Intellectual Output_O2:
EMERALD e-toolkit manual for digital learning in producing biomimetic mechatronic systems

Toolkit 1
Computer Aided Design

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EUROPEAN NETWORK FOR 3D PRINTING OF BIOMIMETIC MECHATRONIC SYSTEMS

E-toolkit – Computer Aided Design

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1 Introduction ... 3
2 Design of mechanical part of the prosthesis ... 4
2.1 Main assumptions ... 4
2.2 Generative CAD model – principles of operation ... 4
2.3 Prosthesis model design ... 6
2.3.1 Prosthetic socket ... 6
2.3.2 Forearm ... 15
2.3.3 End effector ... 18
2.4 Final version of bicycle prosthesis ... 21
2.5 Design of electronic part of the biomechatronic prosthesis ... 25
2.5.1 Main concept of the mechatronic prosthesis ... 25
2.5.2 Design modifications in biomechatronic prosthesis ... 26
3 Summary ... 28

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This toolkit presents practical information on how to a CAD model of a biomechatronic hand prosthesis can be built and structured. An example of modular prosthesis will be considered, with its adjustment to needs and preferences of an adult patient and converting static mechanical device into a mechatronic prosthesis, equipped with sensors for monitoring the activities performed by prosthesis user.

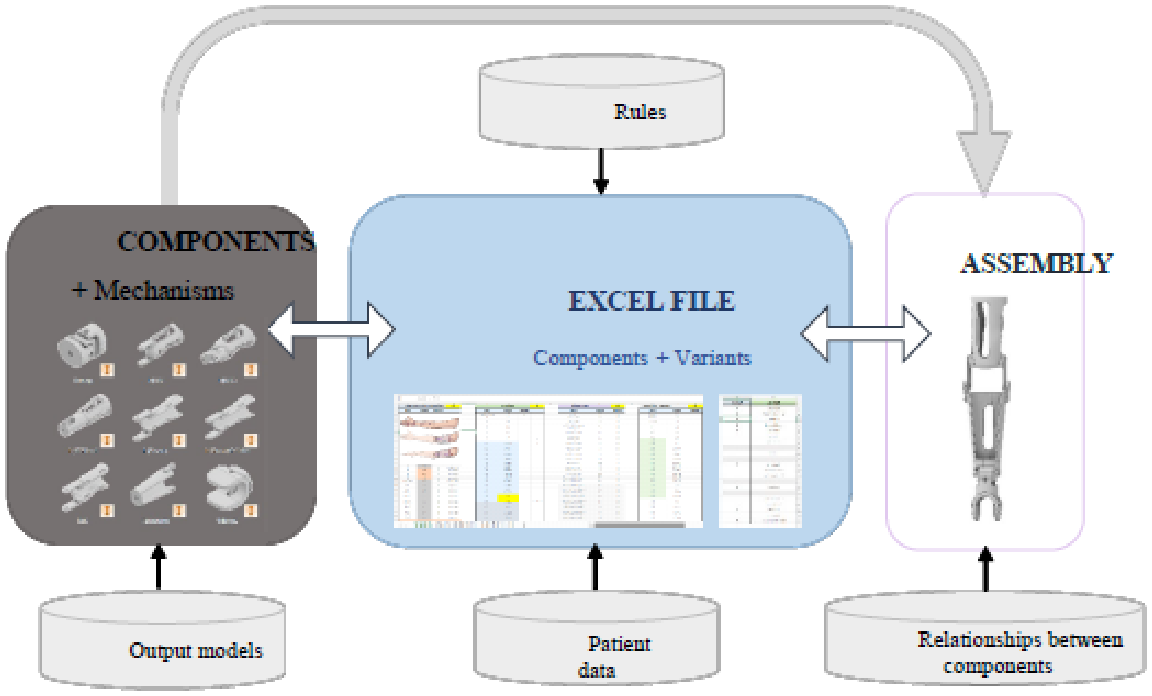

Figure 1 Architecture of the designed system [3]

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Design of mechanical part of the prosthesis

Table 1 List of components of the modular model

Prosthetic sockets	Prosthetic forearms	Effectors
– CRS compression and relaxation socjet (4 variants) – Open socket (2 variants) – Semi-open socket (3 variants) – CRS socket for amputation within the forearm	– Forearm open – Open forearm with a tip dedicated to the adapter – Closed forearm with a tip dedicated to the adapter – Forearm completely closed with a tip dedicated to the adapter	– C-Handle – Fixed straight handle – Fixed angular handle – Straight handle with a spring – A mechanical hand
Connecting and auxiliary elements		
– Cross joints – 2 adapters	– External model of the elbow – A shaped piece that blocks the elbow joint	

