the right amount of information and feedback to the user. The measurements have a lower accuracy because they aren’t double checked, which has as effect that we could give more feedback about how to do tai chi with the same battery consumption. It has lower control on the suit and higher control on the tablet, what makes the challenge of the app interesting. The look of the two suits should be the same; the colors and styling have to be relaxing for the users and for the surrounding people.

**Concept two** has a higher measuring capacity; the values of the measurements are double checked in the suit. The different measurements consume more energy, which is why we can’t give more feedback on the suit. However, because of the accuracy we could use the values of the measurements in our medical report. There are more buttons integrated in the suit that gives us a higher control during our tai chi session.

Considering our target group, user functions are more important than exactness of measurements. The measurements are still exact in concept one but not accurate enough for medical issues. It is more important for elderly that they understand what they are doing, without the control of doctors or being reminded about their health status. They want freedom and they want to understand the ways of tai chi.
4.1 Measurements

4.1.1 Heart rate
Possible to measure heart rate
Feedback on tablet after exercise
Feedback during exercise in front of suit
Give warning when heart rate is too high
Give warning to teacher or surrounding persons when heart rate is too high
The attention may not disturb the exercise
The attention point may not disturb the concentration
The moment the attention is given is personal based on the age
220-age is the calculation for the maximum heart rate
It starts measuring when the suit is activated
It stops when the suit is deactivated
The measurement is done by a sound sensor (see 8.3)
The sensor is 6mm diameter and 1.3 mm thick
The sensor is placed at the artery at the wrist
The sensor is sewn in the suit

4.1.2 Respiration rate
Possible to measure respiration rate
Feedback on tablet after exercise
Feedback during exercise in front of suit
Give warning when respiration rate is too high
Give warning to teacher or surrounding persons when respiration rate is too high
The attention may not disturb the exercise
The attention point may not disturb the concentration
The perfect breathing is called F6 breathing (4s breathing in, 6s breathing out)
It starts measuring when the suit is activated
It stops when the suit is deactivated
The measurement is done with a stretch sensor
The measurement is done at the abdomen
The sensor detects the change in length

4.1.3 Motion capturing
The motion and position of the person can be measured
The measurements are done with accelerometers
The motion and position are reproduced on the tablet
The motion and position can be compared with the right exercise
One sensor for each forearm
One sensor for each shin bone
Data of sensors are transmitted to tablet
The Arduino Lilypads are placed close to the sensor for no resistive losses in the wire
The Arduino Lilypads are sewn in the suit
The Arduino Lilypads are connected with a ZigBee connection to a base point
The base point Arduino Lilypad sends the data to the tablet with Bluetooth 15 m range
The Arduino Lilypads are to the sensors connected with conductive wires
4.2 Feedback

4.2.1 Heart rate
The heart rate is visually explained to the user. 
Gives a vibration when the movement isn’t accurate enough. 
Vibration makes you move to exact position. 
Accuracy is in different levels: easy 55%, moderate 70% and hard 85%.

4.2.2 Respiration rate
The respiration rate is visually explained to the user. 
Gives a vibration when the movement isn’t accurate enough. 
Vibration makes you move to exact position. 
Accuracy is in different levels: easy 55%, moderate 70% and hard 85%.

4.2.3 Feedback of movements in the suit
Negative vibrotactile feedback
Vibrating elements are sewn in the suit. 
Sewn at the tight part of the suit.

Specifications

Specifications

4.2.4 Feedback of movements in tablet
Motion capturing by sensors sent to tablet with Bluetooth. 
The feedback of the motion capturing is shown in a 3D environment. 
Comparison between how you moved and how you should move suit.

4.2.5 Social
Color of the suit can merge with colors of other suits in range of the 15m bluetooth. 
Maximum 2 merges of colors.
A person with a suit can send his movements to another suit with Bluetooth for doing tai chi together.
4.3 Tablet

4.3.1 Exercise
You can choose different exercises in the tablet
You can choose templates of exercises
There is a catalogue integrated where you can consult an explanation of each exercise, written and with a video
You start with a basic level and when you improve your skills, by doing the exercises correctly, you go to the next stage
When you upload your level some exercises will be unlocked and the accuracy will be higher

4.3.2 Feedback
The tablet can give feedback of the movements, the heart rate and the respiration rate of every day that you did tai chi

4.3.3 Social
You can make a profile on the tablet
You can check your level
You can make friends with people you meet with a suit via Bluetooth
You could see your friends profile and exercises
There is the possibility to see how your friend’s level of tai chi is and compare with them

4.3.4 Options
Options have to be changed on tablet
You can choose the time of the exercise.
The positive feedback (light) could be on or off.
Choose between the training and the freedom mode (Light follows the movement instead of movement follows the light).
Change the color of the light.
Each color has a specific meaning
The negative feedback (vibration) could be on or off

<table>
<thead>
<tr>
<th>Color</th>
<th>Chakra</th>
<th>Chakra location</th>
<th>Alleged function</th>
<th>Associated system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>First</td>
<td>Base of the spine</td>
<td>Grounding and Survival</td>
<td>Gonads, kidneys, spine, sense of smell</td>
</tr>
<tr>
<td>Orange</td>
<td>Second</td>
<td>Lower abdomen, genitals</td>
<td>Emotions, sexuality</td>
<td>Urinary tract, circulation, reproduction</td>
</tr>
<tr>
<td>Yellow</td>
<td>Third</td>
<td>Solar plexus</td>
<td>Power, ego</td>
<td>Stomach, liver, gall bladder, pancreas</td>
</tr>
<tr>
<td>Green</td>
<td>Fourth</td>
<td>Heart</td>
<td>Love, sense of responsibility</td>
<td>Heart, lungs, thymus</td>
</tr>
<tr>
<td>Blue</td>
<td>Fifth</td>
<td>Throat</td>
<td>Physical and spiritual communication</td>
<td>Throat, ears, mouth, hands</td>
</tr>
<tr>
<td>Indigo</td>
<td>Sixth</td>
<td>Just above the center of the brow, middle of forehead</td>
<td>Forgiveness, compassion, understanding</td>
<td>Eye, pineal glands</td>
</tr>
<tr>
<td>Violet</td>
<td>Seventh</td>
<td>Crown of the head</td>
<td>Connection with universal energies, transmission of ideas and information</td>
<td>Pituitary gland, the central nervous system and the cerebral cortex</td>
</tr>
</tbody>
</table>

Table 2 Colours
Specifications

4.4 Suit

Exist of a double layer of cotton polymer
Tight part nylon stretchable at wrists and ankle
Two piece suit
Battery in pants at thigh
Battery ergonomically formed
Perfect fit pocket for battery

Battery can be disconnected
Battery pocket can be closed with zipper
Battery is connected with a jack to suit
Battery has to be disconnected for recharging
Tactile reminder of presence of battery with press button over the pocket
Connection made between two pieces with the two press buttons
Press both buttons together to pause
Press back for repeat last exercise
Press forward for go to next exercise
The suit is hand washable
The suit can come in three different sizes: small medium and large
Thickness of 2.5mm
Max weight of suit is 1kg
Suit is a unisex model
Upper part of the suit has a diagonal zipper for best wearability
Upper part of pants is stretchable

Change the intensity of the vibration
The social mode in both can be turn on or off.
You can have music or a voice guide and choose the level of it.
The music can be active or relaxing.
The voice can be a female or male.

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5 Quick Designs

Respiration rate

Attention point

Samurai

Figure 20 Suit design 1
Quick designs

Different styles of guide

Hood

Velcro

Figure 21 Design suit 2
Quick designs

Figure 22 Suit design 3

Diagonal Zipper

Button
Quick designs

Guide lines

Moving balls

Figure 23 Suit design 4
Quick designs

Ying Ynag
inspiration

chakra lines

Figure 24 Suit design 5
Quick designs

2 types of layout

more simple layout

Figure 25 Interface design 1
Quick designs

**Explanation exercise**

There is different kind of catalogues, one for warming, other for the proper exercise and the other for stretching.

**Graphs of feedback**

**Choosing exercise**

Options

**Color mood**

**Breathing**

**Figure 26 Interface design 2**
Quick designs

Figure 27 layout sketch
6 Research on Motion

6.1 Motion Capturing

There are three senses that people rely on to get information about their environment and how to act on it. Two of these, sight and sound, are the ones that get most credit and a lot of research has gone into recording them for later reference. The last one, often forgotten and neglected but invaluable nonetheless, is the sense of touch. Almost all of our everyday actions require some kind of motion, yet apart from in the movie or gaming industries motion capturing is only slowly gaining popularity. However, it could offer major benefits for several areas of human life. For example, video games can be made more accessible, healthy and fun by mapping motion capturing data to a virtual environment. The Nintendo Wii and Xbox Kinect are prime examples of this. As for health care, it could be used to improve recovery by techniques such as gait detection or rehabilitation and to prevent falling for elderly [11].

One of the reasons of the slow adoption of motion capturing is that while audio or video capturing almost always happens in the same way, motion capturing can be done with a variety of different sensors and combinations. Similar to the trade-off between quality and compression in audio and video capturing, there is a trade-off between accuracy and sensor types when we're dealing with motion. In this section a couple of techniques for motion capturing will be discussed. Generally, the techniques can be divided into two main parts: optical and non-optical systems. The optical systems are by far the most popular and will be discussed first.

With optical motion capturing, there is always a camera involved. It can again be subdivided into two parts: with or without markers. In film making, where greater accuracy is generally required, the former are is mostly used. An actor needs to wear some sort of markers on their body, which can later be filtered out of the video images using pattern recognition techniques and then stored in a motion capture dataset. Until recently this was the only reliable way of doing motion capturing, but now several markerless systems are being developed and even put on the market. A well-known and well-loved example is the Xbox Kinect, which uses a combination of video capturing and infrared light to determine the position and motion of a user. Using infrared has several advantages: it is not visible by humans and there isn't much infrared light in everyday environments, which minimizes the chance of false positives or noisy measurements. The main disadvantage is the extra cost and complexity of the Kinect and the fact that the user always needs to stand right in front of the camera, without any kind of obstructions.

Non-optical systems can be divided into three parts: electromagnetic, mechanical and inertial. Electromagnetic systems use an electromagnetic generator to create a fixed electromagnetic field in which the magnetic flux changes induced by smaller electromagnetic generators on a user's body are detected. These fluxes can then be used to determine the movement of a person. In mechanical motion capturing systems stretch sensors are used to determine joint angles, from which a computer model of the motion can be made. However, the accuracy of these systems is highly dependent on the dimensions of the user. As such, a personalized system and personalized calculations are always necessary. Lastly, inertial sensors such as accelerometers and gyroscopes can be used to determine the acceleration and the orientation of a person. Combining these with an external reference point such as a camera, IR-sensor or ultrasound sensor [12] can provide accurate information about a user's position and movement. An example of this is the Nintendo Wii, which uses controllers with ADXL330 accelerometers to determine acceleration and tilt together with infrared light to determine distance and orientation. Additional mechanical sensors can also be used, such as the pressure sensor in the Wii Balance Board, to do a more complete mapping of the user's movements to an animated video game character. While the Wii itself is a popular system, it has worse accuracy then systems such as
Research on motion

the Kinect, while it has more disadvantages: extra infrastructure is needed (at least one WiiMote) and the user still needs to be right in front of the infrared receiver at all times.

In the previous systems, an external reference point was always necessary, be it a camera, an EM-field generator, a precise dimensional model of the user or an IR-sensor. However, systems that do not depend on external reference points are being researched, for example using only accelerometers. One such a system is discussed in [13]. An Arduino board is used together with five ADXL330 accelerometers to get acceleration data from the user, which is then matched to an existing motion capturing dataset, in this case built with a Vicon system. To have it work in the right way, a calibration is done between the real acceleration measured by the accelerometers and the virtual acceleration as it would be if the motion in the Vicon dataset was captured with accelerometers in the same positions. This is necessary because the axes of the accelerometers should be aligned for an accurate matching. The strength of this idea is that in theory any hardware can be used together with any motion capture dataset. However, in order to make the dataset, a traditional optical motion capturing system is needed.

