# FINAL DOCUMENTATION

## Adjustable Fixation for Hand and Lower Arm for High Resolution Computer-Tomography

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## Bachelor-Thesis an der Hochschule Luzern - Technik & Architektur

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|---|---|
| **Titel** | **Adjustable Fixation for Hand and Lower Arm for High Resolution Computer-Tomography** |
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**Abstract Deutsch**

Im Rahmen dieser Bachelor-Thesis wird für das Luzerner Kantonsspital eine Hand- und Unterarmfixation entwickelt. Die vorliegende Arbeit befasst sich mit der Entwicklung und der Herstellung eines ersten Prototyps.

Die Radiologie des Luzerner Kantonsspital ist im Besitz eines hochauflösenden Kegelstrahl Computer-Tomographen. Dieses Gerät ermöglicht die Bildgebung von kleinsten Brüchen und anatomischen Unstimmigkeiten. Eine Schwierigkeit bietet die Bewegung des aufzunehmenden Körperteils während der CT-Messung. Bewegungen verursachen Bewegungsartefakte, welche sich auf den Schnittbildern durch verschwommene Bildbereiche zeigen.

Da dieser Bildqualitätsverlust ein grosses Problem darstellt und es für Hände und Unterarme noch keine geeignete Fixation gibt, herrscht in diesem Gebiet Entwicklungspotential. In dieser Bachelor-Thesis wird ein mögliches Konzept für eine einstellbare Hand- und Unterarmfixation mit Positionsanzeige aufgezeigt und die Funktionsfähigkeit durch einen Prototyp bestätigt.

**Abstract Englisch**

In framework of this Bachelor thesis, a hand and lower arm fixation is being developed for the Lucerne Cantonal Hospital. This thesis deals with the development and production of a first prototype.

The radiology department of the Lucerne Cantonal Hospital owns a high-resolution cone beam computer tomograph. This device enables the imaging of smallest fractures and other anatomical defects. A difficulty is the movement of the body part, which should get imaged during the CT-scan. Movements cause movement artifacts, which appear on the cross-sectional images through blurred image areas.

Since this loss of image quality is a big problem and there is no suitable fixation for hands and lower arms yet, there is development potential in this area. In this Bachelor thesis a possible concept for an adjustable hand and lower arm fixation with position display is shown and the functionality is confirmed by a prototype.

Ort, Datum Horw, 05.06.2019

# Table of Content

# 1 Introduction

Computer-Tomography is a medical image procedure. Many X-ray measurements taken from different angles produce virtual slices, called cross-sectional images. The computed tomography scan allows the user to see inside of the body without cutting.

With the NewTom 5G cone beam CT of the Lucerne Cantonal Hospital it is possible to realize high-resolution images of various body parts. The concerned CT is an established device in pine surgery but is also used for extremities to examine bones, ligaments and compressed inner tissues.

The cone beam CT instrument with a spatial resolution of 0.1 mm is applied for hand and lower arm examinations, in this project as well. Major advantage of this instrument is that even small fractions or other anatomical defects can be imaged.

A challenge of this high-resolution imaging are the patient movements. For many patients it is almost impossible to keep their hands still during the measurement. Movement during measurement leads to a bad output of the CT-measurement. If the patient has move while measuring the reconstruction image is a superposition of several patient position. This can be seen on the blurred image areas. Because movement is the reason for this measurement failure, it is called movement artifact. Below are two images of a brain CT-scan. An example of a movement artifact is shown on figure [1].

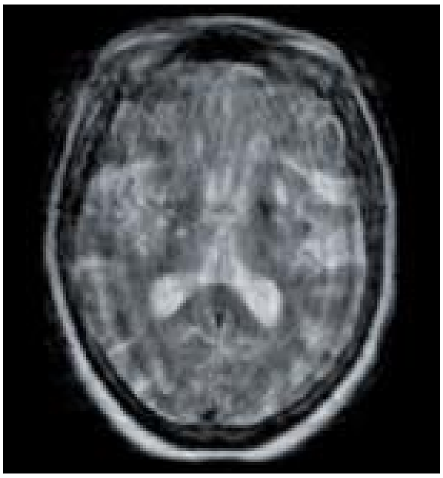


*Figure [1]: Movement artifact of a CT-image*

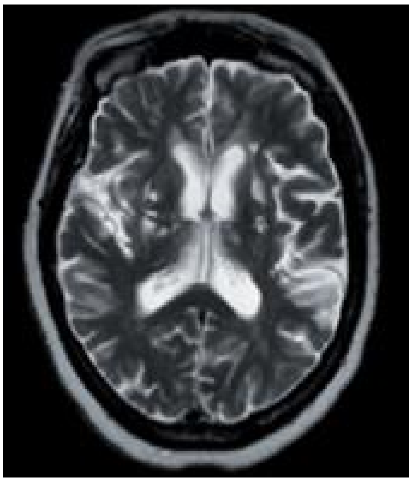


*Figure [2]: Reference image*

The blurred areas are visible on the entire image stack. This is not satisfactory and does not fully exploit the potential of the procedure. In comparison to an image without movement artifact, the loss of quality is made even clearer. The reference image with impeccable Quality and no movement artifact is shown on figure [2].

Of course, the goal of every CT-scan are images without movement artifacts. To achieve that goal, the Lucerne Cantonal Hospital needs an innovative Solution.

To prevent movement artifacts, the corresponding body part (hand and lower arm in this project framework) must not move during the measurement lasting approximately 30 s. The way to avoid movements is called immobilization in the technical terminology. There are already some immobilization devices on the market and in the Lucerne Cantonal Hospital, but a useful device to make high-quality measurements of hands and wrists does not exist.
As often hands and wrists are examined and no suitable fixation option is currently available, a solution to reduce movement artefacts is urgently required.

In framework of this project a fixation-prototype for hand and lower arm should get developed. The corresponding fixation must have some features to meet additional requirements.

The doctors of the Lucerne Cantonal Hospital demand that the fixation-prototype can be adjusted to different positions, e.g. to carry out a CT-scan of a stretched ligament.

In order to facilitate diagnosis, the taken angle must be detected and measured in each case. This angle should be visible on the image stack, afterwards. Due to this feature, the doctors always have the information in which positions the hand was during the CT-scan. This is important information for diagnosis.

Care must be taken that any used parts and components do not contain any metallic materials. Metals and other strongly absorbing structures absorb a lot of low-energy radiation. This is shown on the pictures by brightly shining structures and areas with signal losses.

> *"Metal artifact is one of the major problems in CT imaging, which comes from the fact that X-ray in the diagnostic energy range is strongly attenuated after passing through metal pieces, and much fewer signals are detected by the detectors in these regions."* (Safdari, Karimian, & Yazdchi, 2011)

An example of metal artifact in head region is shown on figure [3].

*Figure [3]: Metal artifact of a CT-image*

Due to this restriction on the choice of materials, it is assumed that plastic and wood are the main materials used.

The NewTom 5G cone beam CT instrument has a patient surface which can get adjusted in every three coordinate directions to move the desired body part to the iso center. The fixation-prototype must be able to get installed on this patient surface. Figure [4] shows the NewTom 5G cone beam CT and the corresponding patient surface.

*Figure [4]: New Tom 5G cone beam CT with patient surface*

The main goal of this project is a functioning prototype for a fixation device of hand, wrist and lower arm in the CT instrument. The prototype is intended for recording a single hand as well as both hands.

The project poses the following key questions:

- **Fixation of the patient:** As mostly injured patients are recorded a key challenge will be to maximize fixation while securing no pain for the patient.
- **Choice of material:** The selected materials must be applicable in the clinical environment. (i.e. low potential for allergies)
- **Position adjustment:** There must be a component or a tool to move the fixation in different directions.
- **Position measurement and display:** The images of the CT-scan must have information or attributes to recognize the position of the fixation to display the angle.
- **Installation on existing patient surface:** The fixation aid shall be able to be installed on the existing patient surface. In order to guarantee no waggle, the connection between fixation aid and patient surface must be rigid.

It is expected, that several mockups and prototypes will have to be produced. Each mockup and prototype will just meet one or a few requirements. In this way it is easier to test the corresponding functionalities and it is also easier to change something for a future test.

The following solutions are possibilities to meet the requirements.

- **Fixation of the patient:** A seal bag is filled up with Styrofoam balls. By vacuuming the bag, the Styrofoam balls cannot move anymore. As a result, the surrounding coating gets hard.
- **Choice of material:** A thin, comfortable, crack-proof, easy cleanable material like plastic, silicone or a cloth.
- **Position adjustment:** Two plates connected by a joint to move in different directions.
- **Position measurement and display:** A software finds the belonging attributes or characteristics and calculates the desired angle.
- **Installation on existing patient surface:** A clamp to put or pull on the patient surface.

# 2 Materials and Methods

This chapter lists the most important requirements and their specifications. The specifications get implemented in the prototyping phase and validated during testing.

## 2.1 Research

This chapter shows which insights were gained from the research.

### 2.1.1 Fixation of the patient

The research in this area showed that the Swiss company Pearl Technology AG from Schlieren has already developed and manufactured excellent products that can be used in this project.

Products of this company (Pearl Technology AG) are used in various scientific publications and are always described as very helpful.