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Prosthesis model design

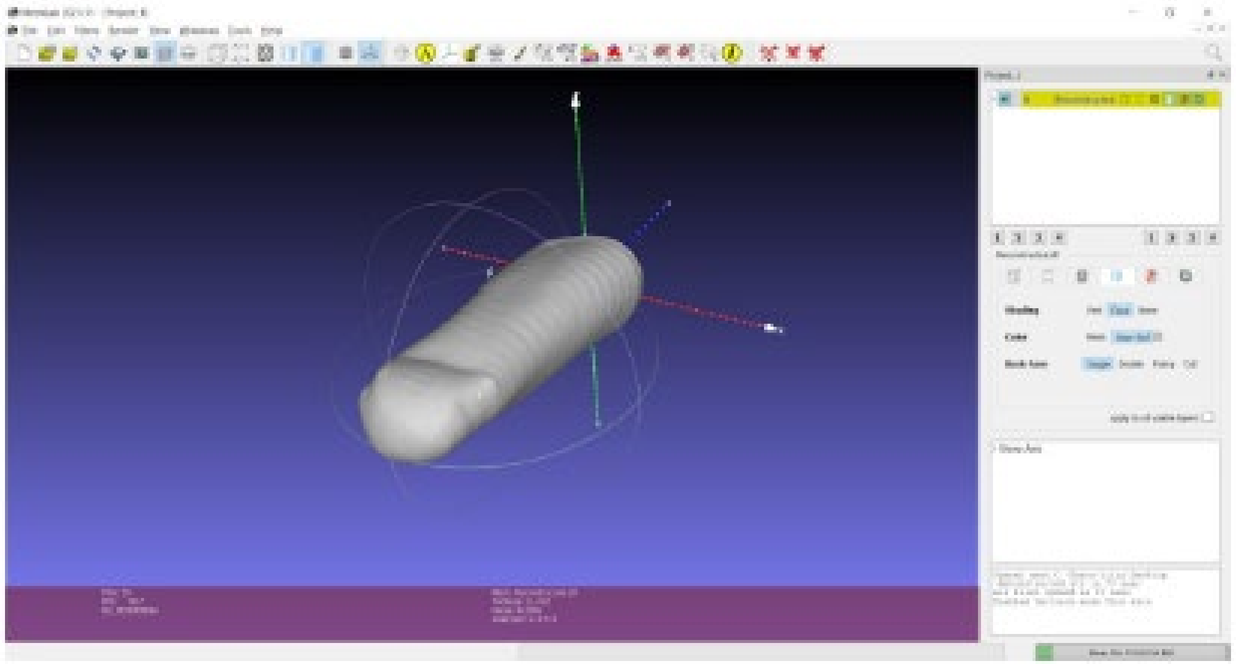

Figure 2 Correct orientation of the STL mesh in MeshLab

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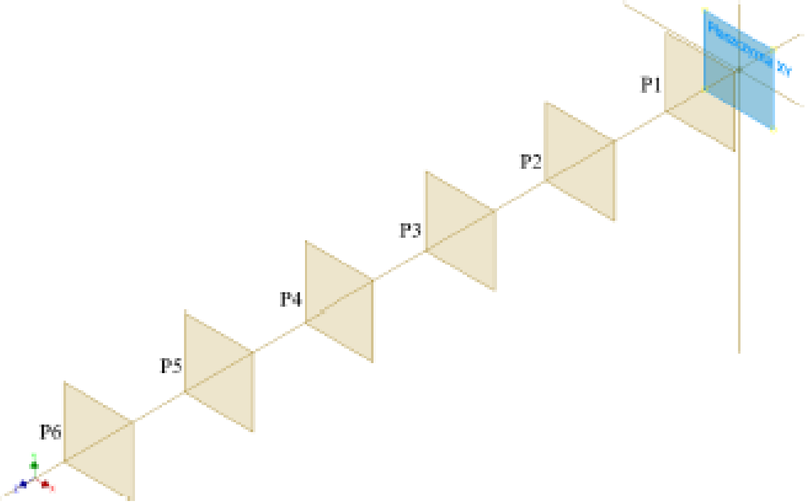

Figure 3 Construction planes defining cross-sections through the patient's vestigial limb

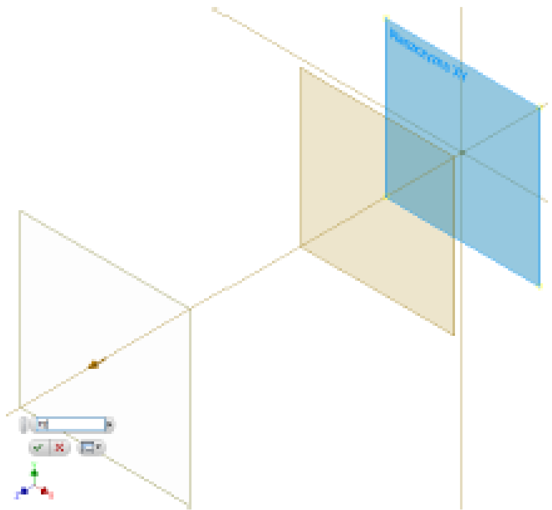

Figure 4 Generating a plane using the Offset from Plane function

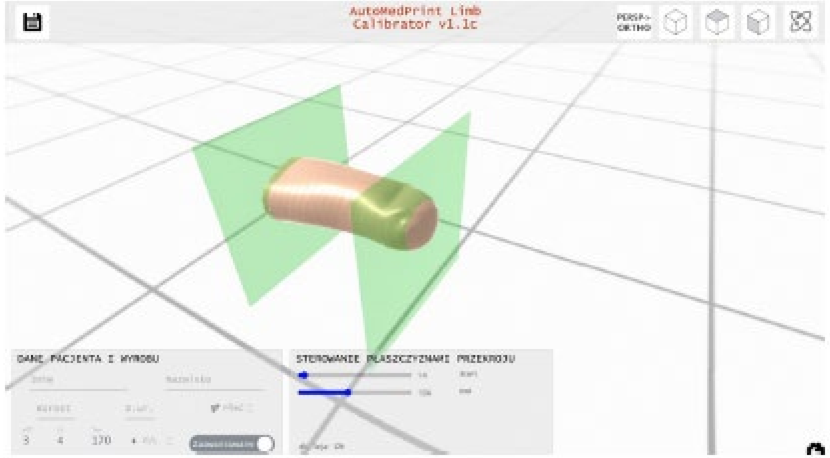

Figure 5 Determination of the extreme positions of the residual limb cross-sectional planes - the AutoMedPrint Limb Calibrator application