6.2 Motion guidance

In the previous section we've already discussed one application of motion capturing, namely controlling a video game character. In this section we will extrapolate on another major application. A lot of the motive actions people take are not thought through, but rather intuitive. Examples are tying shoe-laces, playing a musical instrument, performing a martial art and even walking. We don't need to think about every step we take, we just take the steps. This phenomenon is called muscle memory. Repeat one action often enough and your muscles will 'remember' how to do it without you having to actively tell them to do so. The time it takes to commit this action to muscle memory will depend on how effectively it is repeated. The first step in any motion learning process is to acquire information about how to perform the movement. The next step is translating this information to the actual motion, and this is where things can often go wrong, depending on the medium carrying the information and on the ability of a person to translate this information to motion. For example, learning a new martial arts move requires looking at a teacher, translating their body position to your own and mimicking the movement. In this process, it is often necessary for the teacher to perform some corrections to the movement because the translation didn't happen efficiently. The same goes for learning how to play scales on a musical instrument such as a piano. Notes on a sheet of music have to be translated to finger movements, and afterwards a teacher can correct the movements or it can be matched with a previous recording to find out if the movements were correct. Generally, we can say that learning each movement requires the repeating of the following steps: acquisition, translation, action and feedback.
Research on motion

The acquisition of the information is relatively easy. A lot of instructional videos and texts exist on the World Wide Web, instructional books can be found in libraries and teachers or schools can be found in the yellow pages. Similarly, performing the action itself depends solely on the motor skills of a person and will not pose problems in normal circumstances. The major difficulty lies in the translation and feedback steps. The difficulty with both is that it’s not easy to translate information from one sense to another. For example, you will have a hard time explaining the colour blue to someone. The same goes for movement; therefore providing visual or audible instructions for movement is not very efficient and it will take a relatively long time for people to get the movement right when relying solely on these mediums. Movement is tied to the sense of feeling and thus the most efficient way to learn new movements is by tactile stimuli. These stimuli come in the form of heat, stretching, pressure or vibration. Heat and pressure can both be neglected because the skin is not that sensitive to temperature changes and it adapts to pressure, which makes it difficult to interpret varying intensities of these stimuli in the right way. Stretching is a good way to provide continual feedback and is excellent for applications such as feedback of prosthetic limbs, but it does not provide good event cues and it takes some time for a user to get used to the feedback [14]. Vibration, however, has proven to be an effective guide to motion, which we will show in the next section.

This is represented in Figure 28.

Figure 28  Graphical representation of motion learning
In section 6, we've shown research related to our own work. In this section, we will work out our own motion capturing algorithms. We have tried to use as few components as necessary and thus the algorithms will be based only on accelerometer calculations. Every motion can be seen as the movement between a starting and a stopping position. Therefore, we can distinguish between two necessary feedback mechanisms: feedback on position and feedback on the movement.

7.1 Feedback of the position

Out of these two, feedback about the position is by far the easiest one. Since most accelerometers also measure static acceleration, which is to say the acceleration due to the earth’s gravity, we can easily determine the pitch and roll of the accelerometer. Taking the accelerometer position in Figure 29 as a reference, we know that the z-axis will measure an acceleration of 1g towards the earth. If the accelerometer is tilted, meaning it’s rotated over the x-axis, the pitch α will increase. See Figure 30 for a reference of pitch, roll and yaw angles. Because the z- and y-axis are perpendicular to each other, we know that β will be equal to α. Using Formula 1 we can determine this angle using simple trigonometry.

\[ \cos(\beta) = \frac{z}{1g} \]
\[ \beta = \arccos\left(\frac{z}{1g}\right) \]

Formula 1 – Determining the pitch of the accelerometer

However, using this method, we cannot determine which quadrant the accelerometer is moving in. The angle will have the same sign whether it’s pointing up or down. To remedy this, we can use a dual-axis accelerometer. Taking Figure 29 as reference, we can use Formula 1 to determine the magnitude of the angle and then use the signs of x- and y-axis value to determine which quadrant the accelerometer is moving in, giving us a full 360° of tilt, see Figure 31 and Table 3.

| Sign of z | Sign of y | Quadrant | Calculation of α (z = |g|) |
|-----------|-----------|----------|--------------------------|
| +         | +         | I        | \( \arccos(|z|) \)        |
| -         | +         | II       | \( 180° - \arccos(|z|) \) |
| -         | -         | III      | \( 180° + \arccos(|z|) \) |
| +         | -         | IV       | \( 360° - \arccos(|z|) \) |

Figure 29 – accelerometer rotating over its x-axis.

Table 3 – sign of z- and y-value related to the quadrant.

Figure 30 – pitch, roll and yaw.

Table 3 – sign of z- and y-value related to the quadrant.
### Methods for Motion Capturing

If we only need 180° of tilt, we can use an alternative method with a single-axis accelerometer, see Figure 32. Because the pitch $\alpha$ and $\Phi$ are complementary angles, we can use Formula 2 to determine the tilt of the accelerometer from -90° to 90° as well.

Lastly, we can determine the roll of the accelerometer as well by using the extra axis on a triple-axis accelerometer (the x-axis instead of the y-axis in the previous formulae). However, it’s much more difficult to determine the yaw because the x- and y-axis are both parallel to the ground. Generally, a gyroscope is determined to measure rotation of the z-axis.

### Formula 2

\[
\cos(\phi) = \frac{y}{1g}
\]

\[
\phi = \arccos\left(\frac{y}{1g}\right)
\]

\[
\phi = 90 - \alpha
\]

\[
\alpha = 90 - \phi = 90 - \arccos\left(\frac{y}{1g}\right)
\]

\[
\alpha = \arcsin\left(\frac{y}{1g}\right)
\]
Methods for Motion Capturing

7.2 Feedback on the Movement

Providing exact and continuous feedback on the movements has proven to be difficult using only accelerometer calculations. In theory, the second integral of the acceleration could be taken to determine the moved distance, but since we have only one reference point at the start of the exercise all of the small measuring errors during the movement will add up and make the final result very inaccurate. The longer the movement takes, the greater this error will be and thus simply using the second integral is not a favourable option.

Instead of trying to provide continuous movement feedback, we will first build a dataset by just capturing the values of an accelerometer over time and then comparing the new signal to dataset signals for every movement. Vibro-tactile guidance during the movements itself will be based only on the positions, but if a user feels they receive too much feedback, they can always check the mobile device to see how close their movement was to the intended movement. In order to do this, we will use the cross-correlation function, see Formula 3. Cross-correlation is a measure of the similarity of two signals when a lag is applied to one of them. In the case of a continuous signal this lag is a time difference, but in case of discrete signal such as the signals we are going to work with, the lag can simply be a number of bits, see Formula 4. However, to produce accurate estimates, the correlation function needs to be normalized using Formula 5. When doing an auto-correlation, which is a cross-correlation of a signal with itself, the normalized correlation function will always peak with amplitude 1 at zero lag.

Formula 3 – Cross-correlation function continuous signals.

\[
(f \star g)(t) = \int_{-\infty}^{+\infty} f^\ast(\tau)g(t + \tau)\,d\tau.
\]

Formula 4 – Cross-correlation function discrete signals.

\[
(f \star g)(n) = \sum_{m,n} f^\ast(n)g(m + n).
\]

Formula 5 – Normalized cross-correlation, will peak at 1 at zero lag.

\[
(f \star g)(n) = \frac{1}{N} \sum_{m,n} f^\ast(n)g(m + n).
\]

This property can be used to determine how similar a new movement is to a movement from the dataset. Since we know that for an ideal match, there will be a peak zero, we can firstly look for the existence of such a peak. If there is no peak around zero lag, we know the signals don’t match. If there is a peak, there is a match between the signals, where the amplitude of the peak and the lag at which the peak occurs can both be used to determine how close the signal, and thus the movement, is to the original. The closer the signal is to zero lag and amplitude 1, the better the match.

The user should receive visual information to indicate how he could improve his movements further. For example, a 3D-model could be made of the user or of their body parts and the captured movement could be played back.
8.1 Motion Capturing and Guidance

Based on the methods in section 8.3. We will need at least five accelerometers: one at each lower leg and one at each forearm. We suggest using the ADXL335 because of its low power consumption, but any triple-axis accelerometer with a sensitivity of at least +/- 2g can be used. We will need microcontrollers to read out these accelerometers and relay the information to a computer or mobile device, and for this we have chosen the Arduino LilyPad. Arduino is a cheap, flexible and open-source electronics platform designed for quick prototyping; the LilyPad is an adaptation of the Arduino platform and various components designed to be sewn into clothing with conductive textile. To provide feedback we will use Arduino VibeBoards, and OLED strips will be used among other things to provide an indication of the upcoming movement.

8.1.1 Components list

**Arduino LilyPad 328 Main Board**
This is the main board which we will use consisting of an ATmega328 with the Arduino bootloader, running at 8 MHz, see Figure 34. It is an e-textile technology with a minimum number of external components to keep it as small and as simple as possible and at the same time wearable. The board will run from 2V to 5V.

**LilyPad VibeBoard**
The LilyPad VibeBoard is an extension to the LilyPad mainboard, see Figure 35. It incorporates a vibration motor and operates at 5 V, which means it can be used with the LilyPad main board without voltage conversion. Driving the VibeBoard works exactly the same way as driving LEDs, so it’s very easy to implement.

**ADXL335 accelerometer**
The ADXL335 is a small, thin, low power triple-axis accelerometer which can measure acceleration of up to +/- 3 g. A sample ADXL335 can be seen in Figure 36.

**OLEDs**
We will use organic LEDs for motion guidance. They are described in more detail in section 8.7.

---

Figure 34  LilyPad 328 Main Board.
Figure 35  LilyPad VibeBoard.
Figure 36  ADXL335 accelerometer.
8.2 Monitoring

In order to monitor the respiration rate, we will use stretch sensors incorporated in the trousers of the suit and placed on the abdomen of the user. The heart rate will be detected using sound, as discussed in section 7.5 In effect, any heart rate or respiration rate sensor can be used, as long as it can be plugged in to an Arduino main board. We will use the following parts for monitoring the vital signs.

8.3 Heart Rate

For the heart rate detection we use the technology of phonocardiography (PCG). In this technique the tone of the heart is detected and analyzed [7]. Out of that it is possible to generate a heart analyzes, detect the heart rate and even possible to detect the blood pressure [7]. In comparison to other techniques it is a poor system, but has some significant advantages which are for our product very important:

- low cost
- low power
- maintenance-free
- robust to 60 Hz pickup
- no electrical contact with body

Battery
for more detail see section 9.3

Charger
for more detail see section 9.4

Interconnections
wire of 3*2.25 mm² section pvc isolated
Wire of 2*1,5 mm² section pvc isolated
2.1 mm connectors (x2)

Standard connector to 230 V 50 hz

Voltage regulator
isolated inside textile, based on LM317.
In the prototype of [7] they captured the heart-waveform from neck and wrist. They have used a commercial microphone from Panasonic (WM-63PR). Figure 37 gives an overview of the specification of the microphones:

![Figure 37 Specification of WM-63PR](image)

<table>
<thead>
<tr>
<th>Specifications</th>
<th>WM-63PR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>-45±4dB (0dB=1V/Pa, 1kHz)</td>
</tr>
<tr>
<td>Impedance</td>
<td>Less than 2.2kΩ</td>
</tr>
<tr>
<td>Directivity</td>
<td>Omnidirectional</td>
</tr>
<tr>
<td>Frequency</td>
<td>20-16,000Hz</td>
</tr>
<tr>
<td>Max. operation voltage</td>
<td>10V</td>
</tr>
<tr>
<td>Standard operation voltage</td>
<td>2V</td>
</tr>
<tr>
<td>Current consumption</td>
<td>Max. 0.5mA</td>
</tr>
<tr>
<td>Sensitivity reduction</td>
<td>Within ~3dB at 1.5V</td>
</tr>
<tr>
<td>S/N ratio</td>
<td>More than 59dB</td>
</tr>
</tbody>
</table>

They captured the sound out of the bloodstream and calculated the PCG waveform [7]. The prototype has given very good results as well in the quality of the measurements, as well as in the power consumption of the system [7]. The prototype shows a good solution to measure the heart rate in a poor low-cost system and point up our decision to use PCG.

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### 8.4 Respiration Rate

To detect the respiration rate we decided to use stretching sensors positioned on the abdomen. In prototype [9] they used the “Respiratory Inductance Plethysmography” (RIP) method for the signal extraction. In this method you use the circumference of the human body. You can see a picture of the prototype’s stretching sensor in Figure 38. The system equipment consists of the following elements [10]:

- Effort belt, consisting of an elastic material with a zigzagging (coiled) wire sewn into the belt
- Connecting wire sets
- Driver module consisting of a frequency generator, signal processor and analog/digital converter

They got good quality of signals in their prototype. In [9] there are different algorithm described how to determine the respiration rate. This proves that the detection of the respiration rate works.

