3.8 Mechanical Design

Corresponding to the modular concept of the NIRS instrument, a modular mechanical design was developed. It is based on a spring-loaded housing for the NIRS module and a chained multiple-unit housing design for the mainboard, the Bluetooth module and batteries for fixation at the upper arm.
The construction of the mechanical elements and housings was done using Siemens NX 7.5 CAD software. For technical drawings of the instrument's housing parts, please refer to fig. A.11 and fig. A.12 in the appendix. The renderings for the figures for concept illustrations were done with Blender3D, using the meshes from the CAD design and meshes from the "BodyParts3D" life science database archive [80]. The designed elements were then produced from polylactic acid (PLA) plastic material, using a 3D printer.
In the following, both mechanical design concepts will be discussed in detail.

3.8.1 NIRS Module Attachment

The geometrical arrangement of the four NIR light emitters and the detector on a NIRS module is shown in figure 3.32. With the NIR light detector based at the center of the arrangement, the four LEDs are placed at opposite corners in equal distances of configurable $30 - 35\,mm$.

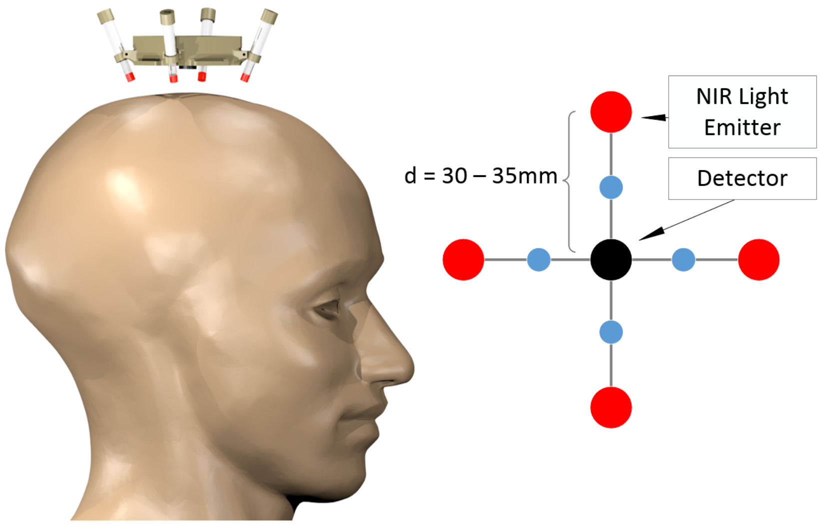

Figure 3.32: Geometrical arrangement of NIR light emitters and detector.

The blue dots in the figure represent the resulting points of the highest sensitivity for functional cortex activity.

For the optimal signal quality, it is important that the NIR light detector and the NIR light emitters are as close to the scalp as possible, while at the same time being perpendicular to the surface for maximum sensitivity and light penetration depth.
To adjust the emitters/detector perpendicular to the surface and at the same time provide an optimal fit of the NIRS module to the head, the NIRS module mechanical design was based on a spherical approximation of the head (see fig. 3.33).

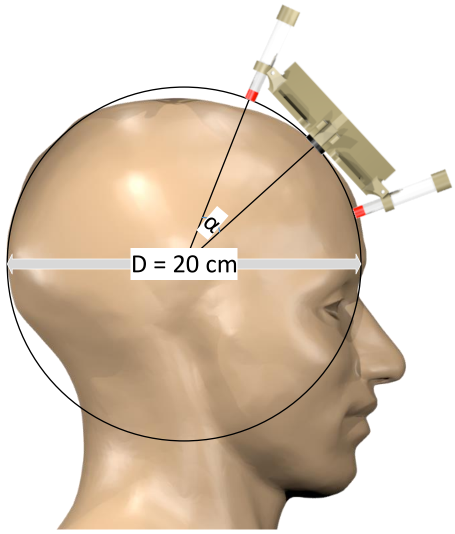

Figure 3.33: Design for head geometry alignment.

Using a sphere with a 20 cm diameter for the head, the necessary angle of slope α between detector and emitters could be specified as approximately 16 ° and the mechanical construction could be based on defined geometrical constraints.
With the module holder being a completely stiff construction, no alignment to the natural unevenness of the head and its deviations from the spherical approximation is possible. To enable an alignment and minimize influences on the signal due to movement of the head, the design is based on a spring-loaded concept (see fig. 3.34).