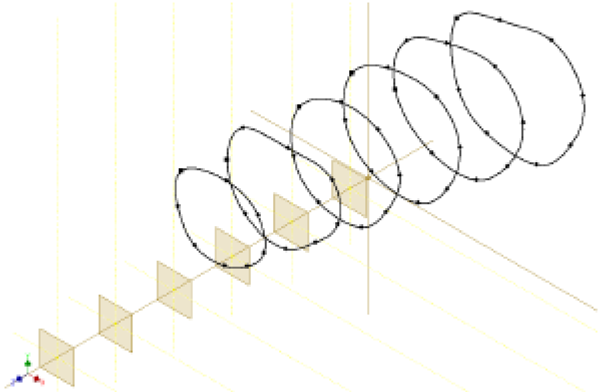

Figure 7 Six splines mapping the outline of cross-sections through the patient's vestigial limb

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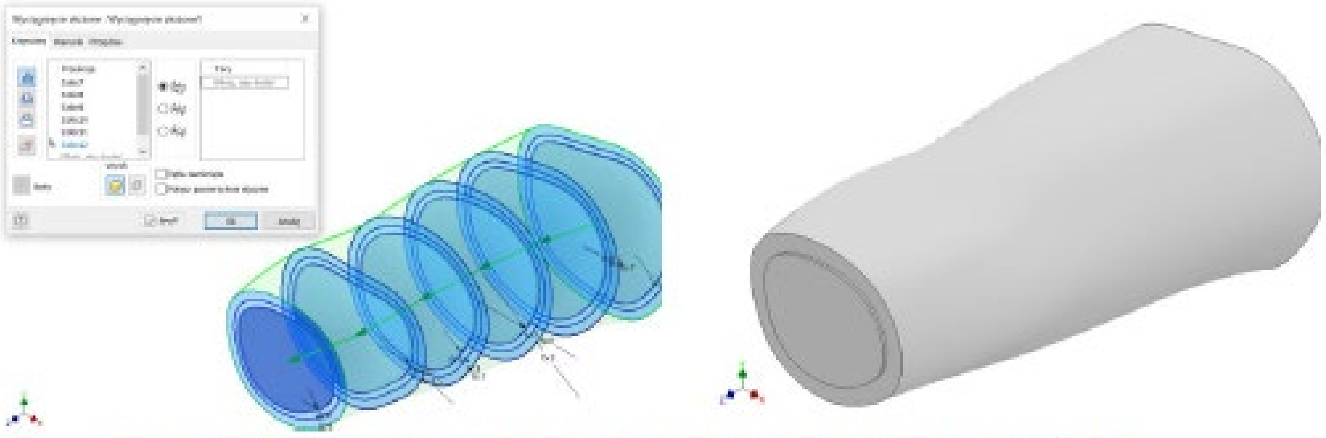

Figure 11 Execution of the Loft operation (A) and the resulting solid (B)

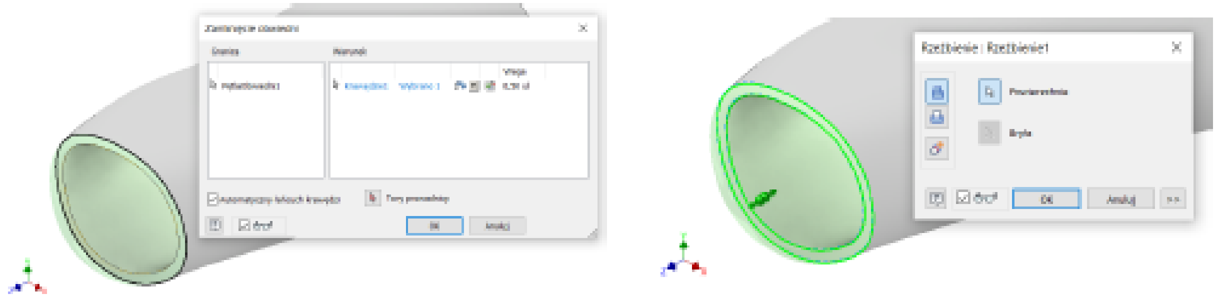

Figure 13 Perform a Close Boundary operation (A) and a Sculpture operation (B)