> *"Image quality is affected by too much head motion. Therefore, head motion in cranial–caudal direction has to be limited to a range of 2 mm over a period of three seconds, i.e. over a period required for a complete functional scan of the head. Head motion up to this value can be corrected by the motion correction algorithm of the Matlab toolbox SPM (statistical parametric mapping). In several pre-studies, different versions of fixations were tested with respect to comfort, ease of use and effectiveness of head motion suppression. Shoulder belts, a vacuum pillow placed at the back, a custom-made rigid hip fixation, and a custom-made head bowl in combination with the Crania fixation (Pearltec AG, Zurich, Switzerland) were rated as most successful and, thus, applied during fMRI measurements. The Crania fixation is an inflatable ring that is placed between the head and the head coil. Subjects can regulate the pressure via a small pump, similar to those used for blood pressure measurements. Subjects are asked to use as much pressure as possible without compromising comfort."*
> (Hollnagel, et al., 2011)

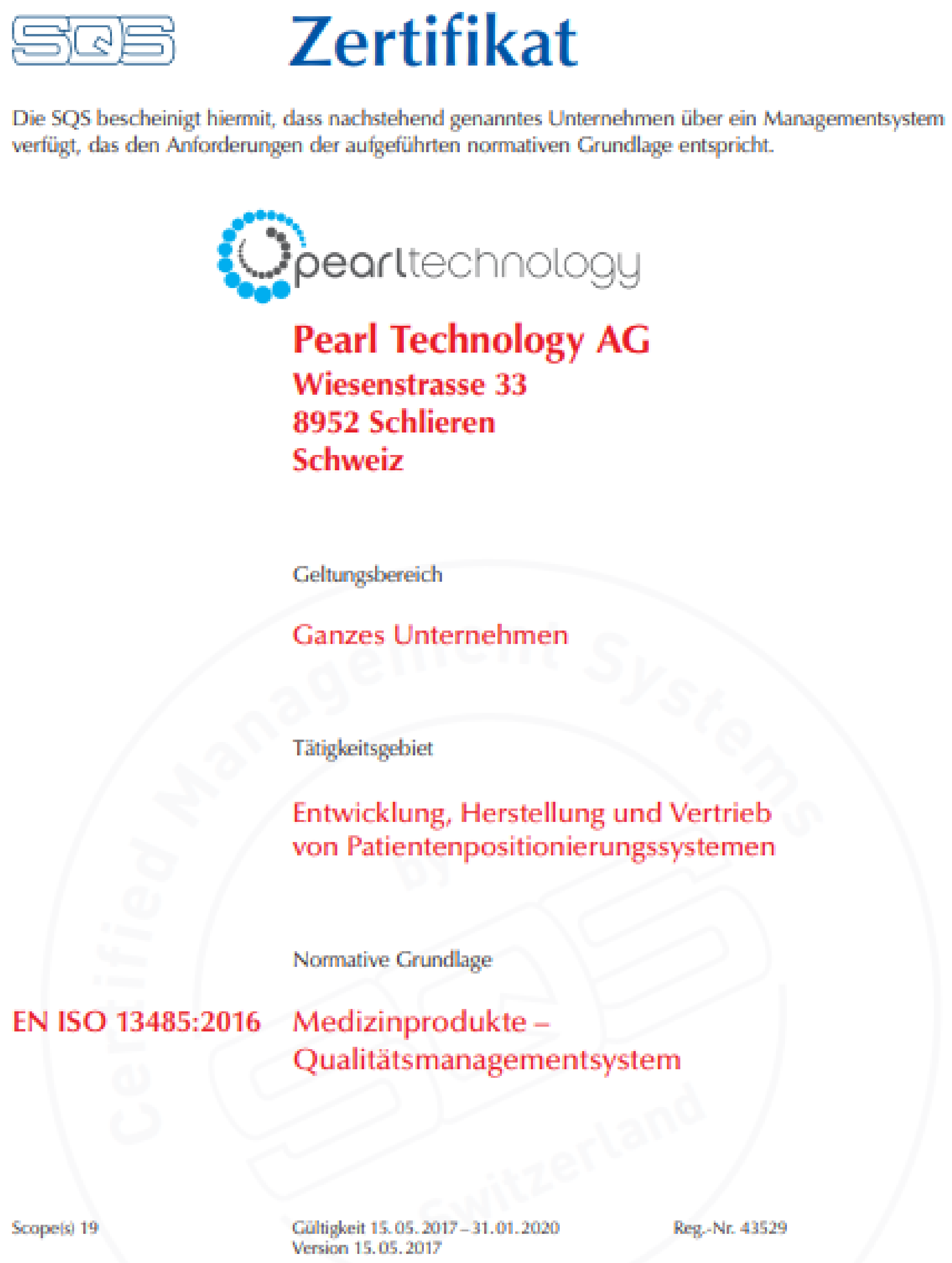
The company Pearl Technology AG holds the EN ISO 13458 certificate (medical device quality management standard), which states that the regulatory requirements in development and manufacture are met. There are also CE declarations of conformity which confirm that the requirements have been met. The EN ISO 13485 certificate is shown on figure [6] on the next page.

### 2.1.2 Choice of material

The material research also showed that the company Peal Technology AG only uses materials that meet regulatory requirements for products and components. The corresponding EN ISO 13485 Certificate is shown on figure [6] on the next page. On figure [5] material examples can be seen.

| | |
|---|---|
| **Intended use** | Universal Patient Positioning Aid |
| **Directives & classification** | CE according to MDD – Directive 93/42/ECC<br>Class 1 product |
| **Applied quality assurance** | SN EN ISO 13485:2016 |
| **Instructions for use** | Enclosed to the product |
| **Restrictions of use** | Do not use the product for purposes other than those described. |
| **General safety notes** | Non sterile. Do not sterilize.<br>Caution: Federal law restricts this device to sale by or on the order of a licensed health-care professional (Rx only). |
| **MR safety note** | MR Safe |
| **Materials** | **Material** – **Component**<br>TPU – foils<br>EPS – pearls white<br>EPP – foam Tilt15<br>PET – membrane<br>LDPE – packaging |
| **Marking** | CE |

*Figure [5]: Material example and information*



SQS **Zertifikat**

Die SQS bescheinigt hiermit, dass nachstehend genanntes Unternehmen über ein Managementsystem verfügt, das den Anforderungen der aufgeführten normativen Grundlage entspricht.

pearltechnology

**Pearl Technology AG**
**Wiesenstrasse 33**
**8952 Schlieren**
**Schweiz**

Geltungsbereich

Ganzes Unternehmen

Tätigkeitsgebiet

Entwicklung, Herstellung und Vertrieb von Patientenpositionierungssystemen

Normative Grundlage

EN ISO 13485:2016 Medizinprodukte – Qualitätsmanagementsystem

Scope(s) 19 Gültigkeit 15.05.2017 – 31.01.2020 Version 15.05.2017 Reg.-Nr. 43529

*Figure [6]: EN ISO 13485 certificate Pearl Technology AG*

### 2.1.3 Position measurement and display

During the research for position measurement and display it turned out that there are still no established methods to determine the hand position from a CT image.

The extension of the search resulted in a potential software solution. Emgu CV is a cross platform .Net wrapper to the OpenCV image processing library. There is an example code in C#, called “edge detection”. With this it is possible to detect lines, circles, triangles and rectangles. Due to these possibilities this example already contains functions that can be modified and used for this project.

## 2.2 Requirements-Engineering

This chapter contains tables, which point the requirements and specifications of each fixation-prototype component.

### 2.2.1 Fixation of the patient

The fixation requirements and specifications are listed in table [1] and table [2] below.

| ID number | Requirement |
|---|---|
| R 1 | Fix hand during measurement of approximately 30 s |
| R 2 | May not cause any pain during the whole time |
| R 3 | Possibility for one- and two-handed fixation |
| R 4 | Possibility for several hand position |
| R 5 | Lower arms must be supported |
| R 6 | Have an angle of 8-10° in the initial position (fingers are parallel to the horizontal plane) |

*Table [1]: Fixation requirements*

| ID number | Specification |
|---|---|
| S 1.1 | Fix hand with Velcro fastening |
| S 1.2 | Fix hand with a Styrofoam filled case |
| S 1.3 | Fix hand with a flexible strongly tensioned strap |
| S 2.1 | Use soft materials |
| S 2.2 | Regulate fixing pressure |
| S 3.1 | Design sufficiently large dimensions |
| S 4.1 | Use soft materials |
| S 4.2 | Use a large area instead of areas with predetermined shapes |
| S 5 | Built a lower arm support with arm splints |
| S 6 | Construct and built a hand support with an angle of 8-10° |

*Table [2]: Fixation specifications*

### 2.2.2 Choice of material

The material requirements and specifications of each component are listed in the table below.

| ID number | Requirement |
|---|---|
| R 7 | Must not contain any metal |
| R 8 | Easy to clean |
| R 9 | Easy to disinfect |
| R 10 | Low potential for allergies |
| | *only for the fixation part with skin contact* |
| R 11 | Soft and flexible to take on the shape of a hand |

*Table [3]: Material requirements*

| ID number | Specification |
|---|---|
| S 7 | No use of metallic materials such as screws, nails, electric wires, etc. |
| S 8.1 | General materials with smooth surface |
| S 8.2 | Plastic |
| S 8.3 | Lacquered wood |
| S 9.1 | General materials with smooth surface and ethylene oxide-resistant protective layer |
| S 9.2 | Plastic with ethylene oxide-resistant protective layer |
| S 9.3 | Lacquered wood with ethylene oxide-resistant protective layer |
| S 10.1 | Plastic |
| S 10.2 | Lacquered wood |
| S 11.1 | Tissue-equivalent material (bolus from Qfix) |
| S 11.2 | Thermoplastic Polyurethane (TPU) |
| S 11.3 | Low Density Polyethylen (LDPE) |

*Table [4]: Material specifications*

### 2.2.3 Position adjustment

The position adjustment requirements and specifications are listed in the table below.

| ID number | Requirement |
|---|---|
| R 12 | Allow the hands to assume different angular positions |
| R 13 | Freedom of movement around yaw and roll axis |
| R 14 | Lock in adjusted position |

*Table [5]: Position adjustment requirements*

| ID number | Specification |
|---|---|
| S 12.1 | Joint connection |
| S 12.2 | Soft underlay |
| S 13.1 | Ball joint |
| S 13.2 | Free mounted hinge joint |
| S 14.1 | Pressure on movable joint part |
| S 14.1.1 | Press upper and lower half together with screws |
| S 14.1.2 | Press upper and lower part together with threat connection |

*Table [6]: Position adjustment specifications*

### 2.2.4 Position measurement and display

The position measurement and display requirements and specifications are listed in the table below.

| ID number | Requirement |
|---|---|
| R 15 | Measure position/angle by CT-images |
| R 16 | Object with measurement characteristic must be in iso center |
| R 17 | Display angle on one or more images |
| R 18 | Include image with position information in original image stack |

*Table [7]: Position measurement and display requirements*

| ID number | Specification |
|---|---|
| S 15.1 | Joint features to detect position on cross-sectional images |
| S 15.1.1 | Movable part with ball in bowl - ball follows gravity |
| S 15.1.2 | Extend (down) axis of movable joint part |
| S 15.2 | Search correct lines on CT-image |
| S 15.3 | Angle sensor |
| S 16 | Max. distance from wrist to characteristic point 5 cm |
| S 17 | Print the measured angle as text on the original image |
| S 18 | Save the edited image in folder path of image stack |

*Table [8]: Position measurement and display specifications*

### 2.2.5 Installation on existing patient surface

The installation requirements and specifications are listed in the table below.

| ID number | Requirement |
|---|---|
| R 19 | Whole fixation prototype must be able to be attached to patient surface |
| R 20 | Rigidly connection without waggle |

*Table [9]: Installation requirements*

| ID number | Specification |
|---|---|
| S 19 | Connection which can pulled over the patient surface |
| S 20 | Exact reconstruction of all dimensions |

*Table [10]: Installation specifications*

## 2.3 Prototyping

This chapter describes the different possibilities, which got developed to meet the requirements.

### 2.3.1 Fixation of the patient

The Fixation of the patient is split in three subareas; fixation, hand support and lower arm support.