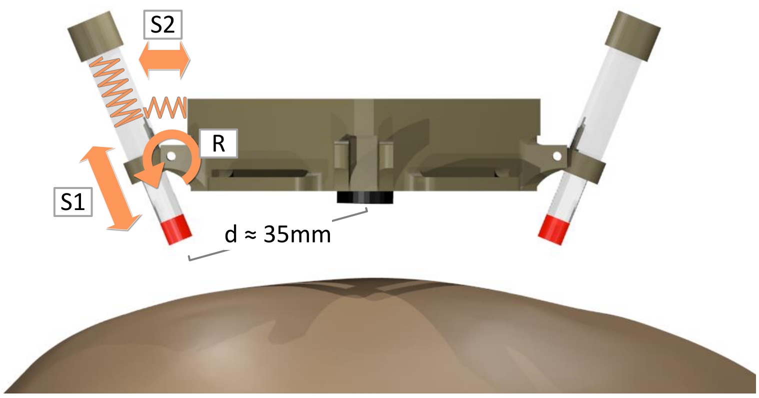

Figure 3.34: Mechanical spring-loaded design for the NIR light emitters.

The NIR light LEDs (depicted red in the image) are not stiffly connected to the module body housing but integrated in movable spring-loaded LED holders. These holders are based on two nested tubes that are spring-loaded against each other (S1) and against the module housing (S2) and are able to rotate around an axis (R).
Spring S1 presses the LED towards the surface of the head, thus enabling alignment and preventing the loss of contact during movements. Spring S2 and the rotary joint R keep the LED perpendicular to the surface while enabling small deviations for comfort and

alignment.

In the following, the components and assembly of the NIRS module body housing and spring loaded LED holders are briefly described. Fig. 3.35 shows the components and assembly.

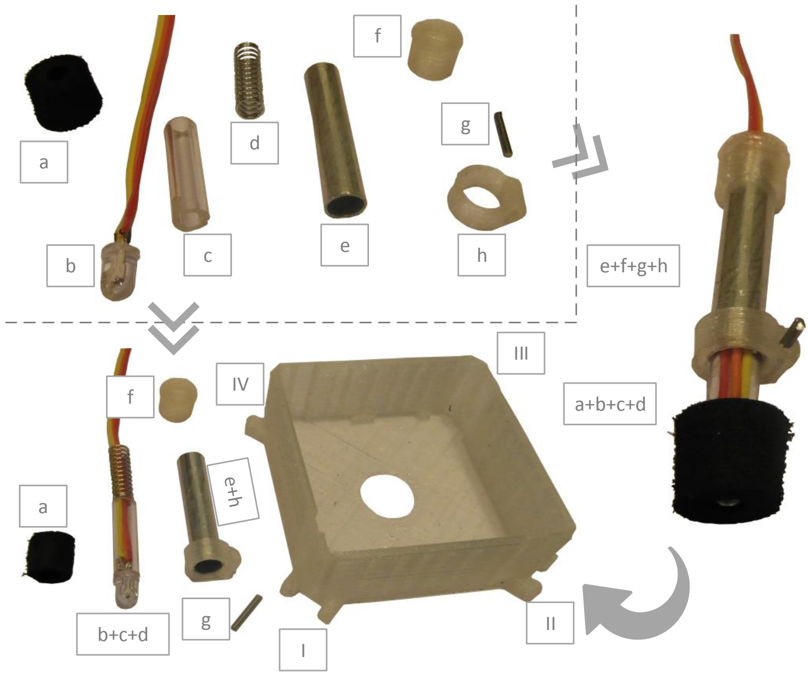

Figure 3.35: Components and assembly for spring-loaded design concept

The spring-loaded LED holders are built using 20 mm-long acrylic glass tubes (c) with an outer diameter of 6 mm, 30 mm-long aluminum tubes (e) with an outer diameter of 7 mm and a wall thickness of 0.5 mm and 18 mm-long metal springs (d) with a 5 mm outer diameter. The multi-wavelength NIR LED is soldered to a 3-wire ribbon cable (b) which is then lead through the treated glass tube and the metal spring (b+c+d), (S1).
A custom 3D-printed holder (h) is glued to the bottom of the aluminum tube (e+h) and a printed stopper plug with a through-hole (f) is glued to the top of the tube. Another custom 3D-printed stopper plate (not in the picture) is glued to the acrylic tube directly behind the LED. The LED is then encased by a thick opaque tube made of cellular rubber (a) for stray light prevention and cushioning, and its acrylic tube, spring and ribbon wire (a+b+c+d) are slid through the aluminum tube with holder and stopper plug (e+f+g+h). Now, four of these constructions are fixed to the module body housing at its four corners (I, II, III, IV) with 1 mm diameter steel pivot pins (g) that are slid through the hubs of the aluminum tube holder (h) and the module body housing corners, creating rotary joints (R).