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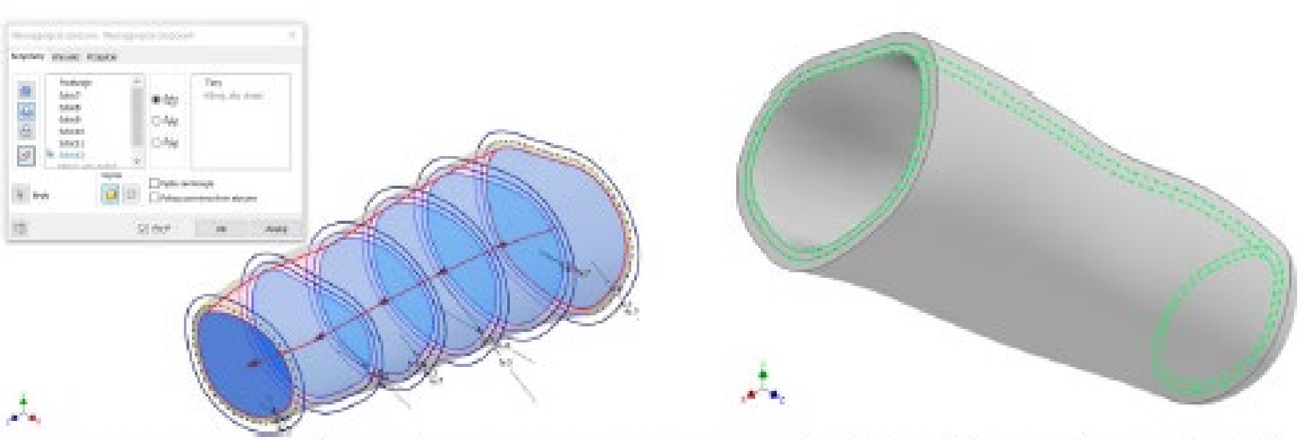

Figure 14 Execution of the Loft operation in Cutout mode (A) and the resulting solid (B)

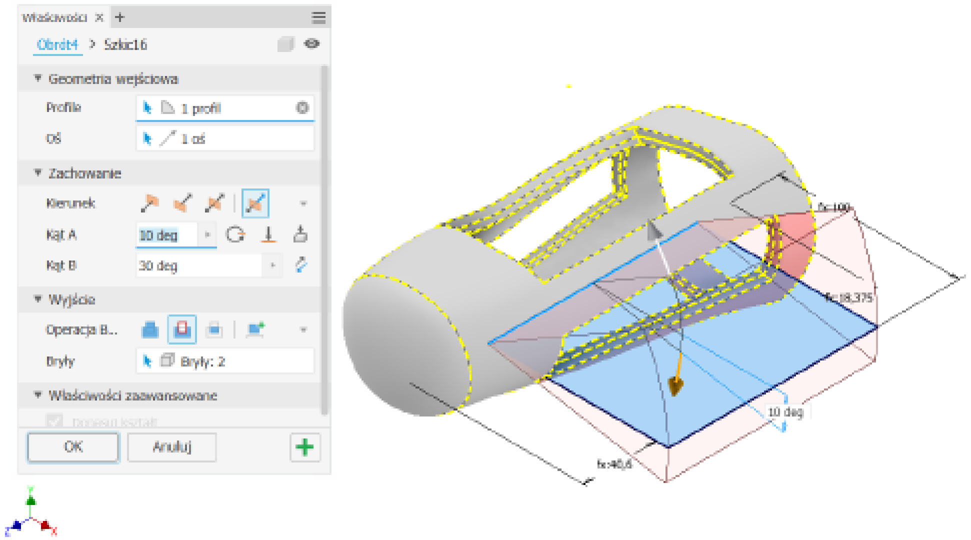

Figure 15 Making a hole using the Revolve operation

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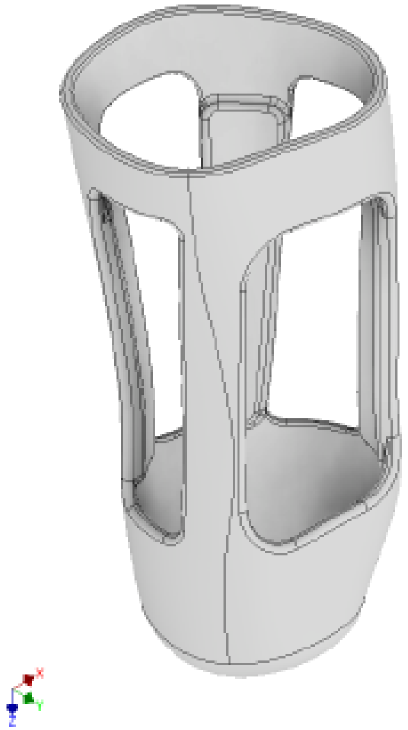