**Fixation**

The fixation is the immobilizing part of the prototype. In order to achieve the requirements of a painless but rigid fixation, a customized fixation was produced together with Pearl Technology AG, because of the professional impression from the research.

Based on the requirements, the fixation was designed in the CAD program. Figure [7] shows the basic dimensions in mm. On the CAD drawing the fixation is unfolded. Therefore, both halves (left = bottom, right = top) are the same size. In the middle 20 mm are included for folding. The two drawn circles are for membranes, which allow the exchange of air, but not water and other liquids.

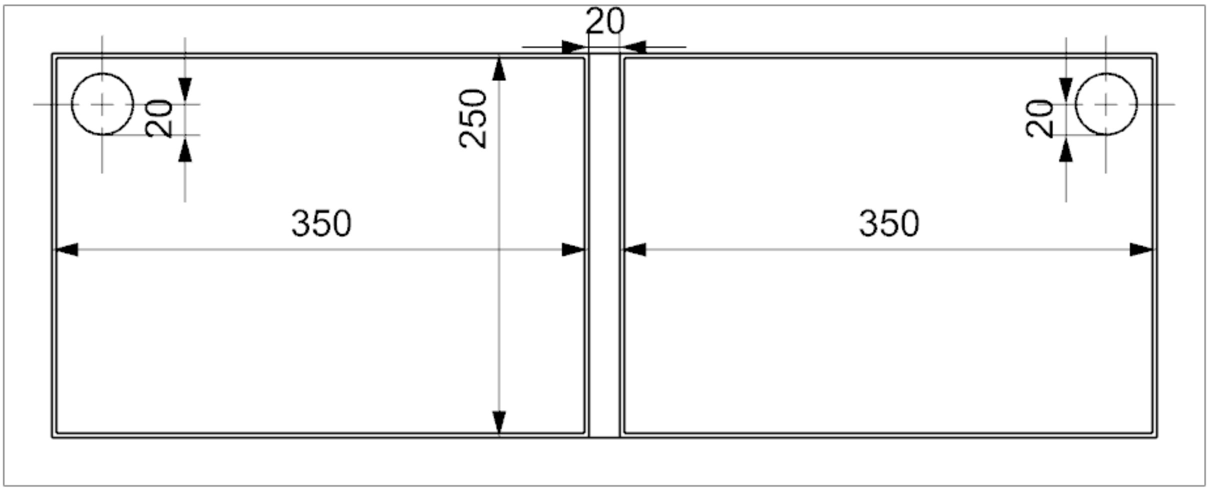



*Figure [7]: Fixation basic dimensions*

The width was designed that both hands can be placed spread apart next to each other. The corresponding measuring position is the measure position with the largest space requirement and shown on figure [8].

*Figure [8]: Measuring position with the largest space requirement*

The side view of the CAD drawing of fixation is visible on figure [9]. The different lines represent the corresponding foils. Between the foils are different thick volumes, which are filled with EPS balls (white, 1 mm diameter) or air. EPS (Expanded polystyrene) is a rigid and tough, closed-cell foam. On the left side (bottom when folded) the thickness is only 10 mm because it is important to stay with the position adjustment in the iso center of 50 mm. On the right side (top when folded) the chamber with the EPS balls is 20 mm thick to increase the comfort. A PV tube with a Carmo angle connection 90° is connected to the air chamber. On this PV tube a hand pump with gauge is installed. With the hand pump the air chamber is inflated with air to best fix the patient.

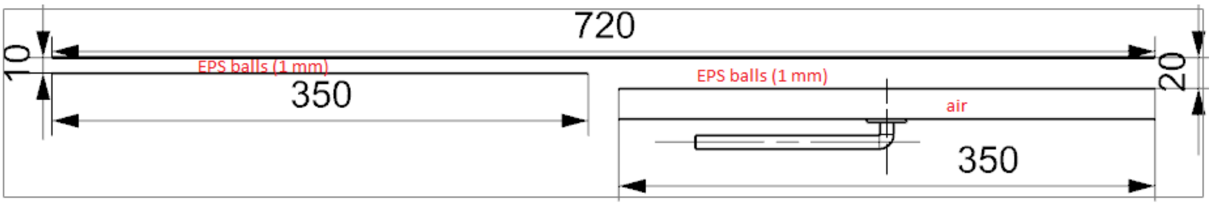



*Figure [9]: Fixation side view*

The hand pump with gauge is shown on figure [10]. The detailed view of the gauge with a range from 1 to 8 is placed next to it on figure [11].


*Figure [10]: Hand pump with gauge*

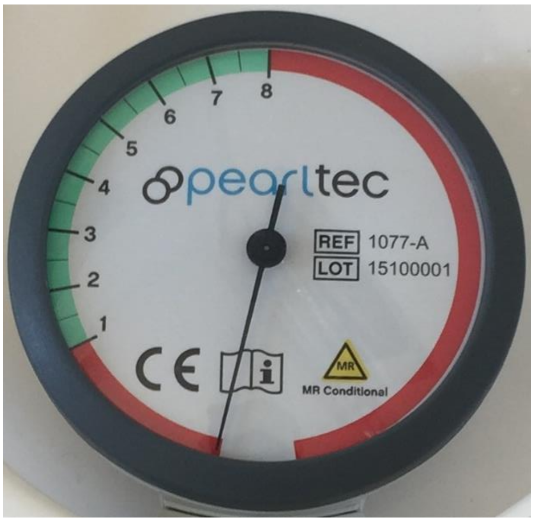



*Figure [11]: Detailed view of the gauge*

In order to find out which pressure level is best for most people, a little study was carried out to determine the ideal pressure level. Ten test persons were asked to report when they could clearly feel the pulse in their hands. According to Pearl Technology AG, this pressure should not be exceeded during the measurement.

The result of this study is shown on figure [12] on the next page.

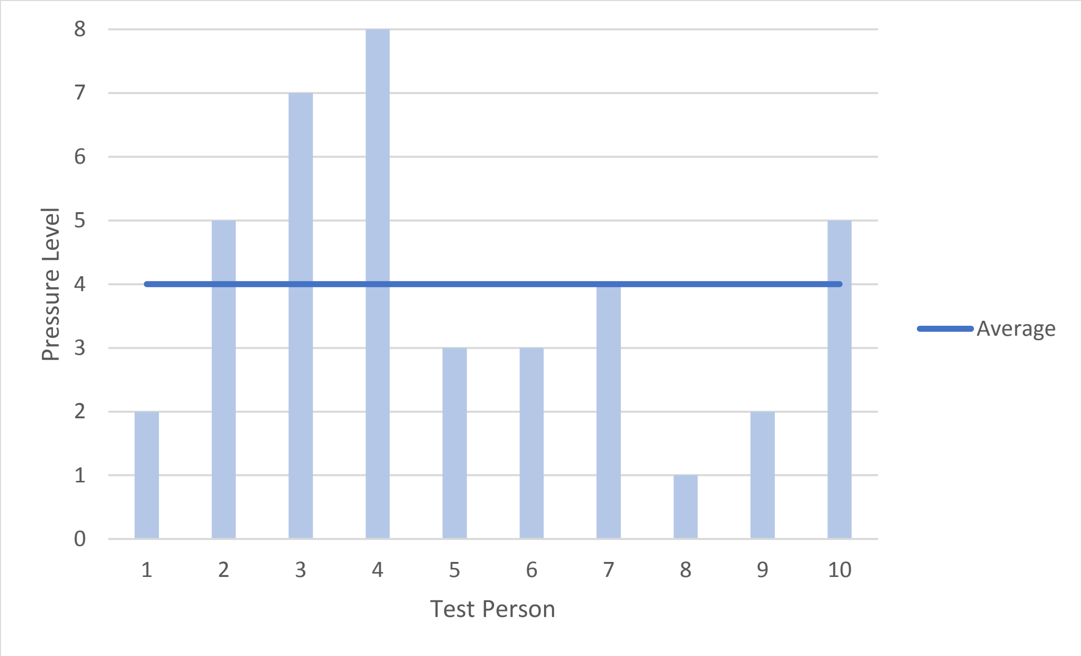



*Figure [12]: Pressure level study result*

It can be seen, that the pressure levels of the test persons differ greatly from each other. The calculated mean value is 4. For a firm but also pleasant fixation this is an impeccable guide value. But there are several test persons who have already felt the pulse in their hands before this level.

It is therefore recommended that the pressure is usually set to level 4. If a patient feels the pulse in his hands before, it is important to stop the inflation process and minimize the pressure to the next lower level.

### Hand support

The hand rest was also designed according to the requirements in the CAD program. Figure [13] shows the hand rest with the dimensions viewed from below.

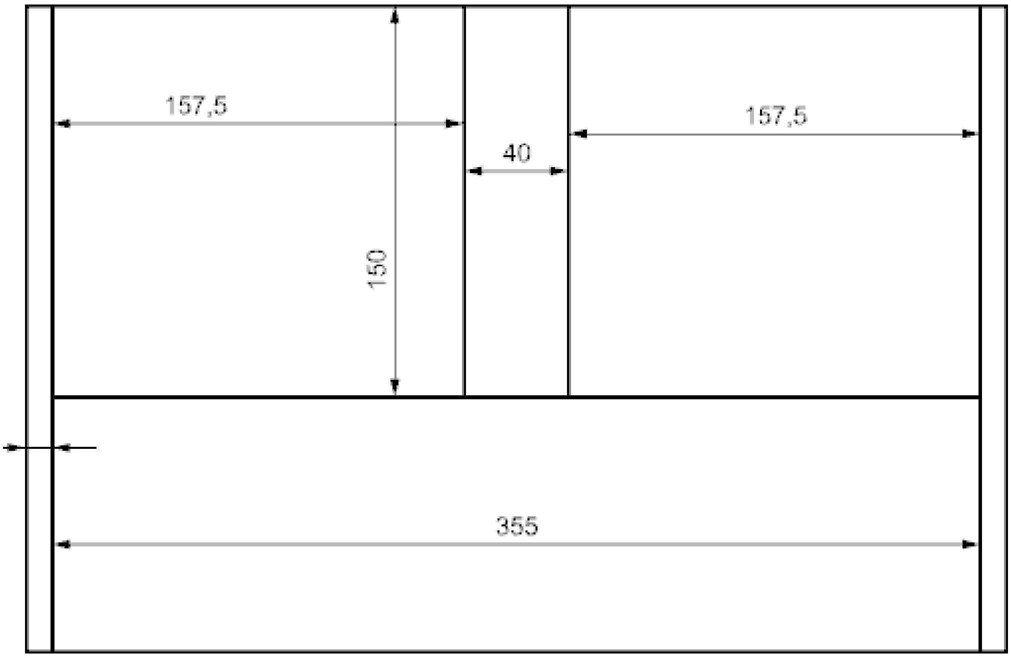



*Figure [13]: Hand support dimensions*

The surface of the hand support must be slightly larger than the fixation. This allows the fixation to be easily installed on the intended surface. The small area in the middle (150 mm x 40 mm) should be recessed by 2 mm. At this point the connecting piece is mounted and the recess should prevent lateral slipping, especially when gluing.