The springs S2 are then inserted between the module housing corners and the LED holders. Figure 3.36 shows the finished NIRS modules.
To minimize stray light influences and for cushioning purposes, the detector is encased by an opaque cell rubber tubing. Also, the NIRS module body housing is painted with

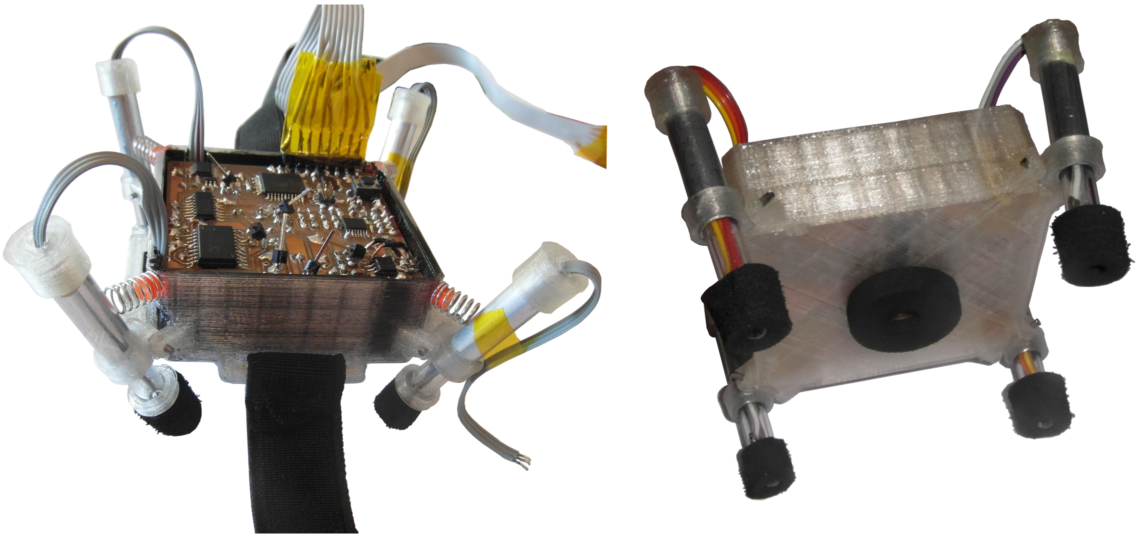

Figure 3.36: Complete mechanical spring-loaded NIRS module.

opaque black paint from the inside to minimize NIR light effects on the sensor from directions other than perpendicular to the sensing surface. For fixation to the head, a flexible ribbon with hook-and-loop fastener for length adaption is sewed to the module housing.

3.8.2 Mainboard and Batteries

Two fundamentally different approaches for the casing and wearability of the mainboard module and batteries were developed.
The first approach uses the mainboard prototype and will be only briefly discussed, as several improvements were made for the second approach using the final version of the mainboard. In the first approach, mainboard, on-board Bluetooth module and two 9V batteries are encased by a neck-worn case cushioned with cell rubber (see fig. 3.37).

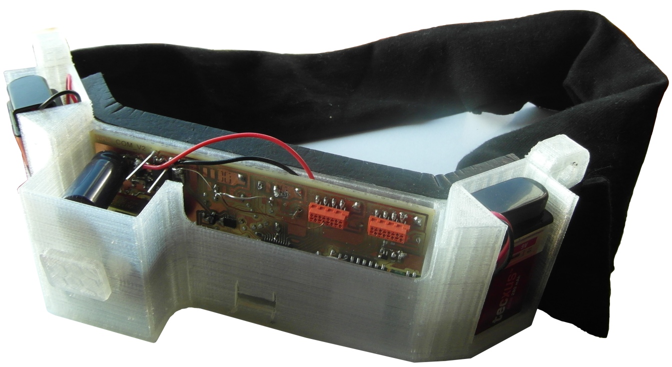

Figure 3.37: Neck-worn mainboard module.