Figure 16 Modeled geometry of the prosthetic socket

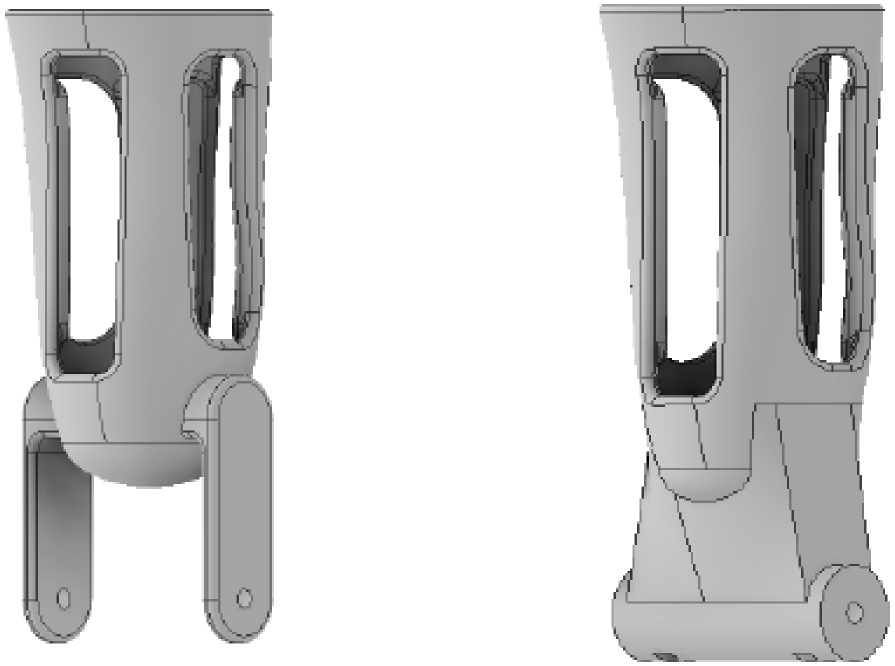

Figure 17 CRS sockets obtained as a result of analogous operations: A: with universal fastening; B: with flush mount

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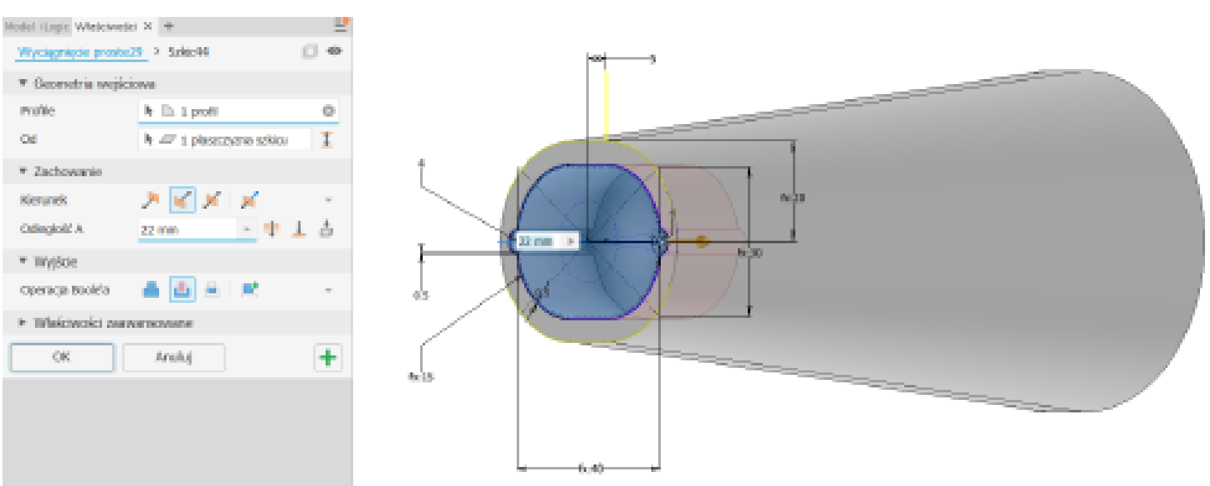

Figure 20 Designing geometry dedicated to the connection with the adapter - a cutout in the base solid