The connectors are located at the intended place hand support and on the top of the position adjustment. The T-connection is shown in figure [14] and figure [15]. The two parts can be pushed into each other.


*Figure [14]: T-connection of the Fixation*

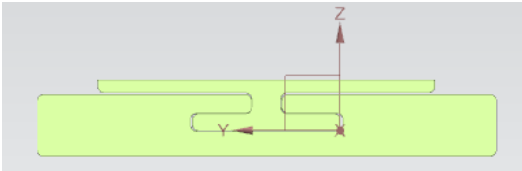



*Figure [15]: Cross-section of the T-connection*

One requirement is that the fixation must have an angle of 8°-10°. This is guaranteed with the hand support. The surface on which the fixation is installed is angled at 8° to the horizontal plane.

This can be seen more precisely on the CAD 3D image of the hand support on figure [16] and on the CAD cross-section on figure [17].

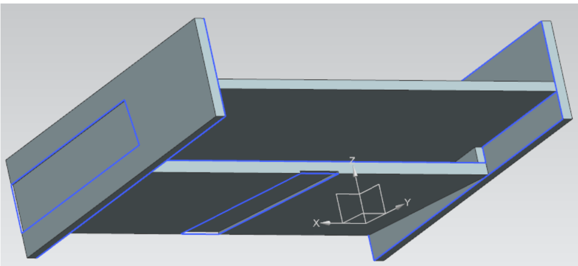


*Figure [16]: CAD 3D image of hand support*

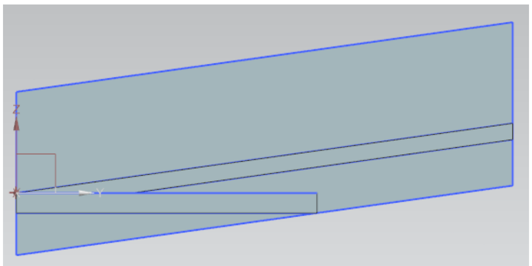


*Figure [17]: CAD cross-section image of hand support*

Micro Velcro is mounted on both sides of the hand support. A fleece, which adheres to the micro Velcro, can then be stretched over the fixation during usage. This fleece creates the initial pressure on the hand and holds against it when inflating the fixation.

### Lower Arm Support

In order to relieve the patient's musculature and weight on the fixation, the lower arms must be able to be supported. For this purpose, two splints have been designed which will fit most patients with these dimensions. One of the splints is shown as a CAD image in figure [18] and figure [19] shows the corresponding cross-section with the dimensions.

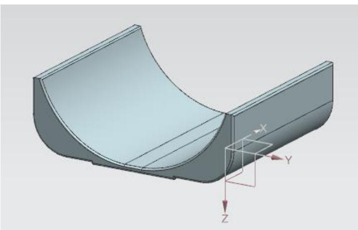


*Figure [18]: CAD image of the lower arm support*

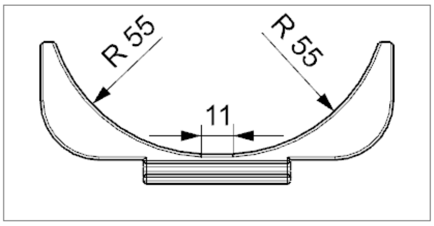



*Figure [19]: Cross-section with dimensions of lower arm support*

The two lower arm supports are connected again with a T-connecter on a post. This allows the splints to be moved sideways or even removed. The T-connection system is the same as between hand support and positions adjustment.

### 2.3.2 Choice of material

The following table shows which components were realized with which materials. The most important aspect of any material is that it does not contain metals. As shown in table [11], all materials are therefore plastic and wood.

Wood was chosen for price reasons and because it is an easily machinable raw material. It contains no metal and can be glued very strongly with white glue. Therefore, no metallic objects, like metal screws, are necessary for the connection. Wood meets the requirements and can be used for a prototype. For a final product, plastic is recommended, especially for weight reasons.

| Main component | Partial component | Material |
|---|---|---|
| Fixation | Foil | TPU - Thermoplastic polyurethane |
| | Tube | TPU - Thermoplastic polyurethane |
| | Hose clamp | PP - Polypropylene |
| | Pump ball | PVC - Polyvinyl chloride |
| | Valve body | LDPE - Low-density polyethylene |
| | Valve lid | PP - Polypropylene |
| | Valve sealing element | TPE - Thermoplastic elastomers |
| | Pearls | EPS - Expanded polystyrene |
| Hand support | Lacquered wood | MDF - Medium-density fiberboard (wood) |
| Lower Arm Support | Splints | PLA - Polylactic acid |
| | Post | MDF - Medium-density fiberboard (wood) |
| Connection | T-connection parts | PLA - Polylactic acid |
| | Plastic screw | PE - Polyethylene |
| | Glue | Callano A 1970 |
| Position adjustment | Ball joint | PC/ABS - Polycarbonate/Acrylonitrile Butadiene Styrene |
| Installation | Installation board | MDF - Medium-density fiberboard (wood) |

*Table [11]: Material list*

### 2.3.3 Position adjustment

Position adjustment involves choosing different measuring positions for the hand or hands, depending on the patient and the injury, in order to make the best diagnosis possible.

In order to guarantee all required degrees of freedom of movement, a ball joint is a possible option. The difficulty is locking the ball joint. Two concepts have been developed to meet these requirements.

#### Screw lock with plate feature

The basic idea is to separate the socket of the ball joint into two halves. These two halves can be pulled together with plastic screws and thus lock the ball by the pressure. The screw holes are shown in figure [20] on the next page. This lock system works in any ball joint position.

Furthermore, it is possible with this system to lock only one axis. When the ball joint is in the initial position, two plates can be pushed up to the groove of the sphere. These plates prevent the roll and pitch movement and the ball joint can only be moved in the yaw direction.

The concept is illustrated in figure [20], figure [21], figure [22] and figure [23] on the next page.

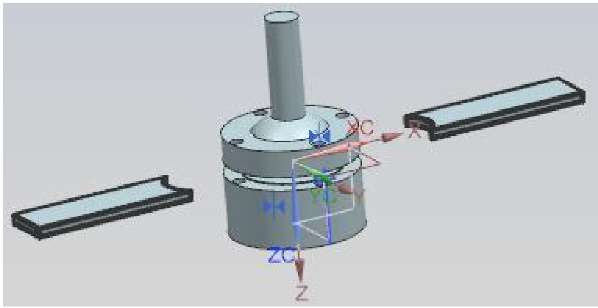


*Figure [20]: Screw and disk lock system unlocked*

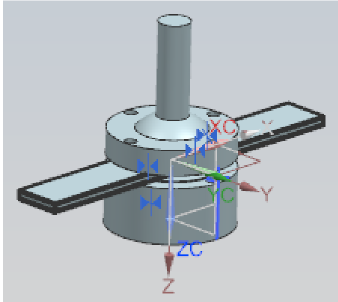


*Figure [21]: Screw and disk lock system locked*

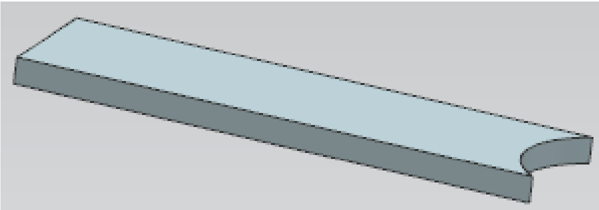


*Figure [22]: Plate detailed view*

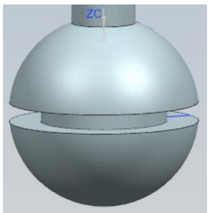


*Figure [23]: Sphere with groove detailed view*

### Threat lock

The basic idea of this system is again that the socket of the ball joint is separated into two halves and firmly pressed together for locking. With this system, no further parts shall be used.

To press the two halves together without further parts, the two parts must be connected and the distance between the parts must be adjustable. The easiest way to do this is with a thread. The upper socket part has an internal thread and the outer socket part has an external thread. This way the upper part of the socket can be adjusted upwards or downwards by screwing it in or out. If the upper part of the socket is screwed down further and further, the ball gets locked between the two halves.

The figure [24] shows the completely disengaged system with thread locking. Figure [25] shows a cross-section of the screwed but not locked system.

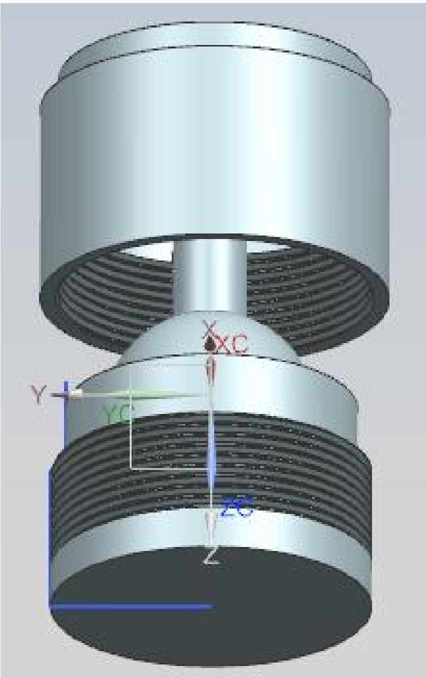


*Figure [24]: Threat lock system*

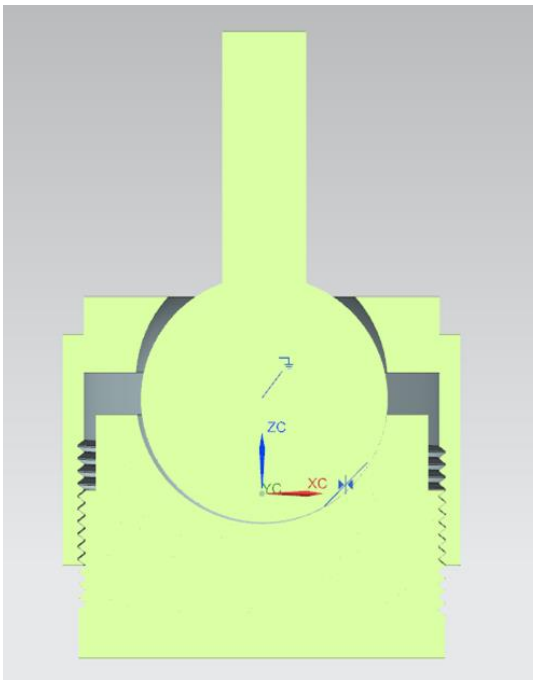


*Figure [25]: Cross-section of the threat lock system*

### 2.3.4 Position measurement and display

The position measurement and display is intended to provide the diagnosing persons with further information. It is a great advantage if the hand angle used for the CT-scan is still visible on a CT image stack.