![Figure 38 Stretching sensor](image)
8.5 Communication

For the communication between the components we will use Zigbee because of its low power consumption. The reason we have chosen not to work with conductive thread is that it adds 14 Ohms of resistance per foot and we need to connect components over the entire length of the body. This impedance would decrease the accuracy of the measurements and so it’s safer to work with a wireless body area network. For communication between the system and the mobile device, we have decided to use Bluetooth, since it has an excellent range and is available in almost every mobile device on the market today. To decrease the impact of Bluetooth’s power consumption, we have developed a flexible communication protocol with as little as possible overhead. We will use the following components for communication:

LilyPad XBee Module
The LilyPad XBee modules are another extension for the LilyPad main board, see Figure 39. It’s very easy to set up a body area network using these components. A separate main board will be necessary to drive the XBee Module for each component where XBee communication is needed.

Bluetooth Mate Gold
This is a standard Bluetooth module that can be used together with any Arduino main board, including the LilyPad, see Figure e. When connected to the main board, the Arduino can use serial communication over Bluetooth to communicate with other device.

8.6 Product data flow diagram

The following figures show the program data flow diagram. In Figure 41, the database or internal data model is shown; in Figure 42, the user model or external data model is shown and in Figure 43 the input/output model is shown.
Figure 41: External data flow between the user, mobile device and textile system
Figure 42 Internal data flow between the user, mobile device and textile system.
Final product

Figure 43 Input/output diagram.
8.7 OLEDs

OLED stands for Organic Light Emitting Diodes. They offer more advantages than the LED or LCD technologies, but first we must explain how they work.

OLED works by passing electricity through micrometer layers of organic semiconductors sandwiched between two electrodes.

The electric current travels from the positive to the negative electrode through the organic film, causing the film to emit light. Using different materials in the film causes the OLED to emit light of different colours (and not filtering out white light to give the appearance of color, as is the case with LCDs). To protect the organic layers, the OLED is completely sealed between two glass plates.

It should be noted that a Human hair is 200X the thickness of the OLED layers what makes a good technology for our application because the size and the flexibility.

Potential of OLED

The main characteristics of OLEDs are:

- They are suitable for thin, lightweight and printable displays, which is an important advantage for our application. They also have broad range and a good colour contrast.
- High resolution (<5 um pixel size).
- Fast switching (1-10 us).
- Wide viewing angle.
- And finally the low cost of materials.

It can be seen in both graphs that both the efficiency and luminance are high in the working point of our product, which is at about 4 to 5 volts.
### 8.7.1 OLED Types

**Small molecular OLED**
Made by vacuum evaporating small molecules to the substrate similar to that used in semiconductor manufacturing
Well proven on fabrication of up to about 15 inches in diameter (shadow mask)
Crystallization due to low glass transition temperature shortens lifetime and reliability

**Polymer OLED**
Made by depositing the polymer materials on substrates through an inkjet printing process or other solution processing methods under ambient conditions
Fabrication of large screen sizes
Oxidation of carbon-carbon bonds between the aromatic rings reduce the conjugation length of the polymer

**Flexible display**
Flexible substrate requirements
Transparent
Robustness
Low cost
Stability
Low coefficient of thermal expansion
Low moisture absorption
Resistant to chemicals & solvents
Processing temperatures limited by:
Deformation temperature of material layers

For common plastic materials, < 300 °C

**Polymer Materials:**
Conductive polymers:
- Polyaniline
- Polyethylenedioxythiophene
Emissive polymers:
- Polyphenylenvinylene
- Polyfluorene

There is another classification according to how they work:

**RGB- Polymer emitters**

*Advantages:*
- Power efficient
- Lower production cost
- Mature ITO technology

*Disadvantages:*
- Emitters have to be optimized separately
- Differential aging of emitters
- Patterning of emitters necessary

**Color filters White emitter**
Advantages:
Well established technology LCD
No patterning of emitter necessary
Homogeneous aging of emitter

Disadvantages:
Power inefficient
ITO (indium-tin-oxide) sputtering on filters
Efficient white emitter necessary

Color Changing Media (CCMs)
Advantages:
Homogeneous aging of emitter,
More efficient than filters
No patterning of emitter necessary

Disadvantages:
ITO (indium-tin-oxide) Sputtering on CCMs stable blue emitter necessary aging of CCMs

After comparing the two types of OLEDs, we have found that the polymer have better advantages then the small molecular OLEDs.
9 Power supply

9.1 Elements

The battery will provide energy in parallel for every main board and base station.

9.2 Maximum Power Consumption

In the following section, a calculation of the power needs for our system will be done. Firstly, we need to consider the maximum power ratings of each component to prevent the battery from damaging the circuit. As shown in section 8.1, there are five LilyPad main boards and one base station, which will all need to be powered. The main boards in their turn each need to power four vibe boards, one accelerometer and a couple of LEDs. The rating for each of the components is as follows:

**Arduino Lilypad 328 Main Board**

Dimensions:
- 50 mm outer diameter
- Thin 0.8 mm PCB
- Input voltage: 2.7 – 5.5 V
- Current Consumption: 0.2 mA

*The input voltage of every main board will be adjusted at 5 volts by voltage regulators defined later in this section.*

Consumption: $5 \times 0.0002 = 0.001$ W
**LilyPad Vibe Board**

Dimensions:
- 20 mm outer diameter
- Thin 0.8 mm PCB

The vibe board diagram can be shown in Figure x. According to the datasheet, the vibrating motor operates at 3 V, 75 mA. However, each pin of the LilyPad main board can only support up to 40 mA.

Consumption: $5 \times 0.04 = 0.2$ W

**Bluetooth**

Operating voltage: 3.3 V
Current: 30 mA (Connected normal mode)
Consumption: $3.3 \times 30 \times 10^{-3} = 0.099$ W = 0.1 W

**Zigbee**

Operating voltage: 3.3 V
Current: 50 mA
Consumption: $3.3 \times 50 \times 10^{-3} = 0.165$ W

**Maximum power**

Assuming the worst case scenario, where all the components are working at the same time, we calculate the maximum power as follows:

- 5 LilyPad main boards: $5 \times 0.001 = 0.005$ W
- 16 VibeBoards = $16 \times 0.2 = 3.2$ W
- 4 Accelerometers = $0.0105 \times 4 = 0.042$ W
- 80 LEDs = 12 W
- Bluetooth = 0.1 W
- Zigbee = $5 \times 0.165 = 0.825$ W
- Prevision heart beat and respiration rate = 1 W

**Total** = 17.134 W
9.3 Battery

9.3.1 Presumptions and terminology
The charge of the battery should last for at least 1.5 h of continuous use, and the maximum power consumption should always be lower than the maximum discharge that the battery pack is able to develop.

\[ C = \frac{1}{h} \]
\[ C \ [\text{mAh}] \]

A Lithium-Polymer (from here on referred to as Li-Po) element or cell has a nominal voltage of 3.7 V. The battery should never be discharged below 3.0 V per cell and it should never be charged more than 4.3 V per cell. The Li-Po items can be grouped in series (S), to increase the total voltage, or in parallel (P), to increase total capacity. For example, a 3S code indicates three elements connected in series (3 * 3.7 = 11.1 V), a 4S2P code indicates 2 parallel groups of 4 elements in series (4 * 3.7 = 14.8 V with capacity doubling).

What is the “C” value?
C has the value 1 if the battery is 1000 mAh. For such a battery, we can calculate the total current by the following formula:

1000 mAh * 1/h = 1000 mA = 1 A.

Similarly, the total current at 2C for the same 1000mAh battery can be calculated as follows: 2 * 1000 mAh * 1/h = 2000 mA = 2 A.

A 10C pack is capable of discharging continuously up to 10 times its capacity. For a pack of 1000mAh this would mean 10 * 1.000mAh * 1/h = 10000 mAh = 10 A of maximum continuous discharge.

9.3.2 Calcul recomendations
It is recommended to charge the battery at between 0.2 and 0.7 C, and certainly never more than 1 C.

2-cell Li-Po Battery: 3.7 * 2 = 7.4 V

\[ \text{labs} = \frac{171342}{5} = 3.4268 \ A = 3426.8 \ mA \]

Considering that we need 1.5 h of battery life, we will need a battery of 5140.2 mAh.

For discharging, a maximum of 2C should be considered: 2570.1 mAh

Battery 2S
2 elements in series of 2500 mAh: (2C)
Charging: between 0.2C and 0.7 C
Discharging 2C = 5000 mA (> 3426.8 maximum real consumption)

Specifications:
Nominal capacity: 2500 mAh 18.5 Wh
Density: 92 wh/kg
Weight = 18.5 wh/92wh/kg = 0.2 kg = 201 grams, with isolation and case 300 g.
Life: > 500 Times
Charge: 1.75 A Max. (Between 0.2C - 0.7C)
Discharge: 5A Max. (2C)
Size (1 Cell): 66 Longitude x 60 wide x 5.5 thickness +/- 5%
9.3.3 Inside the battery:

This part will be composed by 2 cells, one next to the other, between two sheets to hold them. These cells will be isolated against heat etc. by a tight plastic film. They will then be encased inside a designed plastic box, together with the wires, interconnections and the wire-to-power plug adapter. This case will never have to be opened, except in case of failure. The battery has a female base (power output) in which the connector from the suit should plug in. This connector is a 2.1 mm power plug.

A circuit protection module (CPM) was not discussed in this project, but should be added to the battery system to stop the discharging when the battery is under a determined value. It will also prevent the battery from overcharging and limit the voltage over each battery cell to 3.7 V. All of this is done to prevent damage to the battery and textile.
9.3.4 Materials

For the box and battery protection and elements we’ve used thermosetting plastics. Thermosetting plastics have a good impact on resistance, solvent, the permeation and gases and extreme temperatures. The charger case is made of the same material.

To design the circuit of the charging source, we need to know the impedance offered by the battery charging source. That is, at the terminals of the charger design.

But, what is the impedance of a battery and why does matters?

By definition, the impedance is the opposition to the measure of an alternating current. Electrical impedance means the idea of resistance to AC circuits, which accurately depicts the relative amplitude of voltage and current. The reason impedance is so important for a battery is mainly because the equivalent circuit of a battery is based on impedance, see Figure 51.

The diagram at right shows the equivalent circuit for one cell.

\( \text{Rm} \), is the resistance of the metallic path through the cell including the terminals, electrodes and interconnections.

\( \text{Ra} \), is the electrochemical resistance including electrolyte and separator.

\( \text{Cb} \), is the capacity of the parallel plates forming the electrodes of the cell.

\( \text{Ri} \), is the nonlinear contact resistance between the plate or electrode and the electrolyte.

The typical internal resistance is in the order of milliohms. The impedance test is a modern, fast, inexpensive and non-destructive method to monitor the “internal strength” of the battery.

In our case, without the battery physically constructed, it is impossible to know the exact impedance, but knowing our data and by searching databases for similar cases an estimate can be made in which the equivalent circuit for our two elements is seen in Figure 52.
9.4 Charger

9.4.1 Introduction
Each battery needs a charger, and this charger must be specially designed for the battery. As calculated in section 8.1, we will charge the battery at a certain intensity of 0.2 C and 0.7 C, i.e. a maximum of 1.75 amps.

The charging operation when charging at a standard European outlet of 230 V, 50 Hz, is shown in Figure 53.

9.4.2 Theory
For the design of this charger we used the following system[1], presented in figure 54, which goes through several stages to get the desired effect:

All of these physical elements are incorporated into the plastic box, as discussed in section 9.3.
Firstly, we need a voltage step-down transformer for voltage adaptation to our needs, this stage is AC. The second stage could be called the filter rectifier, which basically goes from AC to DC, see figure 56, and finally a more precise voltage regulator for our battery. It also includes a current limiter, which in our case will be through transistors.
Below is a brief description of every stage.
Diode rectifier: Full-wave rectifier
Without going into detail, this part is based on a diode Graetz bridge[2] see figure 55.
In figure 58, you can also see the input signal $V_s$ and the output $V_o$. Then this signal is filtered by capacitors to obtain a more uniform and straight signal. To do this in the calculation, we've used approximations:

- If $RC >> T \Rightarrow V_r$ smaller than $V_p$
  
  - $v_{omin} = V_p - V_r \Rightarrow$ approximation
    
    - $V_o \approx V_p$
    
    - $V_o \approx V_p - 0.5 \ V_r$

- If $\Delta t$ small $\Rightarrow$ approximation
  
  - $\Delta V = V_i \approx V_p e^{-T/RC}$ where $T$ is the period.

- If $RC >> T \Rightarrow$ approximation
  
  $V_{pi} e^{-T/RC} \approx V_p \left(1 - \frac{T}{RC}\right)$

With these approximations, the filtered signal becomes more straight, which can be seen in figure x.

![Figure 58 Input signal Vs versus flattened output signal V0 with filter](image)

9.4.3 Voltage regulator

Finally the last step, voltage regulation[3], shall be done by the LM317, see figure 59.