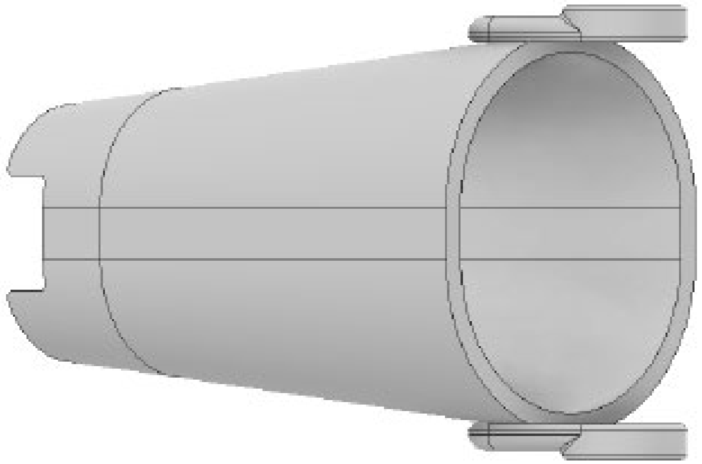

Figure 21 Closed forearm form

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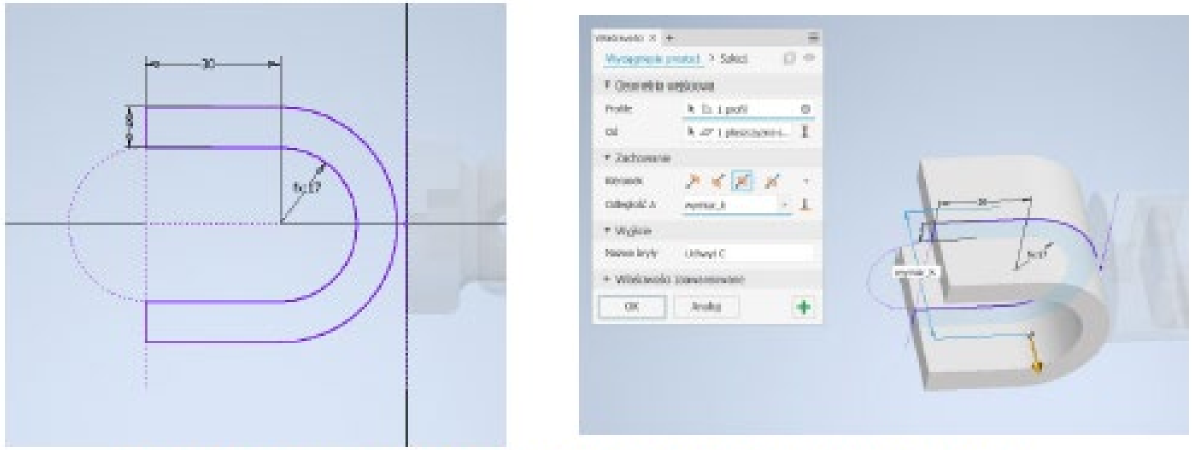

Figure 22 Start modeling the effector: A: sketch; B: straight pull out

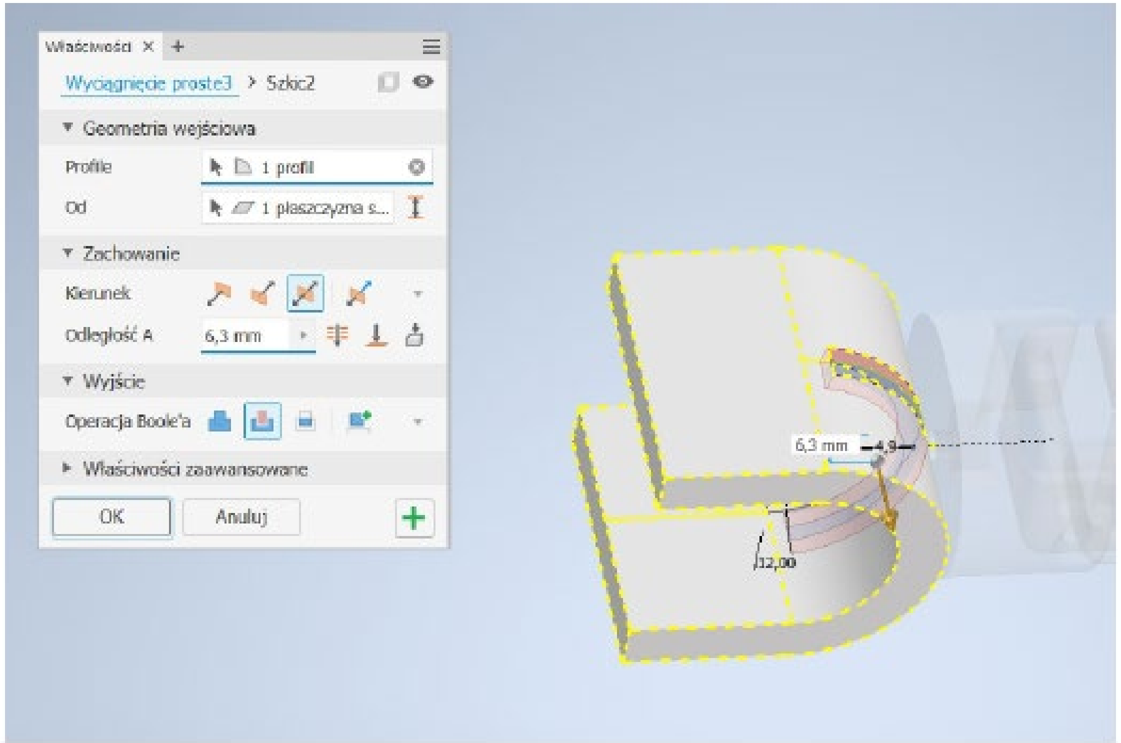

Figure 23 Opening for access to connecting elements

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Final version of bicycle prosthesis