Due to these requirements, the characteristic with which the angle is measured must be visible on the image stack. No recorded sensor values may be used as an angle value, since these values are then not contained in the image stack.

In order to recognize the characteristic of the angle on the image stack, various adaptations to the hardware were developed. The developed concepts will be explained in the next subtitles.

#### Pillar reference points

The system with the pillar reference points is based on an extension of the sphere axis downward. This extension always runs in opposite direction to the upper part of the ball, where the hand is, during use. Figure [26] shows a 3D image from the CAD program. The extension of the sphere axis, with arrow at the bottom for the yaw determination, and the three reference pillars with different diameters are visible in this figure. Figure [27] shows how the cross-sectional view could look after a CT-scan, in theory.

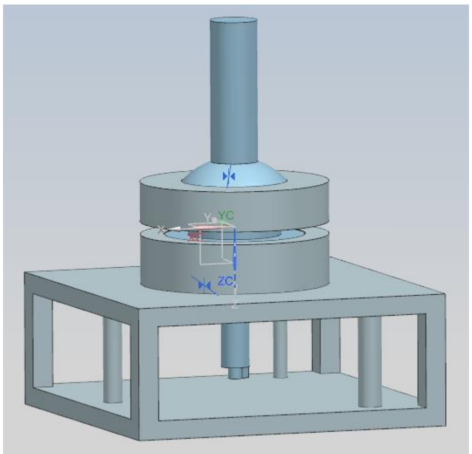


*Figure [26]: CAD 3D image of system with pillar reference points*

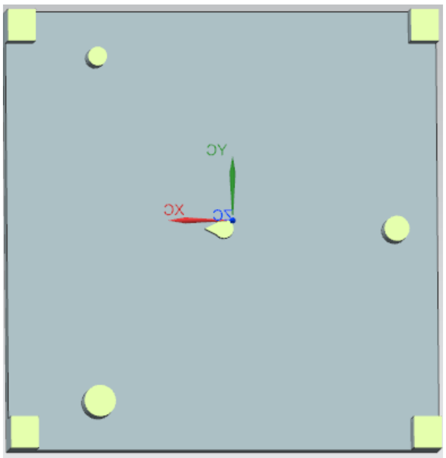


*Figure [27]: CAD cross-section of the pillar system*

A CT-scan of the produced prototype showed that the sectional images look as assumed. An example of cross-sectional image is shown on figure [28]. In order to calculate the angle, the position of the axis extension must first be determined. This is achieved by measuring the distances from the extension point to the pillars. Each point of the extension in this plane corresponds to an unambiguous angle of the sphere in the ball joint. Figure [29] shows the distances to be measured.

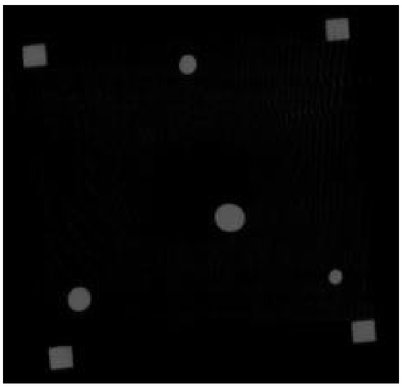


*Figure [28]: CT cross-section image*

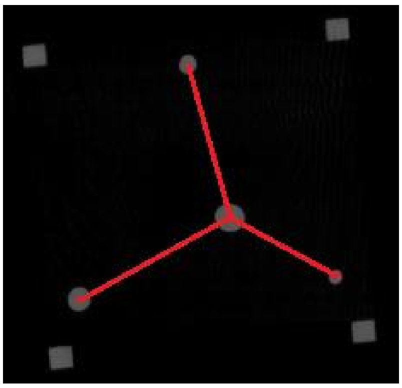


*Figure [29]: The distances to be measured*

This position measuring system has two main problems.
The first problem is that when the sphere is in an oblique position, the position of the extension axis cross-section in the plane changes when sectional images of a different height are viewed.
The second problem is that the area with the characteristics for position measurement is far away from the top of the sphere (where the hand is positioned). Because the crosshairs of the iso center are always set on the hand, the axis extension and the pillars should be a maximum of 50 mm further down to remain in the iso center. Otherwise the characteristic for the position measurement is not contained on the image stack at all.

### Bowl with ball

In order to stay closer to the isocenter with the range of position measurement characteristic, another system has been developed.

The basic idea of the bowl with ball is to place a hollow body just below the hand in which a ball roll around. This is shown in the cross-sectional view on the figure [30].

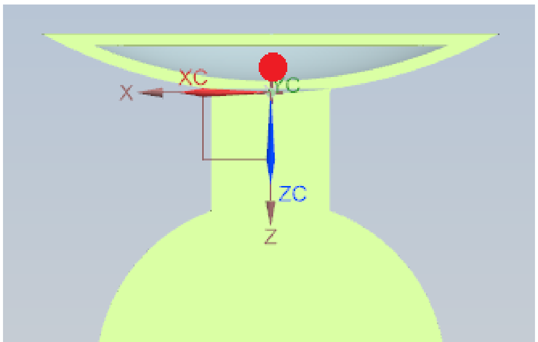


*Figure [30]: Bowl with ball cross-sectional view*

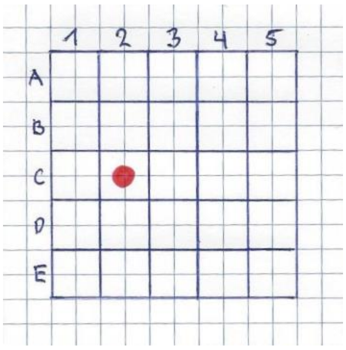


*Figure [31]: Coordinate system with ball position*

Due to gravity, the ball is always at the lowest point of the bowl.  The surface under the ball moves with the hand position. A coordinate system can be placed on the area. Depending on the measuring position, the ball is located at different points in the coordinate system, shown on figure [31]. A table can be created that assigns an angle to each coordinate point.

The problem with this system is that it is difficult to find the ball and the surface on a cross-sectional image. Since the cross-sectional image is in the horizontal plane but the bowl is curved, the whole coordinate system will never be visible.
If the sectional view with the largest ball radius is selected, the coordinate point where the ball is located is also not visible, because the sectional view with the largest ball diameter is exactly the radius length away from the ground.

### Sphere axis extension with hollow cylinder

A further developed method does not contain any additional components. Only a cylindrical cavity was created in the extension of the sphere axis. This is shown on figure [32].

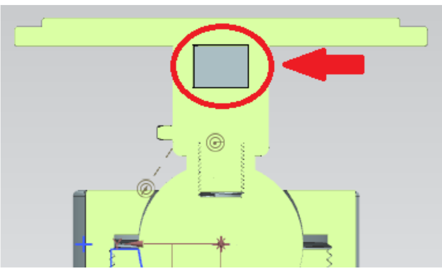


*Figure [32]: Extension with cylindrical cavity*

Viewed as a sectional image, a cylinder shows a circle. When the joint is tilted (roll rotation), the circle changes to an ellipse when the extension is viewed as a cross-sectional image from the vertical. Figure [33] illustrates this theory and shows how the tilt angle can be calculated.

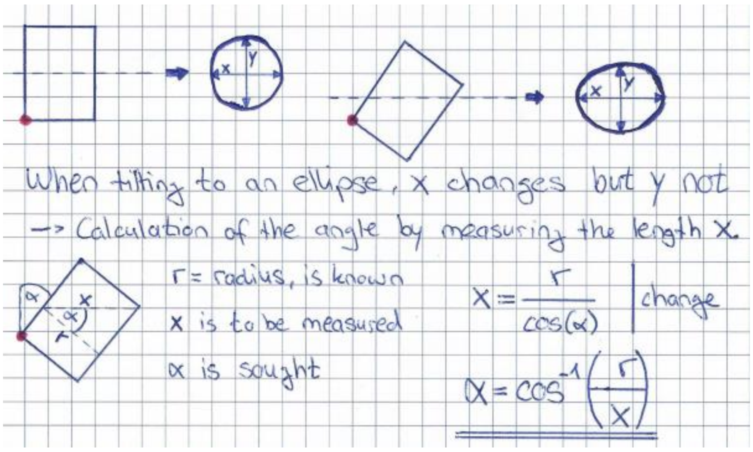



*Figure [33]: Angle calculation*

The problem with this method is that the yaw rotation cannot be determined.

Another problematic is that the cosine near 0 changes strongly with small deviations. This would probably result large measurement faults if a CT-scan close to the initial position is carried out.

### Sphere axis extension with hollow three-sided prism

This last method was developed to determine the yaw rotation as well. The method is very similar to the Sphere axis extension with hollow cylinder method. Here a prism cavity is created.

As can be seen in the cross-sectional images of figure [34], the base side changes when tilted. The height of the triangle remains the same. Thus, an angle can be deduced with a ratio calculation.

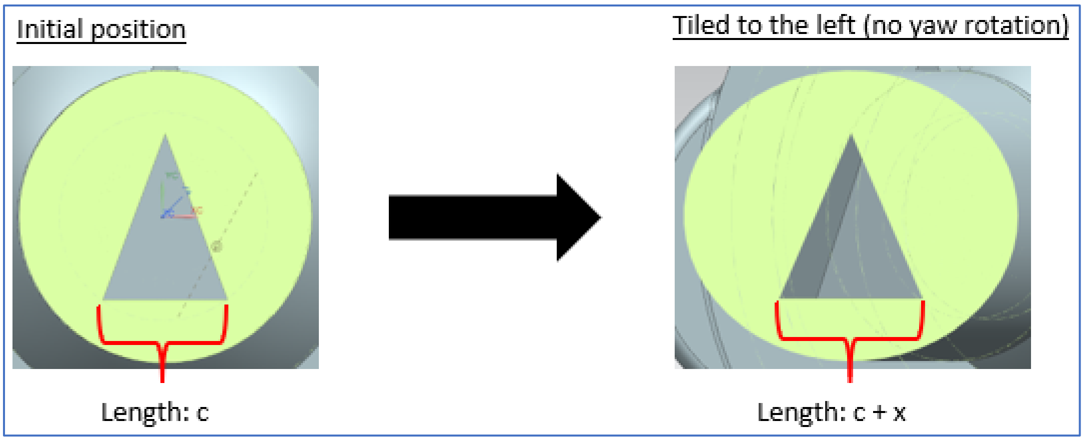



*Figure [34]: Change of the triangle base side*

The yaw rotation can be calculated by comparing the coordinates of the front corner point to a vertical.