The LM317 is a positive voltage regulator with only 3 terminals and an output voltage range from 1.25 to 37 volts.

Where: Input (IN), Output (OUT), Adjustment (ADJ)

To achieve this change in voltage only requires 2 external resistors (one is a variable resistor).

Its main features include current limiting and thermal overload protection. The voltage between ADJ and OUT pin is always 1.25 volts (voltage set internally by the controller) and thus the current through the resistor $R_1$ is: $I_{R1} = V / R_1 = 1.25 / R_1$.

This same current flows through the resistance $R_2$. Then the voltage in $R_2$: $V_{R2} = I_{R1} \cdot R_2$. If we substitute $I_{R1}$ in the last formula it yields the following equation: $V_{R2} = 1.25 \cdot R_2 / R_1$.

As the output voltage is:

- $V_{out} = V_{IN} + V_{R2}$
- $V_{out} = 1.25 \ V + (1.25 \cdot R_2 / R_1) \ V$

Simplifying (common factor)

- $V_{out} = 1.25 \ V (1 + R_2 / R_1)$

![Figure 59 Schematic of a LM317 voltage regulator](image)
From this formula it is clear that if you modify $R_2$ (variable resistor), it will adjust the voltage $V_{out}$. In the above formula has blocked the current ($I_{ADJ}$) circulating between the adjustment pin (ADJ) and the union of $R_1$ and $R_2$. This current can be neglected, has a maximum value of 100 µA and remains constant with varying load and/or input voltage.

In order to optimize the control resistor $R_1$, it should be placed as close as possible to the regulator, while the terminal is grounded. Resistor $R_2$ should be as close as possible to the ground of the load.

In our case, the desired output voltage is 7.4 volts. If we impose this voltage $V_{out}$ and a resistance of 500 Ohms $R_1$, $R_2$ is 2460 Ohms. Finally we have an approximate voltage of 7.5 volts, regardless of the $V_{in}$. (Provided it is between 1.25 and 37 volts, as mentioned before, and the converter transformer is used)

\[ \frac{R_2}{R_1 + R_2} = \frac{V_{out}}{V_{in}} \]

\[ \frac{2460}{500 + 2460} = \frac{7.4}{\text{Vin}} \]

\[ \text{Vin} = 37 \text{ volts} \]

\[ V_{out} = \frac{7.4}{0.472} \approx 15.64 \text{ volts} \]

\[ \text{Imax} = \frac{0.7}{R_{2}} \]

\[ \text{Rs2} = \frac{0.7}{\text{Imax}} \]

\[ \text{Rs2} = \frac{0.7}{1.75} = 0.4 \text{ Ohms} \]

Finally, some electrolytic capacitors should be added in order to improve transient response and ripple.

---

**Figure 60: Voltage regulator with limitation**
9.4.5 The Multisim verification:

The basic outline of the charger output can be seen in Figure 61. [5] The devices whose name starts with the letter X are measuring devices and should not be included in the final battery.

As discussed, we then need to add the following components: first we have the rectifier with four diodes; in this case a virtual simulation is enough. However, in order to build the real charger, we would have to compare several models in order to find the best one. Then we have a filter with a 0.155 µF curling capacitor, followed by a voltage regulator with current limiting incorporating electrolytic capacitors to improve transient response. The schematic for this system can be seen in Figure 62; the simulated results in Figure 63 (together with the 50 Hz input signal). This shows that this system achieves a level output voltage, as desired.
In Figure 63, the battery is connected to the previous schematic to verify the current, which should be less than 0.8 C. (0.8 C = 2000 mA, 2 A). This theoretical schematic [6] shows a current of 1.992 A, which is according to our needs.

**Recharge time:**

We have a battery of 2500 mAh, 7.4 Volts, and the calculated charger works approximately at 2 A. The recharge time can then be found with formula x.

\[
\text{(Battery capacity/Output intensity of charger) } \times \text{ safety value for slow process}
\]

(Formula x)

\[
T = \frac{2500 \text{ mAh}}{2000 \text{ mA}} \times 1.1 = 1.375 \text{ h}
\]

Time = approximately one and a half hour.

### 9.4.6 Real Aspect

The real aspect of the charger depends on the components used in the physical fabrication of the product, but it should be done with the same materials as the cover of the battery, with a size of 150x70x30 mm. An example can be seen in **figure64**. The wires and connector are described below.

### 9.4.7 Recommendations

In the next section, we provide some extra information about the handling of these kinds of batteries, both lithium ion (Li-Ion) as lithium polymer (Li-Po). These types of batteries are used today in almost all existing mobile devices: phones, laptops, cameras, etc...
Because of a lack of information and misinformation caused by previous generations of batteries (NiMH and NiCd), a lot of people have developed wrong charging habits, which can shorten battery life and even cause serious damages.

Operation:
The lithium ions that are inside the battery move from the cathode (negative electrode comprising a lithium alloy with other metals such as cobalt and manganese) to the anode (positive electrode consists of graphite) spontaneously, through an electrolyte that allows the circulation of ions, but not electrons. When we close the circuit from the outside, the ions can travel from the cathode to the anode, because now the electrons can travel on our circuit to balance the loads. This movement of electrons produces energy. When all ions are in the anode, the flow of electrons will stop (the battery is discharged.)

The charging process involves the application of electron flow in opposite direction of discharging (so-called “mirror chargers”), so that the ions now move from the anode to the cathode, recovering the starting position.

Batteries consist of one or more cells with a voltage set at around 3.6 V and can be connected in series, parallel or a combination of both. It is because of these 3.6 V to these values we find such a voltage characteristics on the battery (11.1 V, 14.8 V, etc.).

Use of Li-Po batteries:
The first charge-discharge cycles should be complete, leaving a charging batteries a couple hours after completion of the charge, and making the discharge as fast as possible: this is done because during a period of non-use, a film of lithium chloride (LiCl) forms on the anode of the battery, which decreases the ion exchange and therefore the number of electrons in motion by the circuit. This in turn decreases the number of mAh and therefore the amount of energy that can be generated.

This layer is also formed when we keep the battery in storage for a long time (several months), after which the same procedure should be followed before reuse. It is recommended to keep the battery at half charge when not in use, never empty or fully loaded. This does not affect the duration of load, and extends the battery life time and ensures that the Li-Cl film is removed gradually with use.

Lithium batteries do not suffer from memory effect, in contrast with what is called “digital memory” caused by the internal meter charge on each cell (a maximum and a minimum level). It manifests itself in computers with more than one battery cell in series (typically on laptops) and occurs because not all cells are discharged at once. Usually the cells located at the ends are emptied before the ones in the centre, and thus, the centre is loaded before the end.

If we consider that the charger is stopped as soon as you have a cell charged and the first cell that be exhausted, marks the point of zero charge, we can imagine that gradually increasing the imbalance between cells, and therefore reduces the duration of the battery. To avoid this, always take a full charge cycle (fully discharge the battery and fully charged) after about 30 incomplete cycles.

The great enemy of lithium batteries is heat (as a rule, with some exceptions of Li-Po), which greatly accelerates the oxidation process, increasing the internal resistance of the cells and thus decreasing the operation time. This is because subjecting the battery to high consumption levels, the terminal voltage decreases due to the potential drop that occurs within and may give early warning of low battery. Therefore, it is not advisable to leave the battery permanently placed in hot places (e.g. the car). Keeping this in mind, charger should preferably be disconnected when charging is complete.
It is not advisable to completely drain the battery in everyday use, but to ensure that daily use the charge does not drop below 20%. Otherwise, the number of life cycles will fall.

Dead batteries should be handled with care, because a 0% load represents a voltage of approximately 3V, which still has a lot of energy inside. Original chargers should always be used. Since lithium batteries have a tolerance of 0.25%, voltage differences of hundredths of a volt could damage them. Supermarket chargers should be avoided and a lithium battery should definitely not be charged in a car, where the output voltage constantly fluctuates and peaks.

Do not use fast chargers: the slower the charging, the less traumatic the breaking of molecular bonds at the anode for the passage of ions to the cathode, and therefore the less wear.

We must also take into account that only the original chargers usually have an electronic safety circuit to cut off charge from the battery when it reaches a critical temperature. Although the manganese cathode stop passing current if the battery overheats, this should not be trusted blindly.

Its lifespan is about 500 full load (cycles), i.e., two battery charges with 50% added as a full charge, but due to oxidation within the cells, they never last more than 3 years. This is a point to keep in mind when purchasing a new battery, and although it is not unusual to see that date engraved on it if you can mark the date of purchase.

---

9.5 Interconnections

9.5.1 Between charger - home network

The battery will be charged on AC, from 230 V, 50 Hz. We will use standard PVC isolated wired of 0.75 mm², which means we will need three of these: one for each phase and one for the ground. This translates to a wire with of 2.25 mm².

9.5.2 Between battery - charger

This will work on DC, which means calculate the size of the wire can be calculated with formula x.

\[ S = \frac{2 \times L \times I}{56 \times \%} \]  
\( S = 2 \times L \times I / 56 \times \% \) (Formula x)

Where

- L: conductor length
- I: Intensity (in this case, charging is always 2 C at least)
- 56: a constant (56 for copper, aluminum 35)
- %: the percentage of maximum admissible voltage drop (we considered 0.5\% = 0.005 * 7.5 = 0.0375 Volts

Then,

\[ \frac{(2 \times 0.75 \times 2)}{(56 \times 0.0375)} = 1.428\ mm², \ \text{approximately} \ 1.5\ mm² \]

Since we need two wires, this will be 3 mm² and the wires will also be isolated by pvc.

---
9.5.3 Between battery-suit

Between the battery and the beginning of the next regulator, the calculation is the same as in section 9.5.2. In this case, the intensity depends on how active the “suit” is. It could be small, but it could also be the maximum consumption (3426.8 mA). The wire has to be able to hold these conditions. And (using formula x):

\[
\frac{(2 \times 0.4 \times 3.5)}{(56 \times 0.0375)} = 1.33 \text{ mm}^2, \text{approximately} 1.5 \text{ mm}^2.
\]

In this case we also have two wires together, again translating to a size of 3 mm² with PVC isolation.

We must note that the cable connecting the battery with the suit and the one connecting the battery with the charger are in the same section, so that the battery only has a single hole arranged to connect to 2.1 mm.

Once the battery is charged, we can start using our product by inserting it in the corresponding pocket and connecting the cable from upper and lower parts of the suit.

This battery is capable of delivering 7.4 volts. However, we must feed our product system with around 5 V, which is the operating voltage of most components. The output voltage should never exceed 6 V, because this could cause damage to the components. We used a voltage regulator based on a LM317 regulator. The final aspect of this controller is the printed circuit board, which should be made as small as possible, approximately 50x50 mm. The simulation model for the calculation and the findings are as follows:

\[
V_{out} = 1.25 \times (1 + \frac{R_2}{R_1})
\]

\[
R_2 = \left(\frac{V_{out}/1.25 - 1}{R_1}\right) \times R_1
\]

\[
V_{out} = 5 \text{ V}
\]

\[
R_1 = 470 \text{ Ohms}
\]

\[
R_2 = 1410 \text{ Ohms}
\]
V1 in figure y, 7.4 V symbolizes the battery; the rest is part of the regulator and integrated in the suit. This shows that we get the required 5 V output voltage from the battery to our system.

This regulator will also be isolated with the same material as the battery in the other leg of the suit. It will be encased in a small box of about 60 x 60 x 20 mm.
10 Materials and methods

We have developed two different prototypes to verify the hypothesis in the previous section. The first prototype was used to verify the motion capturing and communication protocol and to implement and debug the motion guidance. The final prototype was built using almost the exact same elements, but with LilyPad components so it could be sewn into clothing. Apart from the motion capturing and communication protocol it also allowed us to test the motion guidance with LEDs and vibrating elements.

10.1 First prototype

This prototype was meant to have the same functionality as one sensor/feedback unit in suggested product, implemented on one main board. It was not meant to approach the look and feel of the final product, but to serve as a rapid prototype to test and debug both the mobile application and the sensor/feedback unit functions.

10.2 Needed elements

In the follow list there is a definition of the needed components and a description of the use:

- **Tablet**
The tablet is used to design new exercises, upload them to the textile and show heart-rate in a visual illustration.