Figure 27 Prosthesis made for a selected adult patient – test with the bicycle

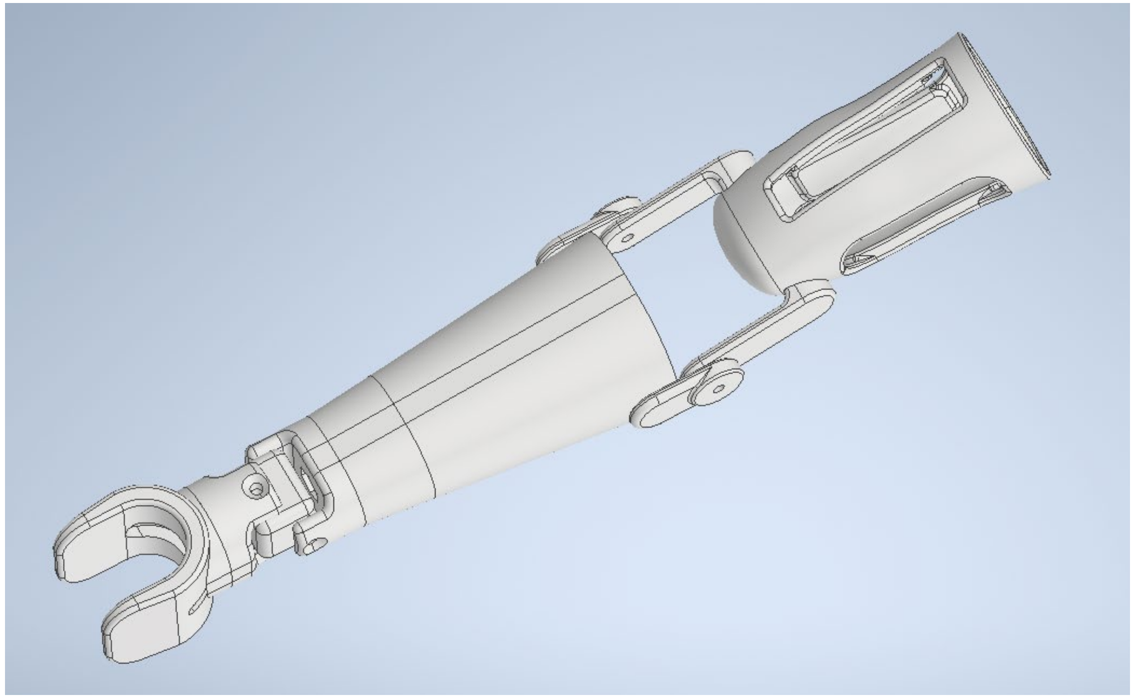

Figure 26 The effect of work of intelligent model - bicycle prosthesis for a child

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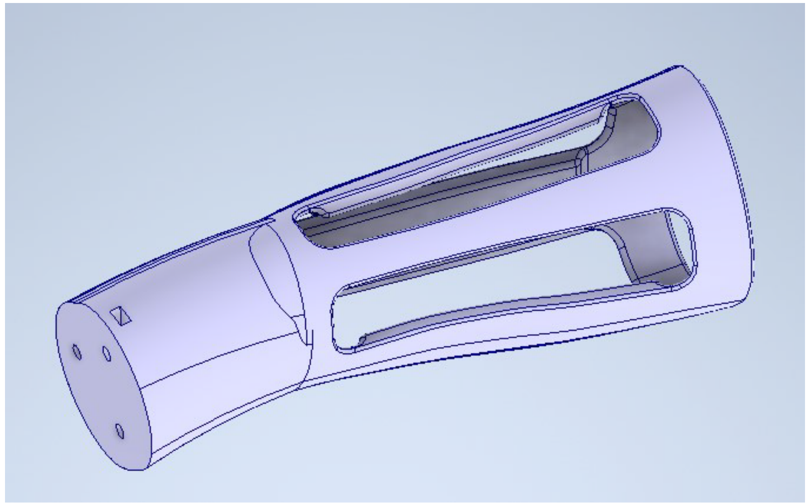
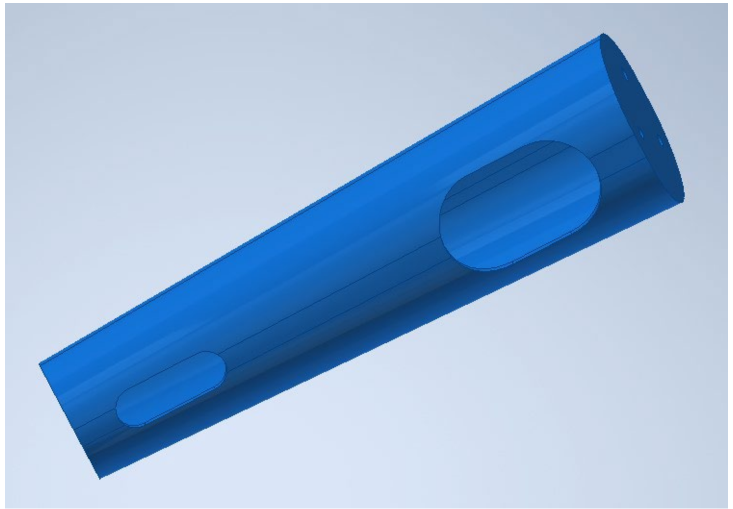