The only problem of this method is that the change of the base side c is going to be very small. In this case, no exact ratio change can be calculated and thus no exact angle.

### Software

To measure the angle, the images with the angle characteristics, explained in the previous subchapters, must pass through a software. This software is described in this subchapter.

The code example “Edge Detection” from Emgu CV was used as the basis. Emgu CV is a cross platform .net wrapper to the OpenCV image processing library. While programming and adapting the sample code it was noticed that it is much easier to detect only lines instead of whole areas and shapes.

Figure [35] and figure [36] show which images must be used for which angle. The red marked areas must be visible on the picture in any case.


*Figure [35]: Defined image for yaw rotation*

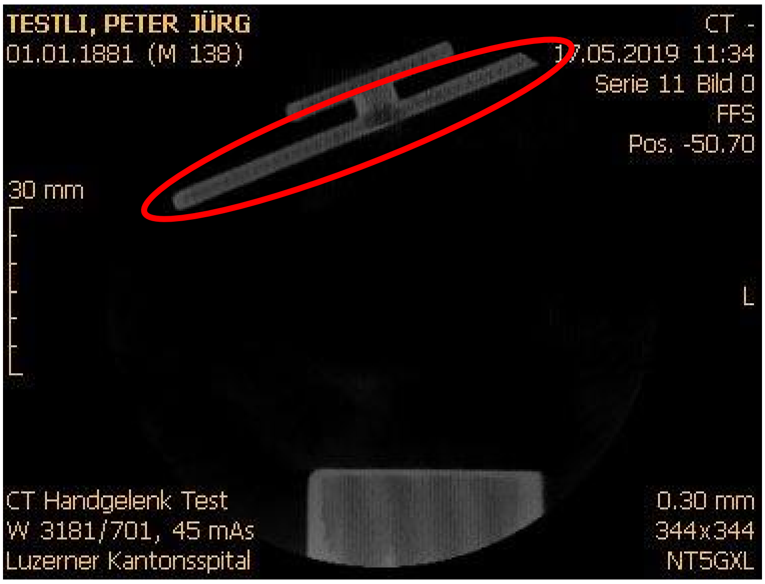
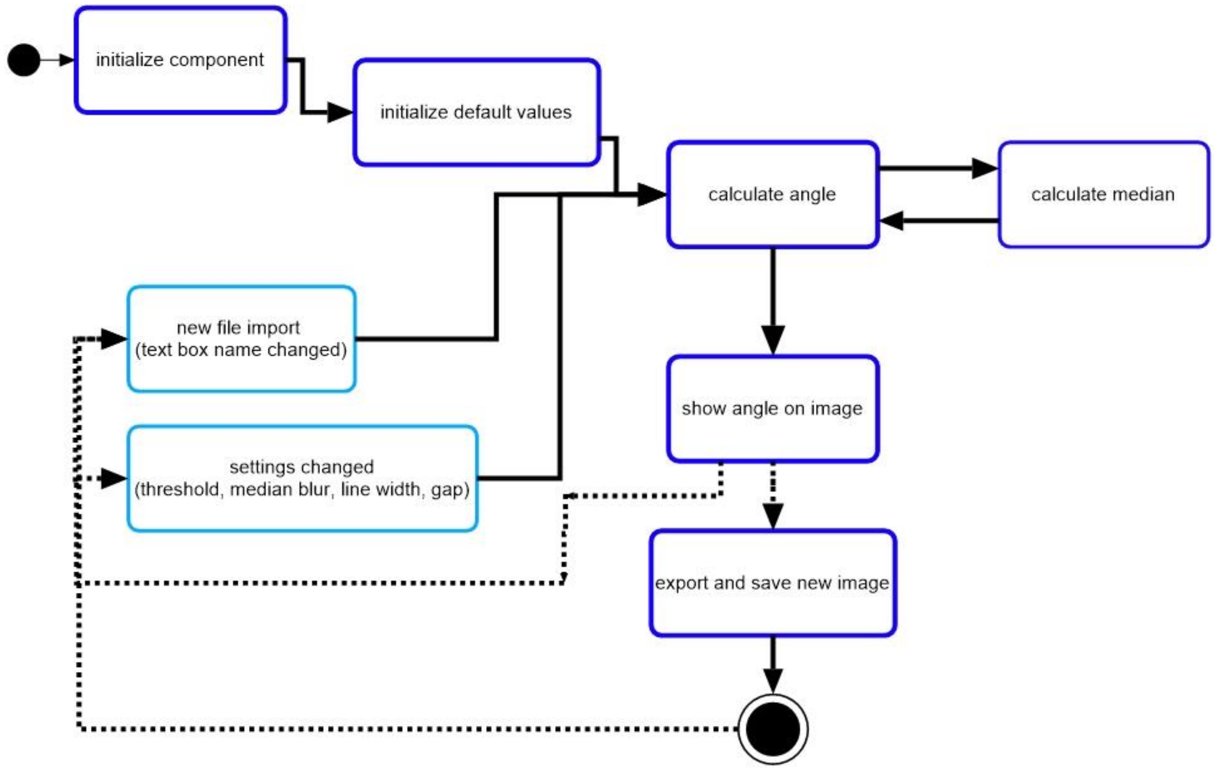



*Figure [36]: Defined image for roll rotation*

The software code is completely contained in the attachment and described with comment lines. The following UML diagram on the next page shows the general procedure how the software runs through the main functions.




The paths and boxes on the UML diagram are designed with different lines and colors. The continuous lines represent paths that are inevitably run through. This means that when the program is executed, an angle is surely calculated and displayed. The export and storage process then depend on the user. It also depends on the user whether he changes settings or imports a new file. If this is done, a new calculation process is always triggered, and the angle is displayed on the corresponding image.

The settings that can be made serve to help the system find the best lines. A total of five variables can be set. These are:

- **Threshold 1 and 2** to set the values for hysteresis.
- **Median Blur filter** to blur unwanted structures. The higher the value, the fewer structures are recognizable and the blurrier is the image.
- **Min line width** to define the shortest allowed line. This way small lines can be hidden. These lines are not considered in the calculation.
- **Max gap** to define the maximum distance between lines. The higher this value, the more lines are considered, because connections between lines are found on the image.

These variables have a default setting, which is always the same at the beginning (initialize components). The values for the default setting have been shown to be the best by various tests over several images. In most cases, therefore, no more changes need to be made.

The main part of the software is the angle calculation. After the matching lines have been detected, the angle of these lines to a horizontal plane is calculated. Due to the limitation of the roll rotation (tilt movement) by the ball joint, it is always possible to clearly determine whether it is the yaw rotation angle or the roll rotation angle. These lines are marked with different colors, if they were recognized as yaw rotation angle or roll rotation angle.
**Important: To measure both angles (yaw and roll), images from two different views must be imported one after the other.** Figure [35] and figure [36] on page 20 show the two required views.

The last step was to create an execution file which containing the software code with all functions.

### 2.3.5 Installation on existing patient surface

The entire fixation prototype must be able to be mounted on the existing patient support surface.

A head fixation of the Lucerne Cantonal Hospital has a clamp for installation. This clamp has the following dimensions, which can be seen on figure [37].

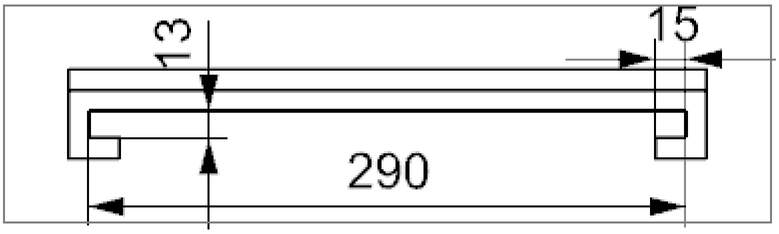



*Figure [37]: Dimensions of the clamp*

Because the head fixation on the surface is holding very well, it was decided to use the same dimensions for this project and this prototype. The only difference is that in this project the clamp is made of wood and not plastic. (see material list on page 15)
Four holes were drilled on the surface to screw the position adjustment to the installation.

## 2.4 Testing

In this chapter the developed concepts and products are compared with the requirements. In each case it is described with which specification the requirement was met.

| ID number | Fulfilled | By specifications |
|---|---|---|
| R 1 | ✓ | S 1.2, S 1.3 |
| R 2 | ✓ | S 2.1, S 2.2 |
| R 3 | ✓ | S 3.1 |
| R 4 | ✓ | S 4.1, S 4.2 |
| R 5 | ✓ | S 5 |
| R 6 | ✓ | S 6 |
| R 7 | ✓ | S 7 |
| R 8 | ✓ | S 8.1, S 8.2, S 8.3 |
| R 9 | ✓ | S 9.1, S 9.2, S 9.3 |
| R 10 | ✓ | S 10.1, S 10.2 |
| R 11 | ✓ | S 11.2 |
| R 12 | ✓ | S 12.1 |
| R 13 | ✓ | S 13.1 |
| R 14 | ✓ | S 14.1.2 |
| R 15 | ✓ | S 15.2 |
| R 16 | ✓ | S 16 |
| R 17 | ✓ | S 17 |
| R 18 | ✓ | S 18 |
| R 19 | ✓ | S 19 |
| R 20 | ✓ | S 20 |

*Table [12]: Testing*

# 3 Results

This chapter explains which methods were used for the final prototype.

## 3.1 Patient fixation components

The fixation was fabricated according to the CAD file. Figure [38] shows the finished product (already folded) with pump and gauge. On the underside there are four Velcro pieces to fasten the fixation on the hand support and to avoid slipping during use. The underside view is shown on figure [39].

*Figure [38]: Finished product*

*Figure [39]: Underside view of fixation*

The hand support was also produced according to the CAD file. The micro Velcro was glued on both sides and the T-connector was mounted at the intended place. The counter pieces of the Velcro were also glued to the upper side of the hand support. The corresponding images are shown in figure [40], figure [41] and figure [42].

*Figure [40]: Micro Velcro from side view of 8° angled hand support*

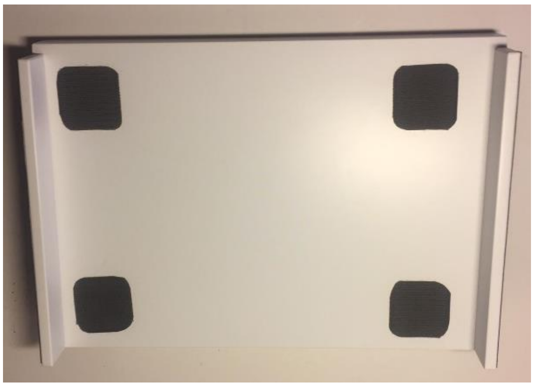


*Figure [41]: Velcro pieces of hand support*

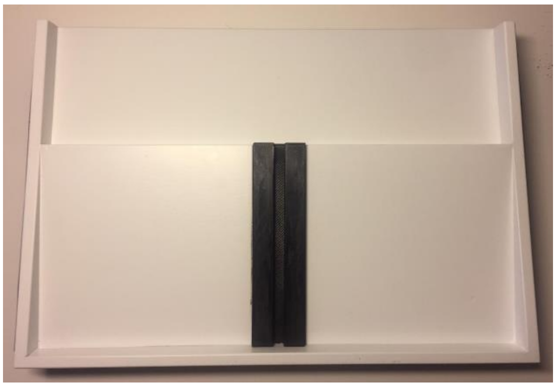


*Figure [42]: T-connector of hand support*

The splints were printed with the 3D printer. Small strips of micro Velcro were also glued to the side to fix also the lower arm with the corresponding fleece. Figure [43] shows one of these strips.