- **Microcontroller**
The microcontroller is responsible to control the application and textile (later should be included in textile)

- **Vibrating motor**
Gives vibration for motion guidance (later should be included in textile)

- **LED**
Gives visual guidance for motion (later should be included in textile)

- **Memory**
Memory should save information for motion guidance as well as the heart-rate during exercise (in microcontroller)

- **Conductive elements (wires)**
Connection of sensors and the microcontroller
Materials and Methods

10.2.1 Communication protocol

The communication protocol will be designed to transmit information from the tablet to the microcontroller. The information should be transmitted as bytes. By the protocol it should be enable to configure the application of the microcontroller (means to upload exercises, switch on/off guiding components etc.) and to transmit measurements from the microcontroller to the tablet. Furthermore it should be designed to include easily a live transmission during the exercises as well.

10.2.2 Motion guidance (Remembering)

The motion guidance should work to guide a person for movements, by vibration and light. They should be connected with the microcontroller by wires and also controlled by the user (via software or button on the prototype). The guidance should be started and controlled with buttons connected to the microcontroller. The motion guidance should work as a reminder for the exercises.

10.2.3 Heart rate

Main characteristic of measuring the heart rate is the comfort of the measuring process. Especially measuring heart rate in neck and wrist should be focused. Therefore an alternative technology such as electrocardiography should be found to measure the heart rate. At first research for the possibility of sound and light should be done. If there is no alternative, the common way of measuring the heart rate will be used. The heart rate should be saved in a local memory and after the exercise transmitted to the tablet. On the tablet the heart rate should be illustrated in a graphical way.

---

Materials and methods

- **USB- cable**
  Energy supply and communication layer of the microcontroller and tablet
- **Buttons**
  Buttons to switch on/off the application and to control the exercise guidance (go step back/ skip some movements…)
In the next list you can see components we don’t need for the first prototype and the description why:
- **Battery**
  The components of the first prototype won’t be in the textile. The components are permanently connected with wire which will be the energy supplement
- **Bluetooth**
  For the first prototype is planned to use USB for transmitting information
In the next list you can see components which might be needed and a description of the reason:
- **Bluetooth- toggle**
  Depending on the development time Bluetooth could be included at the end
- **Electrocardiography electrodes for heart rate**
  During the development it will be tried to find a new way to measure the heart-rate. The electrodes will be needed if there is not an efficient way.
- **Sound/Light sensor**
  Is used for an alternative way to measure heart rate instead of electrocardiography. After a research if it works there could be a need of these sensors
10.3 HARDWARE IMPLEMENTATION

We used an Arduino Uno as a main board, see Figure a. For the motion guidance, we used three regular LEDs to represent the OLED strip, since OLED strips were not yet commercially available at the time of writing, and two more LEDs to represent the vibrating elements, since a LED and a VibeBoard are controlled in exactly the same way. Since this prototype was used for the verification of the motion capture, the most important component is the accelerometer. We decided to use the ADXL345 because it was easily available to us. It has a bit more capabilities than the ADXL335 suggested for the product and even consumes a bit less power, but since we only need to detect accelerations of +/- 2g this should not be a problem.

The board was programmed using the Arduino’s IDE and GVim on a Windows 7 Home Premium 64-bit system.

10.3.1 Wiring the board

The Arduino Uno, see Figure 68, is a microcontroller board based on the Atmega328P running at 16 MHz. It has 14 digital input/output pins and 6 analog input pins. Pin 3, 5, 6, 9, 10 and 11 provide 8-bit Pulse Width Modulation output, which can be used to vary the output intensity. Therefore, we chose to connect the 3 LEDs to pins 9, 10 and 11; and the VibeBoard to pin 5 and 6.

Digital pins 2 and 3 can be programmed for external interrupts. We will use pin 3 to trigger an external interrupt when a button is pressed.

Communication between the accelerometer and the Arduino Uno is done according to the I²C protocol, which is a serial communication interface with a bus structure especially designed for communication between low-speed components on integrated chips. The Arduino Wire library allows for easy use of this I²C protocol.

The operation voltage of the ADXL345 is between 2.0 V and 3.6 V. The Arduino Uno has a 3.3 V output power which we will use to power the ADXL345. It will need to be connected to the VCC input on the ADXL345, as well as to the CS (Chip Select) to enable I²C communication. It should also be connected to the SDA (Serial Data) and SCL (Serial Clock) pins on the ADXL345, together with a couple of pull-down resistor to prevent small electrical fluxes to be seen as communication signals. The SDA and SCL need to be connected to the Arduino analog pins 4 and 5, respectively, to communicate with the main board. Lastly, the ADXL345 GND should be connected with the Arduino GND pin, as well as the SDO (which should never be left open). The INT1 and INT2 outputs can trigger hardware interrupt, but we will leave them open for now.
The ADXL345 will send digital output to the Arduino controller in the form of signed integers. It has a 13-bit ADC resolution and the output values will range from 0 to 282 LSB for a sensitivity of +/- 2g. For the same sensitivity, its scale factor ranges from 3.5 to 4.3 mg/LSB, so the actual g values can be found either by dividing the LSB by the max LSB or by multiplying it by the sensitivity.

In Figure 68, a complete schematic of the first prototype can be seen.

10.3.2 Software implementation

Because of issues related to the timing it was necessary to split up the software implementation into several parts. Firstly, we created a PC application and the accompanying Arduino microprocessor code to test the communication protocol. Secondly, we created a Processing application to read in the accelerometer data, calculate the tilt and provide a simple 3D-model of the microcontroller to give feedback about the position. Lastly, we adapted the Processing application to save the data in text files that could be read with a Matlab application in order to calculate the cross-correlation functions and give feedback about the movement. In the following sections, all of these parts will be discussed.
10.4 PC application

Base on the specification we started to make our models for development. The models are designed especially for the prototype and may be different to the specification of the design. First we built up some use case diagrams.

10.4.1 Use case diagram

Figure 69 shows Use case about the smart textile. The system “smart textile” represents every components of the textile except the microcontroller. This includes transmission (e.g. Bluetooth), sensors, input and output elements, memories, batteries…

![Use case diagram of the smart textile](image)
It shows what the textile is able to do. This use case has three actors:

• User
The user of the textile
• The microcontroller
The Microcontroller in the textile which controls the textile
• Working station
The working station which is not specially defined what it is. It can be a laptop, computer, smart phone, tablet etc.

In the following list, a description of the use cases is given:

• Start Guidance
This use case is used to start the guidance. It includes that the microcontroller starts to detect the heart rate and the motion detection.
• Stop Guidance
This use case is used to stop guidance. It includes also that the microcontroller stops the motion detection and the detection of the heart rate
• Skip motion
This use case skips the actually motion guidance to the next
• Restart guidance
This use case restarts the actually exercise
• Upload heart rate
This use case uploads the detected heart rate on the one side from the textile to the microcontroller, on the other side to the working station
• Download exercise
This use case downloads the exercise on the one side to the working station on the other side to the microcontroller
• Upload configuration
This use case uploads the configuration from the working station to the textile, to configure the micro controller. On the other side the microcontroller uploads the configuration to the working station to the textile(to send this to the working station)
• Download configuration
This use case downloads the configuration from the working station to the textile and from the textile to the microcontroller

Figure 70 shows the use case diagram as a point of the working station. The system working station represents any components which communicate with the smart textile. It is not defined if it is a laptop, computer, smart phone, tablet… It is general designed to be flexible. It just shows the function and the responsibilities of the Working station. The use case diagram has 3 actors:

• User
User of the textile
• Smart textile
The smart textile (this time all components together)
• Database
The database behind the application
• Smart textile
This represents every components which is included in the smart textile

In the following list there is a description of the use cases:

• Create exercise
The user has the possibility to create exercises on the working station. New exercise includes that it is saved in the database.
• Change exercise
For a save exercise should be given the possibility to change the exercise. This includes also to save in the database.

- **Prepare exercise**
  The user can prepare exercises. This includes that the existing exercises are load from the database and also uploaded to the textile.

- **Configure textile**
  The user can configure on the working station the smart textile. A finished configuration includes that they uploaded to the textile.

- **Display heart rate**
  The user can display the heart rate. This includes also that the heart rate is loaded from the database.

- **Upload heart rate**
  This indicates that the heart rate uploaded to the working station. There it can be displayed but always includes to be saved in the database.

After finish up the use-case-diagrams we started up to make sequence diagram, to get deeper into the issue of the process how it should work.

---

**Figure 70 Use-case-diagram of the point of the working station**

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10.4.2 Sequence diagram

Figure 71 shows the sequence diagram of the finally system. It interacts between 4 roles: Textile, microcontroller, user and base station. The role textile represents in general the sensors, vibrating elements and lighting elements... The microcontroller requests the values from the textile and sends them to the working station, which displays the values to the user and saves it. The sequence diagram is about starting and transmitting data during an exercise.
10.5 Realization

Because of time limitation we had to change our specification and decided to skip the heart rate detection (just simulation) and make a guidance and motion detection prototype. We also changed the working station from a tablet to a normal laptop. Furthermore we didn’t include any memory to the micro controller. In the next chapter the communication protocol is described.

10.6 Communication Protocol

10.6.1 Introduction

To keep the dataflow as low as possible, the design of the protocol is based on a point-to-point protocol. The structure of each packet is strictly kept. It is possible to calculate the complete length of the received packet because the length of the data is included. For the parity Bit calculation, “start flag” and the parity Bit itself are ignored. If parity Bit control failed, the last packet must be sent again. Every direction description in this protocol is from the perspective of the textile user.

10.6.2 General structure

In figure 72 a basic structure of a packet is shown. It is divided into 5 parts:

- Start flag
- Length of Data (LOD)
- Command-Bytes
- Parity Bit
- Data

The length of the data is flexible and must appear in the second Byte of the packet. There is a maximum of length of 255 (0xff) Bytes.

Figure 73 shows the packets used for acknowledge received packets. There are 3 scenarios which may occur:

- ACK (0x01)
  Signals a successfully received packet. It is sent as the first packet after suc-
cessful connection. It is also used to signal that the base station is ready to receive measurements.

• Unknown (0x03)
Notifies the user that a wrong packet has been sent and cannot be used in the current situation.

• NAK (0x02)
Is send for a received packet with a failed parity Bit control. If a NAK is received, the last packet must be sent again.

### 10.6.4 Start and Stop measurement + Disconnect

*Figure 74* shows the structure of a “start measurement” packet. It is used to signal the base station that the exercise has begun.

The “stop measurement”- packet shown in *figure 75* is used when the exercise has finished. After receiving this packet, the base station returns to the same status as after the first received “ACK”- packet. It can send “ACK” which signals ready for the exercise or a “Configuration”- packet. Furthermore it is possible to disconnect by the “Disconnect”- packet shown in *figure 76*. After sending this the connection closes.

### 10.6.5 Configure the textile (0x01)

• Configure guidance (0x01)
This packet is used to switch on or off sensing components as well as guiding components. That is realized by 1 Byte in the Data part of the packet. The following list shows a description of the Bits:

1. Bit- vibration
2. Bit- light
3. Bit- Heart rate
4. Bit- Motion detection

A positioned Bit means that it is switched on. All other Bits are reserved for additional functions (not yet implemented). You can see the packets in *figure 77*. 

---

**Figure 73** Packets used for acknowledge receipt

**Figure 74** Start measurement packet

**Figure 75** Stop measurement packet

**Figure 76** Disconnect packet

10.6.6 Measuring packet (0x03)

There are two different types of packets which are used to transmit measurement information.

- **Acceleration data**
  *Figure 78* shows the structure of an acceleration data. The length of the data can be flexible (depending on the amount of acceleration sensors). The information from 35 acceleration sensors can be implemented. The order of the information is always the same. First you have the identification of the sensor which delivers the information, then you have the values of x, y and z. These values can flexibly consist of one or two Bytes. You use two Bytes if you have a value higher than 63. The information for this is in the first Byte. The first Bit of the Byte signals if you need a second Byte for the value. The last Bit is the signe Bit.

- **Vital signals**
  In *figure 79* there is a packet for transmitting vital parameters shown. Each parameter uses one Byte.

10.6.7 Guidance packets (0x05)

The guidance packets are sent from the client to the server. First the number of guidance packets is sent. For this a packet shown in *figure 80* is used.

In *figure 81* there is shown a vibration guidance packet. For each sensor you
use one Byte. The last Bit of the packet defines if the sensor is switched on or off. The rest of the byte is used for the identification of the sensor. The data part of this packet can be flexible up to a maximum of 127 bytes.

In figure 82 there is a light guidance packet shown. For each lighting group one Byte for configuration is reserved. For each Byte the first 6 Bit defines the identification of the lighting group. The 7th Bit of the Byte defines the direction (as described in the figure 82). The 8th Bit defines if the lighting group is on or off. There is a maximum of 63 lighting groups possible. The length of the data part remains flexible.