As even low pressure on the throat during fixation of the module is instantly perceived as unpleasant, the case is worn like a necklace: With the cushioned mainboard housing at the back of the neck, the module is counterbalanced by a weight fixed to a soft fabric sewn to the body housing hanging down the chest.

For the final design, a different approach was developed. Resulting from the necessity to physically separate the Bluetooth module from the rest of the mainboard (see subsection 3.5.3), to enable the use of bigger battery packs for prolonged instrument operation, and to maximize user mobility, a multi-module concept for the attachment to the upper arm was designed (see fig. 3.38).

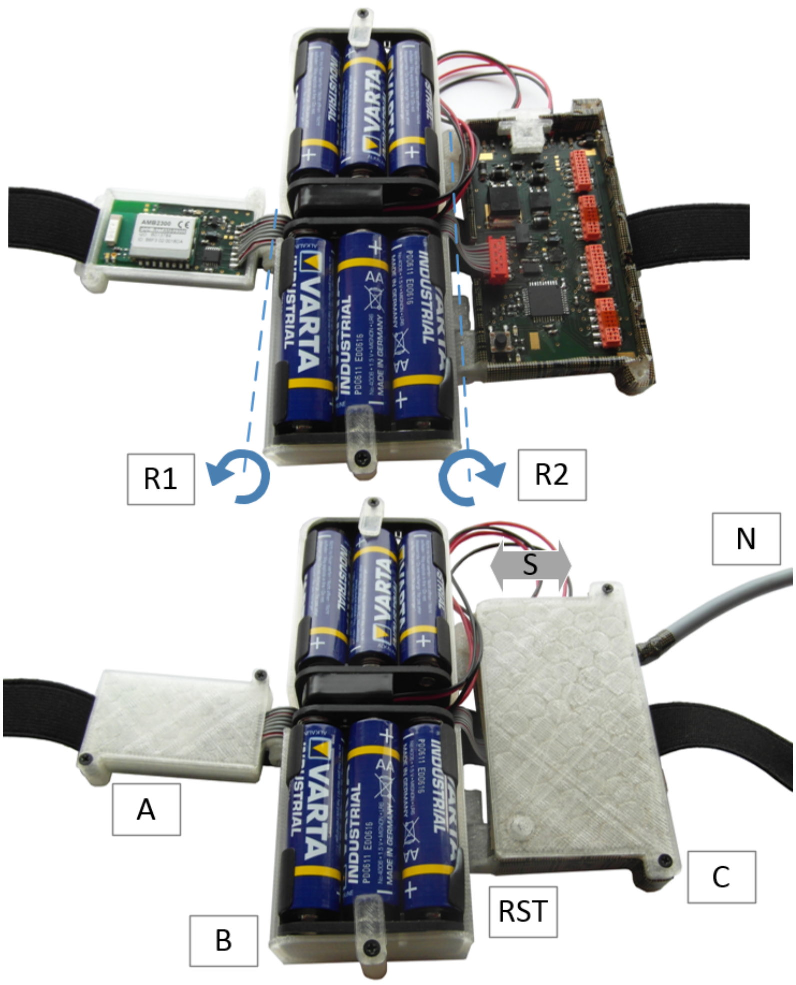

Figure 3.38: Mechanical concept for mainboard arm attachment.

The design is based on three main module cases that are interconnected via rotary joints (R1, R2): The Bluetooth module (A), the battery holder (B) and the NIRS mainboard (C).
The battery holder holds two 6 AA battery packages (9V) and allows easy battery replacement. The Bluetooth module case is placed as far as possible from the mainboard case and the module is connected via a ribbon cable connector.
The inside of the mainboard module case is lined with conductive shielding grid tape (Desco, type 81250). Custom on-off switch and reset push button adapters were designed

for access to the on-off switch (S) and microcontroller reset button (RST) when the case is closed.
To close the Bluetooth and mainboard module cases, the corresponding lids are screwed in place. Screwing the mainboard case and lid together also fixates the shielded NIRS cable (N).

For the attachment to the arm, a flexible ribbon is guided through fixation elements of the module cases. The unit can then easily be tied to the arm of a subject (see fig. 3.39): The rotary joint connections allow mechanical adaption to the shape of the arm and the flexible ribbon prevents slipping.

Figure 3.39: Mainboard and batteries: arm attachment.