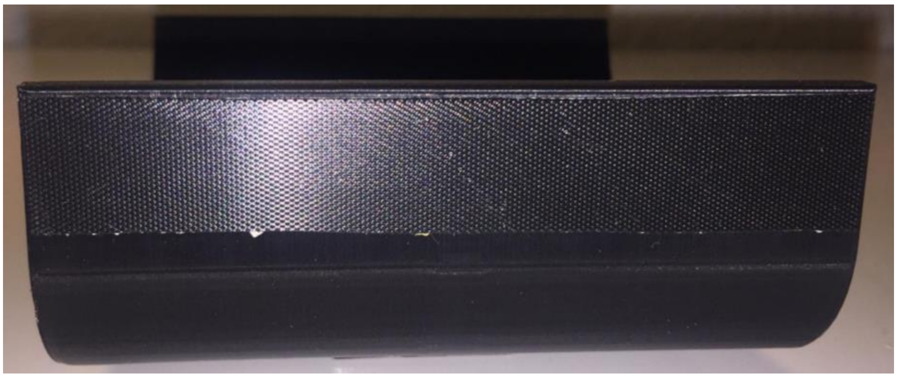


*Figure [43]: Splint with micro Velcro strip*

In order to really be able to support the arms, the splints with the T-connections are mounted on a post. Due to the completely continuous T-connection, the splints can be moved and removed. This allows more position possibilities and more space on the rail for one-handed use.

*Figure [44]: Post with T-connection rails*

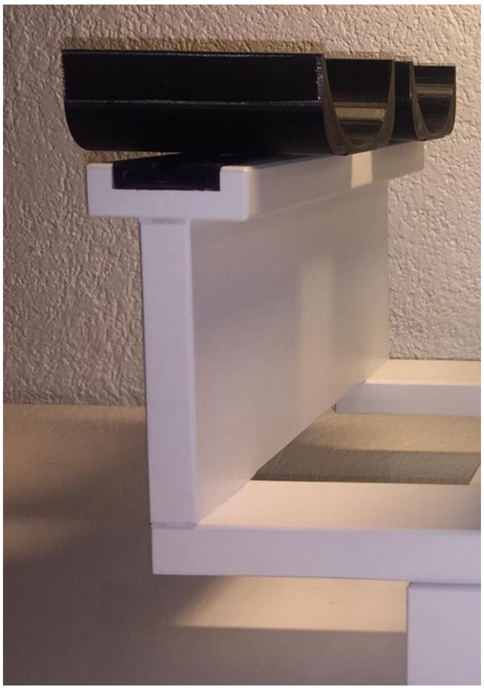


*Figure [45]: Post with two splints*

## 3.2 Selected position adjustment method

The ball joint is selected for position adjustment. It offers freedom of movement in all required directions. The locking of the joint was realized with the thread locking method. To increase the usability, the upper part of the socket, which must be screwed downwards, is provided with a pleasant shape.

The complete ball joint comes from the 3D printer. For moving parts, it is very important to keep the tolerances. The sphere has a 0.3 mm smaller diameter than the socket. This results in a good sliding movement.
It is almost impossible to give a suitable value for all threads. Too many factors play a decisive role. For the thread of this prototype 0.8 mm tolerance selected.

Figure [46] shows the final position adjustment method. Also, the T-connection, where the hand support is installed, is visible. At the bottom there are blue circled holes. Through these the ball joint can be screwed to the installation.

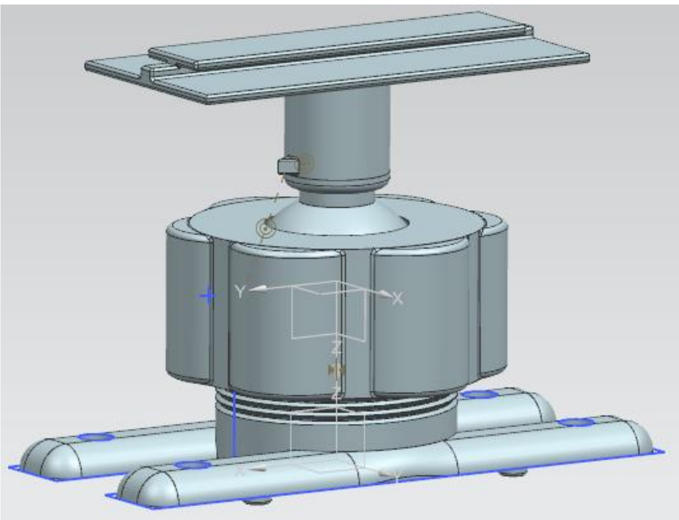


*Figure [46]: CAD image of final ball joint*

The printed and already installed ball joint is shown on the figure [47] below.

*Figure [47]: Installed final ball joint*

## 3.3 Selected position measurement and display method

For position measurement, no hardware features of the ball joint are required for the final software. The lines to be detected by the software are the edges of the T-connectors. These are always present and always visible on the image. They are also parallel to the hand support. So, the hands always have the same angle.

The figure [48] below shows the GUI (graphical user interface) as it should be used by the employees of the Lucerne Cantonal Hospital.

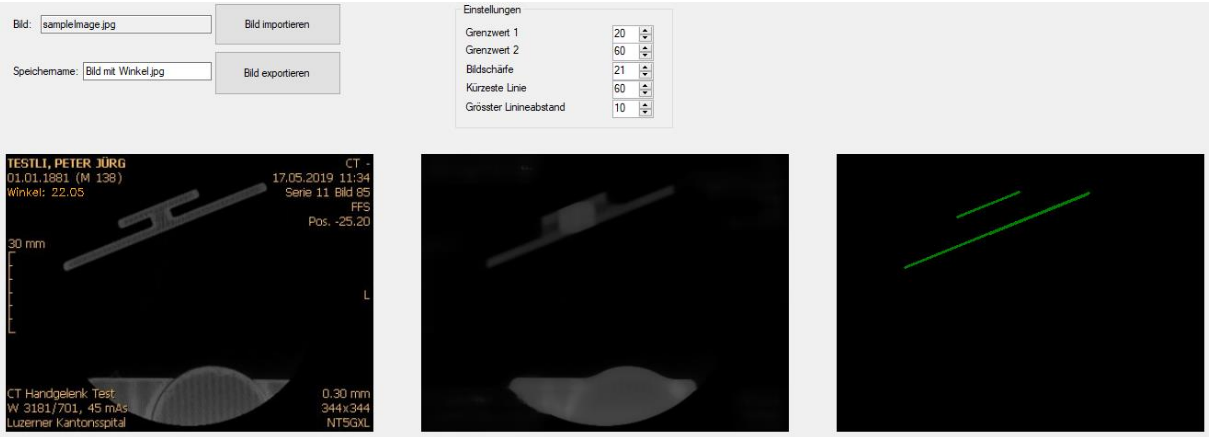



*Figure [48]: Graphical user interface of the final software application*

Figure [49] and figure [50] show two examples of an angle calculation.


*Figure [49]: Image with displayed yaw angle*


*Figure [50]: Image with displayed roll angle*

The accuracy of the position measurement is different. It varies in an image stack from +- 0.1° to +- 2° with the default settings. Changing the variable values changes the displayed angle, since different lines are always included in the median and each change triggers a new calculation.

## 3.4 Installation

The installation made of wood was produced according to the dimensions of the CAD file. Figure [51] shows the installation.

*Figure [51]: Produced installation*

In addition, the installation has been designed with four holes to fix the ball joint. Further the installation has been connected to the lower arm support posts so that all weight can be transferred to the patient surface. These two features are shown on figure [52] and figure [53].

*Figure [52]: Underside view of installation*

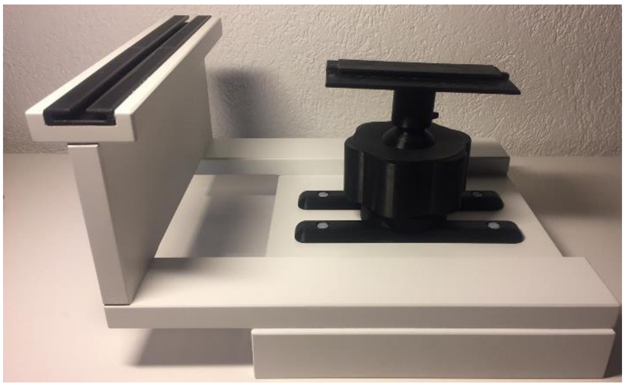


*Figure [53]: Connection between Installation and post*

## 3.5 Assembled prototype

The finished prototype, assembled with all components, is shown ion figure [54] and figure [55].

*Figure [54]: Finished prototype*

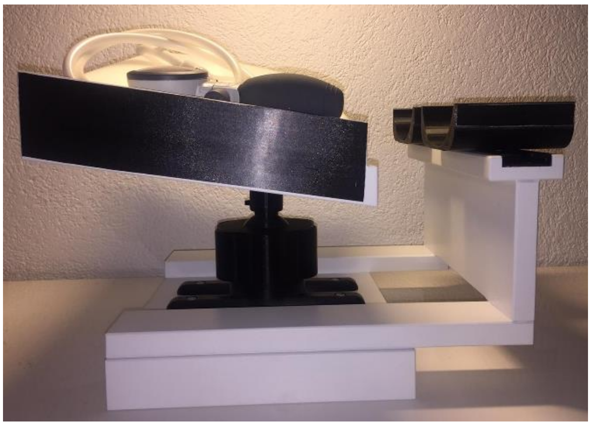


*Figure [55]: Finished prototype sideview*

# 4 Conclusion

The main objective of this project is to build a working prototype for the Lucerne Cantonal Hospital.

The Radiology and Nuclear Medicine Department of the Lucerne Cantonal Hospital has a high-resolution computer tomograph. During use, movement artefacts occur repeatedly, because patients are unable to hold their hands still for 30 seconds.
To prevent this problem, a prototype of a hand and lower arm fixation is to be developed. This prototype will also meet other requirements. It must be possible to carry out measurements in different hand positions and then to indicate the hand position as an angular value using the cross-sectional images of the image stack.