<table>
<thead>
<tr>
<th>Start flag</th>
<th>LOD</th>
<th>CF</th>
<th>Cmd.</th>
<th>Parity Bit</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x0F</td>
<td>0x02</td>
<td>0x05</td>
<td>0x01</td>
<td>1 Byte</td>
<td>Count of packet 1 Byte</td>
</tr>
</tbody>
</table>

In figure 80 there is an amount of guidance packets shown. For vibration guidance one Byte for configuration is reserved. For each Byte the first 6 Bit defines the identification of the vibration motor. The 7th Bit of the Byte defines if the vibration motor is on or off. There is a maximum of 63 vibration motors possible. The length of the data part remains flexible.

<table>
<thead>
<tr>
<th>Start flag</th>
<th>LOD</th>
<th>CF</th>
<th>Cmd.</th>
<th>Parity Bit</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x0F</td>
<td>0x02</td>
<td>0x05</td>
<td>0x02</td>
<td>1 Byte</td>
<td>Identification of vibration motor 7 Bit ...</td>
</tr>
</tbody>
</table>

In figure 81 there is vibration guidance shown. For each LED group one Byte for configuration is reserved. For each Byte the first 6 Bit defines the identification of the LED group. The 7th Bit of the Byte defines if the LED group is on or off. There is a maximum of 63 LED groups possible. The length of the data part remains flexible.

<table>
<thead>
<tr>
<th>Start flag</th>
<th>LOD</th>
<th>CF</th>
<th>Cmd.</th>
<th>Parity Bit</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x0F</td>
<td>1 Byte</td>
<td>0x05</td>
<td>0x03</td>
<td>1 Byte</td>
<td>Identification of LED-Group 6 Bit ...</td>
</tr>
</tbody>
</table>

10.6.8 Sensor identification

Figure 83 illustrates the ID of the sensor. They are composed of numbers. The direction is always from the perspective of the user, standing straight and holding the hand horizontal to the front. The direction is described as follows:

- for vertical group: a set Bit means up/zero means down
- horizontal group away from the body: a set Bit means away from the body/zero means towards the body
- group parallel to the body: set Bit means to the left/zero means to the right
10.6.9 Example

Figure 84 Sequence diagram of a communication

10.7 Software Solution

The prototype solution for the working station is done in C#. It is simply connected to the microcontroller by USB cable and communicates with a serial port. Before working with the prototype, the correct driver for the microcontroller must be installed. The program is build up based on the Model-View-Controller principle. This offers a clear structure and fast change of communication layer. The program consists of 8 classes. Figure 84 represents the class diagram. In the following list there is a description of the classes and their tasks:

- **SmarTex**
  This class is part of the View-layer and represents the user-interface
- **PortIo**
  This class is part of the Controller-layer and handles the stream
- **Communication**
  This class handles the communication with the textile and calculated the information out of each packaged. The communication occurs via thread.
- **PackageCreation**
  This class offers methods to create packages for the communication
- **Data**
  This class is part of the Model-layer and handles every received data
- **Tilt**
  This class is part of the Model-layer and represents the data of tilt
- **Acceleration**
  This class is part of the Model-layer and represents data of acceleration
- **Vital**
  This class is part of the Model layer and represents every received vital parameter
10.7.1 Communication protocol Arduino

The Arduino code follows the communication protocol sequence as explained in section 10.6. We work with two byte array buffers in this code: a transmit buffer that can hold a maximum of 12 bytes (5 overhead, maximum 7 payload) and a receive buffer that can hold a maximum of 132 bytes (5 overhead, maximum 127 payload). The receive buffer is necessary to store the incoming packet. It will always be filled with one packet and according to the LOD field; this way there is no problem when the Arduino’s serial buffer gets overwritten with new input. It also allows us to easily check whether a received packet is one the Arduino is expecting by checking the second (CF) and third (CMD) index of the buffer. If the board gets a packet it did not expect, it responds with an UNKNOWN. When filling the receive buffer, the parity of the packet should also be checked. However, we did not implement this function yet.

The transmit buffer is needed so we can format the outgoing packet in the right way. This involves calculating the length of data and, in later versions of the program, calculating the parity. One thing to keep in when sending the accelerometer data is that we get the information from the accelerometer in the form of one signed integer for each axis, meaning two bytes using two’s complement. For example, the value 127 is represented in bytes as 01111111, where the first byte stands for the sign. In standard notation, the value -127 would be represented as 11111111. However, in two’s complement it is 10000001. The main advantages of two’s complement is that’s it’s easier to for computers to do byte operations and that there is only one value for 0, namely 00000000 (whereas in standard notation we both 00000000 and 10000000 could mean a value of 0). The complexity is increased further because we’ve implemented a non-standard byte format for the acceleration measurements to make the data size flexible, where biggest value of a single byte can be 63 (6 bits) and the biggest value of a double byte 16383 (14 bits). We’ve solved this problem by formatting our data according to the following algorithm. A ‘sign’ and ‘complete’ byte are used as placeholders for the bit flags.

- Read integer.
- If the integer is negative, set ‘sign’ byte to 10000000 and invert the sign of the integer.
- If the integer is larger than 63,
  o Reset ‘complete’ byte to 00000000.
  o If the integer is bigger than 16383, set it to 16383.
  o Shift integer 8 bits to the right to get the 8 Most Significant Bits.
  o Shift the 8 MSB (of which the first two bits will always be 00) 1 bit to the left and bitwise or it with the ‘sign’ bit and the ‘complete’ bit. This will be the first byte in the data packet for that axis.
  o Set the first 8 MSB of the original integer to 0. We now have the 8 Least Significant Bits, which will be the second data packet for that axis.
- Else (if the integer is smaller than 63),
  o Set the ‘complete’ byte to 00000001.
  o Shift the integer (of which the first two bits will always be 00) 1 bit to the left and bitwise or it with the ‘sign’ bit and the ‘complete’ bit. This will be the only byte in the data packet for that axis.
The algorithm can best be illustrated by an example:

- Integer value = -2 (11111110 in two's complement).
- 'Sign' byte = 10000000 and integer value is now 2 (00000010).
- 'Complete' byte = 00000001.
- Data byte = 10000000 | 00000100 | 00000001 = 10000101.

Together with these acceleration measurements, the heart rate and respiration rate should also be sent. At the moment of writing, we have just implemented a test of this where the heart rate is always a random number between 60 and 80, and the respiration rate is always 20.

Before the measurement start, a user needs to push the Start button. The Arduino board waits for input on pin 4 and sends a START MEASUREMENT once it gets this input. The board will continue sending measurements until the user presses the Stop button. In order to implement this, we used one of the hardware interrupt pins on the Arduino board, pin 3. In order use it to trigger hardware interrupts on its rising edge (when the output from the button goes from 0 to 1); we need to set the INT1 bit in the EIMSK register on the Atmega328P to 1, and the ISC11 and ISC10 bits in the EICRA. Other triggers are also possible, see Figure 4. Lastly we need to write an Interrupt Service Routine that will stop the measurement when it is triggered.

Early debugging was done with the serial emulator program RealTerm, which was connected to the COM4 port the Arduino used on the development computer. The packets were manually send to the Arduino controller and the responses were monitored with the program. Figure 85 shows a screenshot of the debugging process.

| Table 12-1. Interrupt Sense Control |
|-----------------|-----------------|----------------|
| ISC11 | ISC10 | Description |
| 0 | 0 | The low level of INT1 generates an interrupt request. |
| 0 | 1 | Any logical change on INT1 generates an interrupt request. |
| 1 | 0 | The falling edge of INT1 generates an interrupt request. |
| 1 | 1 | The rising edge of INT1 generates an interrupt request. |
10.7.2 Motion capturing

We use the Arduino ADXL345 library to communicate with the accelerometer. This library will allow us to easily set the accelerometer's registers without constantly referring to the datasheet. For example, turning the accelerometer and reading the values of the axis only requires two function calls: adxl.powerOn() and adxl.readAccel(&x, &y, &z). In comparison, manually turning the power on would require at least three actions: writing 0 to the ADXL345 power control register at address 0x2d, then writing 10000 to it and finally writing 1000 to it. This would take up numerous lines of code, especially if we had to implement the I²C communication ourselves instead of using the Arduino Wire library. In Figure 86, communication with the accelerometer using I²C is shown.

10.7.3 Motion guidance

The motion guidance is very simple in this prototype. We simply implement a line of three LEDs and set a pattern for them to turn on and off in one direction, either repeatedly from LED 1 to LED 3 or repeatedly from LED 3 to LED 1. The LEDs representing the vibration sensors can be turned on or off at a desired intensity by writing a PCM value to their input pins. In this prototype these functions will only serve to implement and debug the code that will control the actual motion guidance in the final prototype.
10.8 Position Calculation

10.8.1 Arduino

A simpler Arduino program that doesn’t use the communication protocol was written for this part of the verification. The reason we chose not to implement the prototype is the added complexity of writing a library for Processing so it could use the protocol. By not using it, we could focus on the verification of the calculations. The Arduino code for this application simply prints a string with the accelerometer integer values to its serial port for the Processing application to interpret.

To control the accelerometer we use the Arduino ADXL345 library again. However, in this application we use some of its more advanced features: activity and inactivity detection. The ADXL345 can generate an interrupt when it detects acceleration higher than a certain threshold value on either axis. It can again generate an interrupt when it detects acceleration lower than a certain threshold for a set period of time. We have empirically determined that a threshold of 1.25g (16 LSB * 62.5mg/LSB) and a time threshold of 3 seconds provide the best results. Any lower than 1.25g and tremors will be detected as activity, any higher and it will not respond to slow movements in the right way. When activity is detected, the Arduino sends the string “START” to the serial port. It will then keep reading and sending the acceleration values until it inactivity is triggered. At this point it will send the string “STOP” to the serial port so the Processing application knows that that movement is done and the final position should be checked.

10.8.2 Processing

Every time a serial event is triggered, the Processing application reads the buffer and waits for a “START” string. When this start string is detected, it will start accepting measurements and calculating the tilt of the sensor using Formula 2 of section 7.1. Since we aimed for arm positions in which the arm is in front of the body, we do not need a full 360° of tilt.

The g value is calculated by dividing the y-axis LSB measurement by 270. According to the ADXL345 datasheet, the LSB values should range between 232 and 282 for 1g, so we chose a fixed value in between that worked right.

As long as the measurement is running, a 3D-representation of the prototype is shown on the screen, such as in Figure 87. To show the 3D rotation in the right way, the sign of the calculated angles needs to be inverted. This is because the 3D coordinate system in Processing (or OpenGL) has its origin in the uppermost left corner of the screen and angles are rotated clockwise instead of counterclockwise. When the processing application received a “STOP” string, the final position will be saved to be checked against a reference position.

Figure 87 3D representation of the position of the prototype
Figure 88 prototype
10.9 Movement Calculation

10.9.1 Arduino and Processing

For this application the Arduino and Processing application of the previous section are used. The only change we made in this version is to let the Processing application not only show a 3D-representation of the prototype while the measurement is running, but also log these measurements to a file. This will allow the Processing application (or any other 3D application) to retrace the user's movements on the screen and compare them to a reference movement.

We've built a dataset using three movements: for movement 1 the prototype is rotated over its x-axis towards the y-axis (clockwise) and back, for movement 2 the prototype is rotated over its y-axis towards the x-axis (clockwise) and for movement 3 it is rotated over the z-axis from the x-axis towards the y-axis (counterclockwise).

10.9.2 Matlab

In order to test how well the correlation functions would work, we logged each of the movements 25 times. Looking at the plots of the third data file for each of the movements in Figures 89 and 90, we can clearly see that only the first 100 samples will be significant. After these first 100 samples the signal turns either to noise or to a constant level. We compared more data files with each other and this observation always seemed to hold true. Therefore, we have decided to cross-correlate only the first 100 samples of the data file from each movement.

Figure 89 – Plot of the values of each axis for third data file from each movement.
To prove our concept that correlation could provide a good way to evaluate movements, we first calculate the auto-correlation for a random data file for a movement, and then we calculate the cross-correlation of this data file and other data files from the same movement, see Figure 91. We then calculate the cross-correlation of this data file and data files from other movements, see Figure 92 and Figure 93.
Materials and Methods

Figure 91 – Cross-correlation of the y-values of three data files from movement 1.
Looking at these figures, we see that if different data files for the same movement are compared the amplitude at the peak is always near 1 and the peak occurs within the range of -30 and 30 lags. Therefore, we will use these thresholds to determine whether a movement is similar or not. Whenever the signal’s maximum amplitude within lag -30 and 30 is lower than 0.6, we will consider the movements to be different. We’ve written a small Matlab program that compares to movements this way and simply answers whether they are similar or not to test these thresholds.
10.10 Final prototype

The final prototype was designed to be more like the actual product and uses most of the same components, though using the configuration and pin mapping of the first prototype. The main board is a LilyPad with an Atmega328, which is connected to a LED strip containing 3 LilyPad LEDs and two LilyPad VibeBoards, see Figure 94. This configuration was chosen to verify the sewability and comfortability, as well as test the effectiveness of the motion guidance.