In order to be able to fix the hand or the hands well, a fixation was developed in cooperation with the company Pearl Technology AG, which meets the requirements in all areas.

Care has always been taken not to use metallic materials in order to avoid causing metal artefacts. In addition, all materials must be washable and disinfect able and must not cause allergic reactions in order to be used in a clinical environment.

The freedom of movement was made possible by a ball joint. The ball joint can be locked in any position by a user-friendly thread lock method.

The position measurement was realized with a software code in C#. Emgu CV provides an example code "Edge Detection". By modifying and extending this code, this goal has also been achieved.

Due to the development of an installation board, the entire prototype can be installed and used on the existing patient surface in the Lucerne Cantonal Hospital.

*Figure [56]: The very first test of the assembled prototype*

# 5 Acknowledgements

I would like to take this opportunity to thank all the people who have contributed with their professional and personal competencies and thus played a decisive role in the success of this Bachelor thesis (BAT_MT).

It is worth mentioning Philipp Schütz, who was my supervising lecturer. Philipp Schütz supported me during the whole project work.
He spends the time for meetings and discussions, as well as for e-mail replies late at night.
I appreciated this very much.

I would also like to express special thanks to Thomas Müller from Pearl Technology AG in Schlieren. Thomas Müller took a lot of time to advise me and looked through the entire product range with me. With my customized fixation, he kept the prices low so that my budget was not exceeded.

Thank you very much!

# 6 Lists of Figures, Tables and Bibliography

## 6.1 List of figures

## 6.2 Tables



## 6.3 Bibliography

Hollnagel, C., Brügger, M., Vallery, H., Wolf, P., Dietz, V., Kollias, S., & Riener, R. (2011). Journal of Neurscience Methods. *Brain activity during stepping: A novel MRI-compatible device*.

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# 7 Attachments

## 7.1 Software code

This chapter contains the whole software code, which has been developed during this project.

```
using Emgu.CV;
using Emgu.CV.CvEnum;
using Emgu.CV.Structure;
using System;
using System.Collections.Generic;
using System.Drawing;
using System.IO;
using System.Linq;
using System.Windows.Forms;

namespace positions_measurement
{
    3 Verweise
    public partial class MainForm : Form
    {
        1-Verweis
        public MainForm()
        {
            InitializeComponent();
            InitDefaultValues();
        }

        /// <summary>
        /// initialize default values
        /// </summary>
        1-Verweis
        public void InitDefaultValues()
        {
            FileNameTextBox.Text = "sampleImage.jpg";
            ExportFileName.Text = "Bild mit Winkel.jpg";
        }

        /// <summary>
        /// main funcion for calculation
        /// </summary>
        6 Verweise
        public void Calculate()
        {
            if (FileNameTextBox.Text != string.Empty)
            {
                // load original image (with FileNameTextBox string)
                Image<Bgr, Byte> img =
                   new Image<Bgr, byte>(FileNameTextBox.Text)
                   .Resize(400, 400, Emgu.CV.CvEnum.Inter.Linear, true);

                // set original image in image box
                OriginalImageBox.Image = img;

                // create new empty byte array for output image
                UMat outputImage = new UMat();

                // clone original image and convert to grayscale
                // rewrite the pixel values of the image to the byte array
                CvInvoke.CvtColor(img.Clone(), outputImage, ColorConversion.Bgr2Gray);

                // apply median-blur filter to the output image to eliminate interfering factors
                CvInvoke.MedianBlur(outputImage, outputImage, (int)MedianBlurInput.Value);

                // set median blur image to output image
                MedianBlurImage.Image = outputImage;

                // create new empty byte array for edges values
                UMat edges = new UMat();
```

```csharp

        // search edges of output image by threshold parameter
        // fill values into byte array (edges)
        CvInvoke.Canny(outputImage, edges, (double)Threshold1Input.Value, (double)Threshold2Input.Value);

        // search line segments with HoughLinesP function by byte array (edges) values
        // corner points of each line fill into array (LineSegment2D)
        LineSegment2D[] lines = CvInvoke.HoughLinesP(edges,1,Math.PI / 45.0, (int)Threshold1Input.Value,
            (double)MinLineWithInput.Value, (double)MaxLineGapInput.Value);

        // create list for found angles
        List<double> angles = new List<double>();

        // create blank image (dark background) to draw lines afterwards
        Image<Bgr, Byte> lineImage = img.CopyBlank();

        // search for required lines in list
        foreach (LineSegment2D line in lines)
        {
            // calculate angle
            double angle = Math.Atan2((double)line.Direction.Y, (double)line.Direction.X) * 180.0 / Math.PI;

            // angle preparation and convert to positive angles (positive numbers)
            if (angle > 90)
            {
                angle = 180 - angle;
            }
            else if (angle < -90)
            {
                angle = 180 + angle;
            }

            // differentiate in yaw and roll
            // yaw angle
            if (angle >= 60 && angle <= 88)
            {
                angle = 90 - angle;
                // draw corresponding line from LineSegment2D
                lineImage.Draw(line, new Bgr(Color.Orange), 2);
                // add angle to list
                angles.Add(angle);
            }
            // roll angle
            else if (angle >= 2 && angle <= 30)
            {
                // draw corresponding line from LineSegment2D
                lineImage.Draw(line, new Bgr(Color.Green), 2);
                // add angle to list
                angles.Add(angle);
            }
            // horizontal and vertical lines are left
            else
            {
                lineImage.Draw(line, new Bgr(Color.Red), 2);
            }
        }

        // add drawn lines to blank image
        LineImage.Image = lineImage;

        // applay median filter to calculate angle average
        double median = Median(angles);

        // display angle if valid
        if (median > 0)
        {
            ShowAngle(median);
        }
    }
}

```

```
/// <summary>
/// calculate median of all list items
/// </summary>
/// <param name="items">list of items</param>
/// <returns>angle average</returns>
1-Verweis
public double Median(List<double> items)
{
    // leave if list is empty
    if (items.Count == 0)
    {
        return 0;
    }

    int medialIndex = items.Count() / 2;
    var orderedItems = items.OrderBy(n => n);
    double median;
    // if even number of items exist, take the one deeper item ot the middle
    if ((items.Count() % 2) == 0)
    {
        median = ((orderedItems.ElementAt(medialIndex) +
            orderedItems.ElementAt(medialIndex - 1)) / 2);
    }
    else
    {
        // if odd number of item exist, take the item of the middle
        median = orderedItems.ElementAt(medialIndex);
    }
    return median;
}

/// <summary>
/// show angle on orignal image
/// </summary>
/// <param name="angle">yaw or roll angle</param>
1-Verweis
public void ShowAngle(double angle)
{
    // define text and round angle
    string angleText = "Winkel: " + Math.Round(angle, 2);

    // print whole text (with angle) on the original image
    CvInvoke.PutText(OriginalImageBox.Image, angleText, new Point(1, 45),
        FontFace.HersheySimplex, 0.4, new Bgr(Color.Orange).MCvScalar);
}

/// <summary>
/// display file dialog to choose image
/// </summary>
/// <param name="sender">control which starts event</param>
/// <param name="e">parameter of type EventArgs</param>
1-Verweis
private void LoadImageButton_Click(object sender, EventArgs e)
{
    DialogResult result = openFileDialog1.ShowDialog();
    if (result == DialogResult.OK || result == DialogResult.Yes)
    {
        // assign selected image to text box with file path
        FileNameTextBox.Text = openFileDialog1.FileName;
    }
}
```

```
/// <summary>
/// triggered if export button selected
/// </summary>
/// <param name="sender">butten object of export button</param>
/// <param name="e">paramter of type EventArgs</param>
1-Verweis
private void ExportButton_Click(object sender, EventArgs e)
{
    // leave if export text box emty
    if (ExportFileName.Text == "")
    {
        return;
    }

    // determine directory - path of text box
    var directory = Path.GetDirectoryName(FileNameTextBox.Text);

    // chose temporary directory if no valid directory availabele
    if (directory == "")
    {
        directory = Path.GetTempPath();
    }

    // assemble file path
    var exportFileName = directory +"\\" + ExportFileName.Text;

    // save original image with printed angle information as copy
    OriginalImageBox.Image.Save(exportFileName);
}

/// <summary>
/// execute new calculation process if selected image changed
/// </summary>
/// <param name="sender">control which starts event</param>
/// <param name="e"></param>parameter of type EventArgs
1-Verweis
private void FileNameTextBox_TextChanged(object sender, EventArgs e)
{
    Calculate();
}

/// <summary>
/// execute new calculaton process if Threshold1 value changed
/// </summary>
/// <param name="sender">NumericUpDown of Treshold1</param>
/// <param name="e">parameter of type EventArgs</param>
1-Verweis
private void Threshold1Input_ValueChanged(object sender, EventArgs e)
{
    Calculate();
}

/// <summary>
/// execute new calculaton process if Threshold2 value changed
/// </summary>
/// <param name="sender">NumericUpDown of Treshold2</param>
/// <param name="e">parameter of type EventArgs</param>
1-Verweis
private void Threshold2Input_ValueChanged(object sender, EventArgs e)
{
    Calculate();
}

/// <summary>
/// execute new calculaton process if MinLineWidth value changed
/// </summary>
/// <param name="sender">NumericUpDown of MinLineWidth</param>
/// <param name="e">parameter of type EventArgs</param>
1-Verweis
private void MinLineWithInput_ValueChanged(object sender, EventArgs e)
{
    Calculate();
}
```

```
        /// <summary>
        /// execute new calculaton process if MaxLineGap value changed
        /// </summary>
        /// <param name="sender">NumericUpDown of MinLineGap</param>
        /// <param name="e">parameter of type EventArgs</param>
        1-Verweis
        private void MaxLineGapInput_ValueChanged(object sender, EventArgs e)
        {
            Calculate();
        }

        /// <summary>
        /// execute new calculaton process if MedianBlur value changed
        /// </summary>
        /// <param name="sender">NumericUpDown of MedianBlur</param>
        /// <param name="e">parameter of type EventArgs</param>
        1-Verweis
        private void MedianBlurInput_ValueChanged(object sender, EventArgs e)
        {
            // MedianBlur allows only odd numbers
            // read last set value and convert to Integer
            Int32 oldValue = int.Parse(((NumericUpDown)sender).Text.ToString());

            if (MedianBlurInput.Value % 2 == 0 && oldValue > MedianBlurInput.Value)
            {
                // reduce value if last value is bigger
                MedianBlurInput.Value--;
            }

            else if (MedianBlurInput.Value % 2 == 0)
            {
                // increase value if last value is smaller
                MedianBlurInput.Value++;
            }

            Calculate();
        }
    }
}
```