To test it, the Arduino and Processing programs, described from section 10.8 and 10.9, were altered to provide the guidance. The test user should hold their arm level at the start of the program. At this point, they have been notified of which movements they are allowed to make. The LEDs will then start blinking in upwards or downwards to indicate the direction of the next movement. The user will then move in the right way and stop moving when he feels he is in the right position. If he is not in the right position, the system will make the vibrating element opposite to the desired direction vibrate. After he reaches the right position, the feedback for that position will stop and the cycle will repeat over again.

Figure 94 Final prototype 1
Figure 95 Final prototype 2
11 Tai Chi

11.1 Tai Chi class

To get familiar with tai chi, Alex, Lara and Ruben did a tai chi class. We learned about different stages during a lesson of tai chi, the difficulties, some movements and the breathing. The respiration rate is the most important and most controllable during a session of Tai chi. During a session of tai chi it is necessary to be as calm as possible. This is possible by breathing 4 seconds in and 6 seconds out. That’s why at the beginning of each exercise there is a relaxing exercise focused on the breathing. Someone who starts with tai chi will be in beginners phase for over four years. For elderly, this will even take a longer period. With our product, it should be possible to practice more, have a faster learning curve and easier understand the meaning of tai chi.
11.2 WHAT IS TAI CHI?

Tai chi classes have become very popular in hospitals, clinics, elderly care homes, and community centers in the last twenty years. It is well known as a stress training for elderly that improves the balance and your inner peace. As a result of this popularity there has been some divergence between those who say tai chi is a martial art, those who practice it for aesthetic appeal (wushu), and those who are doing it for the benefits it gives to the body. The wushu aspect is primarily for show. Lately tai chi teachers believe they have to keep the balance between all the forms like yin and yang have a balance.

Tai chi is a ritual movement, it stimulates flexibility and responsiveness and provide a sense of vitality as it considers the human body as an organism that contains vital energy or Ch'i. The energy flows through specific channels and the main function of the practice of T'ai-ch'i is to ensure the continuity of this flow.

“To live well we need to know how to live, experience life, enjoy life and distinguished life. Through the breathing you know that there is life and breath through experience over time and life while sipping a distinction at the end what is the best life.”

Peter Yan

11.2.1 Form

1 - There should be an overall sense of coordination, and the body should act as a unit.
2 - The feet should be firmly located and the rest of the body relaxed, but not loose, so that the Ch'i can penetrate, hip and waist directed energy.
3 - Every gesture and step is quiet and uninterrupted and the breathing unforced and soft.
4 - The focus will be on left and right, forward and backward, up and down, inside and outside, full (“the substantial”) and empty (“insubstantial”).
5 - The movements are executed slow and concentrated.
12.1 Preface

On the next pages we tried to prove and improve some of our design ideas with ergonomic and usability research. We made mockups and basic prototypes of the electronics and the styling part. We tested it on ourselves and on test persons. After doing the tests we used the information we gathered into our definitive design.

Test person one is a male person of 75 years who is still quiet active, he loves to ride his bike and to work in the garden, he has a problem with his knees and needs an operation for this problem but he still remains active waiting for his surgery. 10 years ago he broke his left shoulder and his collar bone with a biking accident because of this he lost some flexibility in his shoulder, he can't reach the same places with his left as with his right hand. The test person has no problems with his condition or with his mental capacity. The test persons isn't afraid of the new technology.

The second test person is a woman of 76 years old, sometimes during the day she has to rest because she is starting to feel a little bit tired. She is a little bit afraid of electronics in her clothing but she understands that it can lead to solutions for elderly persons. She also has broken her shoulder but after an operation she can't feel any difference between her two shoulders. She went a lot to the physiotherapist and the problem healed completely. Mentally she has totally no problems but she feels like she can't follow the latest technologies.

Figure 100 Test user 1. Figure 101 Test user 2
The positive feedback system is critical in the project that is why we tested it with people of our target group. We designed a light-scenario on the clothing and presented it to two persons out of our target group. We tried to simulate the light on the clothing with tape and changed different aspects on the clothing and on the tape.

Figure 102 Light testing 1.
Figure 103 Suit testing

Figure 104 Light testing 2
We tested the interpretation of the light, the visibility of the light, the position and the looks of the light. The conclusions were clear: it was too difficult for the test persons to interpret all the feedback at the same time. Therefore we adapted the scenario and made it simpler, we first wanted a complete guiding system with the light and simplified it to a reminding function with an indication in what way to move. This reminding function is very useful especially for elderly with a bad memory. With the implementation of this feedback they can practice without the help of a teacher and without the constant negative feedback. This kind of feedback is especially very interesting in the early stages of learning tai chi; the base of the sport can easily be taught with the light. Elderly start with simple slow movements and in most cases they don’t have the fast progress of a younger person the light can help fastening up their abilities of tai chi.
12.3 Suit

12.3.1 Textile

The textile is cotton polyester this textile doesn’t need a lot of maintenance it doesn’t need to be ironed and it is easily hand washable. The price of this textile is also acceptable it’s only half the price of kimono’s made out of Japanese silk (€160). At the wrist and the ankle there is a more tight part this is made out of a stretchable nylon.

12.3.2 Sizes

Clothing always comes in different sizes; this is also in tai chi clothing very important, especially because our clothing is focused on elderly. It should fit between the 5th and 95th percentile for woman and men between an age of 65 and 85. We can work in three different sizes small, medium and large. The values in the attached table are in centimeter. And fit these specifications. For the ankle and the wrist we will have to consider the stretchable textile, this gives us more freedom but we can’t stretch the textile too far.

<table>
<thead>
<tr>
<th></th>
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<th>medium</th>
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<tr>
<td>height</td>
<td>157,8</td>
<td>167,4</td>
<td>177,2</td>
</tr>
<tr>
<td>chest</td>
<td>96,52</td>
<td>109</td>
<td>122</td>
</tr>
<tr>
<td>waist</td>
<td>71,12</td>
<td>81,28</td>
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<td>144</td>
<td>160</td>
<td>178</td>
</tr>
<tr>
<td>ankle</td>
<td>190</td>
<td>204</td>
<td>218</td>
</tr>
</tbody>
</table>

Table 5 Sizes

Figure 108 Tai chi park

Figure 109 Ergonomics
12.3.3 Zipper and stretching part of the pants

The zipper goes diagonal from the left shoulder to the right thigh. This is the easiest way for elderly to open a vest.

The upper part of the pants consists out of two parts: the stretching area at the side and the measuring area in front of the pants. In the pants we measure the respiration rate with a resistive wire. The stretching part takes care of a perfect fit.
Our elderly target group shouldn't be aware of the electronics inside the clothing; because of this the components will be hidden underneath a double layer of textile. The sound sensor and vibrating elements are sewn on this tighter piece of textile. Most of the components are too small to feel inside the clothing only the arduino lillypads and the button on the right arm have to be an exact place for not noticing. All the components are sewn in on the inside and can't be touched.

The vibrating elements have to be on the most effective place on the arms and the legs. During our project we tried to define what the most perfect place was. Daniel made a test setup out of two vibrating elements, a Arduino LyliPad battery holder, a AAA battery and a arduino LyliPad processor. This setup we placed on our legs. The vibrating elements can't be pressed to hard on the skin because the vibration becomes invalid this way. The position of the vibrating element is also very important we place two pairs at each fore-arm and under part of the leg positioned in a corner of 180 degrees. They are sewn on the tight part made out of nylon close to the skin for the best effect. Every different person has a different sensitivity of the skin that is why the hardness of the vibration is changeable in the app on the tablet.
12.5 PLACE IN SUIT

In the suit there are 5 arduino lilypads integrated, four of these are part of the motion capturing device and one as a base point for sending all the data to the tablet. The four microcontrollers are connected with the base point with a zigbee connection and the data at the base point is sent to the tablet with a Bluetooth 15 m range connection. At the right wrist there is a sound sensor for the heart rate detection and at the left forearm the button is placed. Every component is connected to the battery with a conductive wire.

12.5.1 COMPLETE SYSTEM SPECIFICATION

Since we have decided to use XBee for communication, we will need five separate LilyPad Main Boards, one for each sensor/feedback unit and one main board to handle information coming from all of them and send it to the microcontroller. We will refer to the former just as ‘main board’ and to the latter as ‘base station controller’. The base station controller will also directly receive input from the stretch sensors. The heart rate sensor will be incorporated at the right wrist of the suit and connected to the sensor/feedback unit on the lower right arm. Figure 116 shows an image of where all of the components should go.
12.6 Battery

There are two possible places of the battery in the back of the upper part and at the thigh. Because we are working with elderly the thigh is the best option. At the thigh the elderly is capable to see the battery when they have to remove or place it. It is also possible to have a tactile connection on this place with two press buttons. The battery fits perfect into the pocket and is connected with a cable to the suit.

Figure 117 Defining place battery
Figure 118 Battery placement
Figure 119 Battery with press buttons
Figure 120 Cable test
Ergonomics and Usability

Figure 121 Render battery placement

Figure 122 Press button

Figure 123 Battery render
12.7 Button

The button is one of the most important and difficult parts of the suit. We decided in the beginning to limit the number of control buttons to maximum three buttons, a pause button a button to start the last exercise and a button to skip to the next exercise. We could make more buttons but this would make the controls too difficult for elderly people. The pause button must be easily reachable for fast stops and therefore we placed the button combination at the right forearm.

The arduino lilypad buttons we sew in are very small so we designed two plates consisting out of a sandwich of two materials, a harder PE and softer EVA foam for a bigger pressure surface. These plates can also be sewn in and will have as effect that the buttons easily can be pressed. Both at the same time with the whole hand to pause and one half to go last or next exercise. The diameter of the whole button is 40mm; this is more than big enough for elderly people who aren’t used to work with small buttons.

Figure 124 Button. Figure 125 Place button test

Figure 126 Explosion view of the button
Our interface is completely focus on elderly people and their abilities, a user friendly interface with a lot of tactile feedback would make it a lot easier for them.

The important part is that the icons and the meaning of the icons have to be perfectly understandable by elderly. With a touch screen we have a gestural interface that combines "direct" physical control with digital interface design. If we want to design an interface we have to know how a finger works and what possible combinations are feasible. Also, people are interacting with interfaces in a range of positions and contexts that go beyond simply standing or sitting in front of a screen. So we will have to search further than only pointing, beyond fingertips, knowing how people can use their body to hold, view, reach and interact.

In other words, it is necessary to know your target group, and design for their requirements taking care of the ergonomic design.
12.9 Tablet

12.9.1 Interface

The integrated user-interface demands a high level of prototype integration, concept and usability testing. Having the first approach to our design, we developed quick and dirty user-interface prototypes for effective research. At the end of the process we did design prototyping and testing with physical mock-ups in order to prove and be sure about our steps. At the beginning the interface was more complicated and had a lot of buttons and options. The goal was to give the user more freedom of choice, but after reconsidering our target group we decided to cut some of the options and design a simple and intuitive interface instead.

The most difficult part of interface design is interpreting how the user will respond to the touch screen that requires them. All the buttons are designed to resemble real buttons by using shadow and lighting tricks, which makes the interface feel more natural to the elderly. We use visual feedback to indicate that an action has taken place (such as a button being pressed).

The test users found the selection of the exercise the most difficult part of the interface. Moving the square was not clear at first sight but once they had learned it, it became easier and more fun. We chose to stick to this design because a requiring to the user to simply press a square would increase the chance of unintended.

At the end we’ll be able to empower the gestures that they already do and give them further influence and meaning.

Figure 129 User testing tablet. Figure 130 Interface
12.10 Feedback

12.10.1 Heart and respiration

The heart rate and respiration rate are shown at the chest and the abdomen. The position of the light should be clear for the user and for the surrounding people, for example the tai chi trainer. The way the light of the OLEDs interact should be as clear as possible and the visibility of the light should be tested.

The conclusions:
The balls at the abdomen have to give less information; they may not give the F6 breathing and your own breathing at the same time that is why we have chosen for only showing your own breathing. A light at the warning point at the wrist will light up when the user don’t succeed in F6 breathing. And the surrounding person can see the persons breathing in only a glance.

The balls at the chest were clear for the test persons and the light at the chest is easy to observe during a tai chi session. Here we also implement a warning point for the heart rate at the wrist because this places it is the most noticeable on the body.
12.11 Pattern

To make an end product we needed to know how the final product was going to be made, this is which is why we made a sewing pattern on pattern paper remove, with the help of a fashion designer. The sizes: (small, medium and large) can be based on this pattern by making the pattern larger or smaller. The pattern is a basic kimono vest and pants.
The vibration can be positive or negative. Positive meaning feedback occurs when an action is done in the right way, negative meaning feedback is given when something needs to be corrected. The most intuitive of these is negative feedback, where the intensity of the vibration is directly related to displacement of the user’s position to the ideal position [15]. Some examples of using negative feedback for motion guiding include teaching a new technique to violin players [15][16][17] and teaching martial arts [18]. These papers show that vibro-tactile feedback can significantly improve the learning of a new skill. However, they also show that it is most effective when combined with visual feedback of some sort. This can be illustrated by the following example. Let’s say a user of a vibro-tactile system is supposed to hold their arm in a horizontal position in front of them. The user hasn’t been told this and they start out by holding their arms next to their body in a vertical position. The user will feel a strong vibration on the back of their arm, indicating they should move their arm upwards. However, since they do not know how far it should move upwards, they move their arm too far up and again get a strong vibration indicating they should move down. This will continue for a while, until the user experimentally gets their arm in the right position, and it will result in both unnecessary discomfort for the user and a lot of superfluous motion, which will effectively prevent them from committing the movement to muscle memory.
Therefore, we propose a system where the acquisition and translation are done by mimicking a teacher or video, the positions are corrected during the action step itself using vibro-tactile feedback, and the evaluation of the movement is done by showing the user a 3D-model of his own movement and the ideal movement for the finer details of the movement. This would significantly shorten the translation and feedback phases, especially when using the system for a longer time. In the first few tries, the user would take instructions from a teacher, translate them to movement and require feedback from the teacher in the usual way or from the 3D-model. When they get more proficient and they roughly know how to perform the movements, the vibro-tactile feedback will provide them with a way to correct their position and they can compare their movements to the 3D-model, eliminating the need for a new translation from the teacher’s movement to the user’s movement. When they get even more proficient in performing the movements, they will no longer need to rely on the 3D-model to compare their movements, but the vibro-tactile feedback will allow them to fine-tune their position, again eliminating a step in the feedback and translation system.

At this point, the feedback is solely tactile and since movements and positions also rely on feeling, the translation step will effectively be much shorter. Because this will allow the user to do more repetitions in a shorter time, the motion can be committed to muscle memory quicker and in a more comfortable and intuitive way.

13.2 Lights

In the next page is explained how the lights work in order to give the positive feedback to the user.

The explanation about the OLEDs is given in the section 8.7
**Feedback**

- Bended: the line is shorter
- Full stretch is a full line
- Direction to move is indicated at the end of the sleeve, with a light that moves around the wrist

- Bending: the line goes down
- Stretching: the line goes up
- Full stretch
- Line is in the direction you have to move
13.3 Measurements

The feedback of the heart rate is given at the middle of the chest on the right of the zipper. It exists out of 5 balls that are rotating among the same point at the centre of the balls. This circulating movement is a representation of the heart rate, the faster it rotates the faster your heartbeat is going. When the maximum heart rate of the user is reached a warning light at the left wrist will light up to give an attention to the user. The maximum healthy heart rate is for each user different, it is calculated with a simple formula: 220 - age. Because there is a profile implemented on the tablet the suit will know your maximum heart rate.

The feedback of the respiration rate is given at the bottom of the vest on the left of the zipper. It exists out of 6 balls moving slowly through each other and OLED light that will shine and fade away at the rhythm of the breathing. The moving of the balls is a representation of oxygen particles. The user will also have a warning light at the left wrist next to the other warning light but with another color when his breathing speed is too high. A perfect respiration rate is an F6 respiration rate, this means 4 seconds breathing in and 6 seconds breathing out.

Figure 138 Feedback measurements Heart rate and respiration rate
(Next three pages) Figure 139 Interface
1 Exercise

You have to move from the catalogue to your exercise.

The options open like a pop up.

When you press the exercise it appears an explanation of it.

**14 Interface**

**Elderly Users**

On the next three pages we tried to define in a simple way how to operate with the interface. We tried to use simple hand gestures for elderly people together with opportunities a tablet can give us. The gestures have to be clear and structured and they may not be misunderstood.
2 Feedback

You can move and see your level every day.

2.1 Select the exercise you want the feedback

2.3 Select the kind of graph
3 Options

Select between the Lights, Vibration and sounds.

4 Personal

Profile, you could go directly to your feedback with the buttons.

Friends, you can move between them. When you press you can see your friends level and their personal details.
15.1 Presentation RENDERS

On the next pages we placed a detailed description of how to use our product, we used some presentation renders of the product and images of the interface.

First, we have two product presentations that explain the movement of tai chi. The suit can be used in any environment at any time. In China, the practice of tai chi is a part of life; it can be done in teams or alone in parts of the open city, nature, or even inside.

Apart from the guidance mode for training, there is also a freedom that opens your possibilities.

Figure 140 Motion render
Figure 141 Environmental render
The tablet is always at a range of 15 meter of the suit and it is used during tai chi for processing all the data.

The tablet doesn’t have to be out, it can be safe away in your backpack.
The social mode of the suit can be used for doing tai chi together with your friends or tai chi trainer.

The colors of the suit can merge together into a new color.

The vibration and light will now interact with the other suit and not with the tablet like before.
Product Presentation

**Colours suit**

- PANTONE DS 45 8-C
  - C:31 M:26 Y:29 K:0
- PANTONE 7C
  - C:64 M:67 Y:61 K:57

**Colours lights**

- Energy
- Power
- Emotions
- Life
- Mind
- Senses
- Empathy

Figure 144: Render with colours
PRODUCT PRESENTATION

APP logo

Figure 145 Interface1

Move from the catalogue to your exercisebar for selecting a movement.

Homepage

Options like a popup in the exercise menu.
Feedback of the exercise menu

With the motion capturing we are able to give a 3D representation of your movement in the tablet.

This 3D representation we can compare with the perfect movement.

The user gets a motivational line of information with this feedback system.

On the page Level the user gets information about his exercise, respiration rate and heart rate. It is a friendly and simple way to give the necessary information to the user.
The light can be adapted in this menu.

The most important part in light is how to select the color of the suit that gives you the feedback of your mood.

There are similar pages for vibration and sound.
Product presentation

Personal menu

In the page friends the user can see how his friends are doing. The size of the balls is an indication of their level. When the user touches a ball a profile page of these persons pops up with more information.

At the profile page the user can see his level and go directly to the feedback pages.
Timono is a smart textile suit together with an App on android that is perfect for learning and doing tai chi. The timono suit combines positive feedback of light, negative feedback of vibration and measurement feedback into a device especially made for elderly who need an extra stimulation for being active. Timono is a new style of kimono with integrated technology based on the user.
16 Scenarios

Why Buying a Timono Suit

Family convinces elderly to do tai chi

it is difficult for the elderly to understand tai chi and the teacher notices this

the school works with a timono suit for better practice and better understanding the ways of tai chi

buys the suit
Scenarios

Before exercise

Set the tabley

Put the suit on

Insert the batery

Switch on tablet in backpack

Before a user can start with an exercise the tablet has to be set. In a tablet a user can choose the exercise, the duration of the exercise, the color of the suit, etc. The tablet has the function of control. They can set the tablet on a time they want, it doesn’t have to be exactly before the exercise.

The user need to put on the suit before starting the exercise.

A last step before the tai chi practice can start is the battery, this has to be connected to the suit at the thigh and you can close the zipper.

When the battery is connected you can connect the two press buttons between the top and the lower part. This action will also function as an on/off button. The line next to the zipper will light up, this is the warning that the suit is on the tablet is in range of the suit with a Bluetooth connection: max 15m around you.
before a tai chi session there is a warm up needed, this warm-up is the breathing exercise. The user has to breathe 1 minute and 30 seconds in F6 breathing to calm down. F6 breathing is 4 seconds breathing in and 6 seconds breathing out. During this session the tablet calibrates with the sensors for the motion capturing in the suit. The suit gives already feedback about the breathing when the breathing is 1 minute 30 seconds in F6 breathing the suit will give a vibration at the wrist. This means that your breathing exercise is completed and you can start with the tai chi practice.

the start position is the posture a user takes when he or she wants to start the exercise. The suit measures the position.
when you stand 2 seconds in your starting position the light in the suit will blink twice. After this two blinks the exercise will start.

The positive and negative feedback will start. The negative feedback is a vibration at the fore arm or shin bone that will lead you to the right position. The positive feedback is light emitted by OLED’s. The change of the surface of the OLED’s will indicate the movements to make.

if the movement comes at an end the user has to stand in a end position for completing the measurements.

for next movements you must repeat these 3 steps again.

Scenarios

EXERCISE

Start the exercise after two blinks

Do the exercise

End position

Another exercise
Repeat 1, 2 and 3
if necessary the exercises can be stopped by pressing the switch at the right forearm. The pause button is divided in 2 parts after pressing the pause button you will have to choose between last exercise again < and next exercise > on this button. Possibility of merging lights and follows the movements of somebody else: when a suit detects the proximity of another suit with Bluetooth, their colors of the timono suit can merge and they can do tai chi together. It is also possible to send the movements of one suit to the other suit. In this case a master can teach the student how to do tai chi with the help of the suit.
the feedback of the heart is given on the chest with OLED light. The balls move in around in a circle like the bloodstream. The faster the circle is going the faster your heartbeat is.

the maximum heart rate of the user is defined by a simple rule: 220- age of the person. If the heart rate is higher than this value a red warning points gives you an alert on the wrist for calming down.

the feedback of the respiration is given on the abdomen with OLED light. The balls are fading away and come back on the rhythm of your breathing. The balls also move slowly through each other like oxygen particles.

Scenarios

the feedback of the respiration is given on the abdomen with OLED light. The balls are fading away and come back on the rhythm of your breathing. The balls also move slowly through each other like oxygen particles.

when the battery is connected you can connect the two press buttons between the top and the lower part. This action will also function as an on/off button. The line next to the zipper will light up, this is the warning that the suit is on the tablet is in range of the suit with a Bluetooth connection: max15m around you.
if the movement comes at an end the user has to stand in a end position for completing the measurements.

for turning of the suit the user have to open the press buttons. When the press buttons are disconnected there can’t be electricity in the suit

after turning the suit of you will be reminded by removing the press buttons about the battery. You have to disconnect the battery and take it out of the suit for different reasons such as washing of the clothing and recharging the battery.

after your tai chi training we can check the feedback on the tablet. You can share some information on a profile or just compare with your practices of before,…
17 Results

In this section, the results of the test we have done with the prototypes will be shown and discussed.

Communication Protocol

The computer running the PC application was connected to the Arduino using a USB-cable and several possible scenarios were tested. Figure 152 shows a screenshot of the command sequence run one time. This means that one measurement is done and one guidance packet is sent for both the LEDs and the VibeBoards. Figure y shows the responses of actuators to these command packages.

As Figures x and y show, the right packets are being sent from both sides, the data is received and interpreted in the right way and the Arduino responds to commands as expected. This means that the communication protocol is successfully implemented.
Position calculation

In Figure x, the prototype is held in various different positions and the 3D-model on the screen is shown to follow these positions. However, there does seem to be a slight offset to the angles, probably because of the fixed maximum LSB value (270) we used to determine g.

This result is good enough for a proof-of-concept, but in further applications a calibration should be added. This calibration could let the user hold their arms in a position where the z-axis of the accelerometer is turned up, measuring 1g, then in a position where the z-axis is pointed down to give the -1g value. The same should be done for the x- and y-axes. When enough samples are gathered for each axis, a 1g-offset for the each axis could be determined by taking the maximum LSB value. Dividing the measured LSB by this value to determine the pitch or roll would yield more accurate results.
Movement evaluation

For the verification of the movement evaluation we have made a dataset of the 3 movements by taking the average of the first 100 samples for each axis of 25 data captures. Each movement was then performed a total of 10 times and compared to the movement in the dataset. The results for the movement evaluation can be found in Table x, which shows how each of the new movements was classified.

Overall, the detection rate is sufficient, except for the second movement. What’s even more promising is that we had no false detection. We are certain that cross-correlation would work with some more work on the algorithm. For example, we suspect it would work better if we would scale the input vectors instead of cutting everything but the first 100 samples of. By scaling the entire signal would be taken into consideration and this should improve the accuracy.
Figure 151 Environment render 2
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