Figure 28 The final form of the CRS socket for an adult adapted to cycling



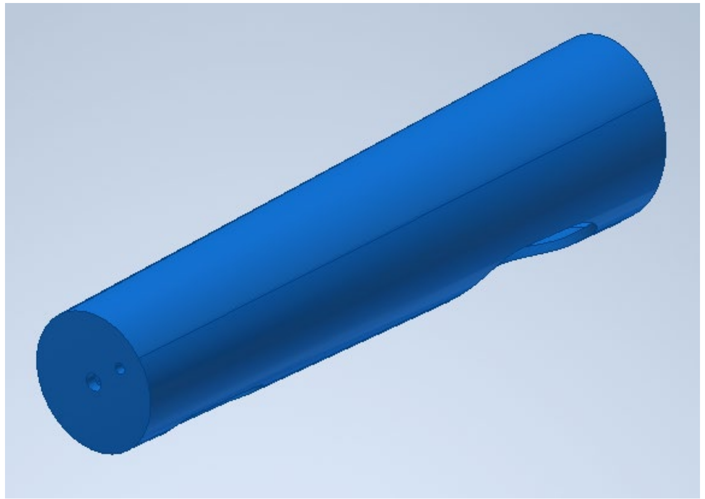


Figure 29 The final form of the forearm for an adult adapted to cycling

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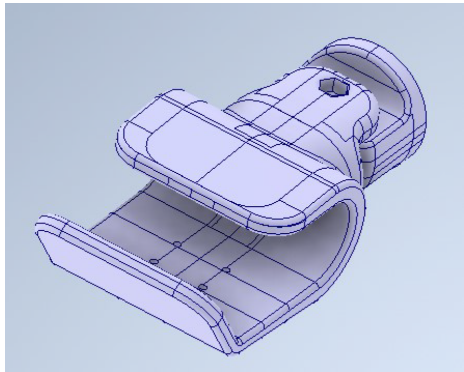
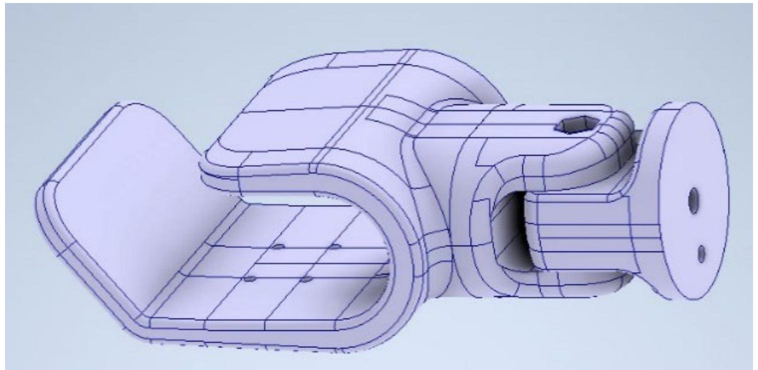
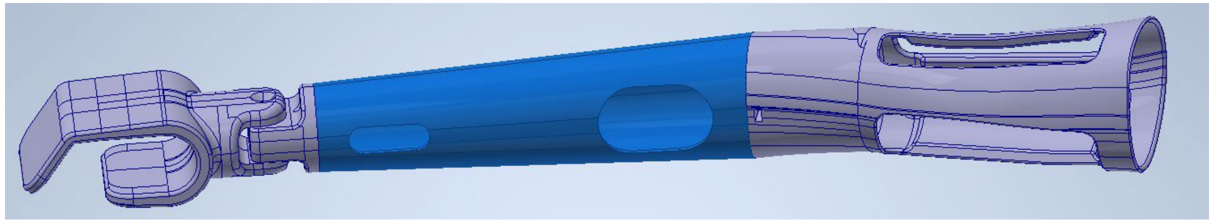
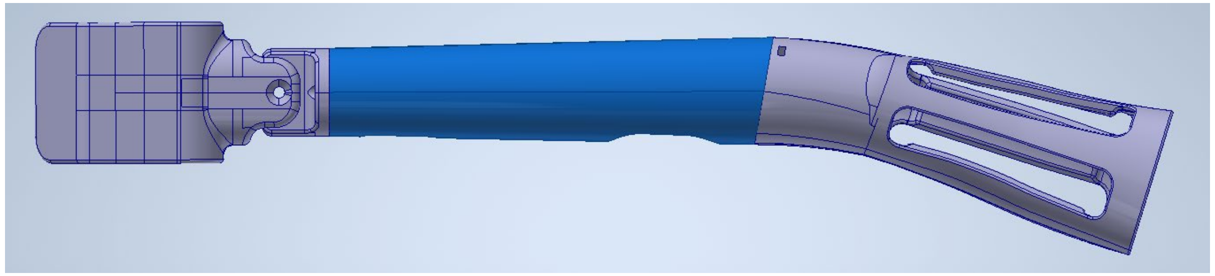
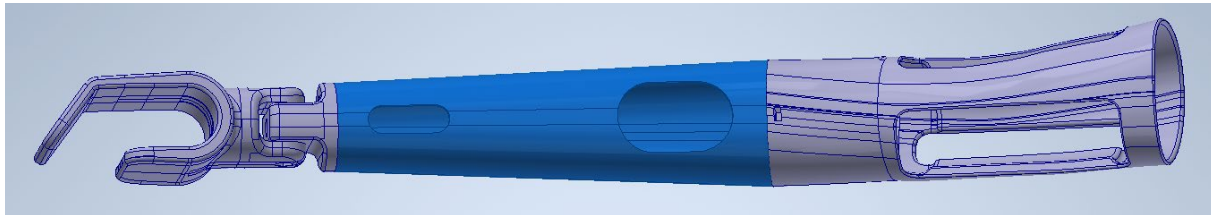



Figure 30 The final form of the C handle for an adult adapted to cycling

Figure 31 The final model of an adult bicycle prosthesis. A: Isometric; B: from above; B: from the side

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Design of electronic part of the biomechatronic prosthesis

The aim of the work was to modify the hand prosthesis in order to create a biomechatronic device, used by human, with monitoring of activities performed in the prosthesis (mostly cycling or similar activities). Main aim was placing an electronic measuring system in the prosthesis, thanks to which it would be possible to determine its operating properties. The detailed purposes of the built electronic system were to:

- measurement of the orientation of the upper limb prosthesis in space,
- measurement of the force exerted in the wrist,
- saving data on the SD card.

The device consisted of the following components:

- microcontroller module (Arduino NANO),
- force sensor measuring amplifier module (HX711 with force sensor up to 200N),
- inertial sensor module (BOSCH BNO055),
- SD card module,
- power source (a USB connected powerbank).

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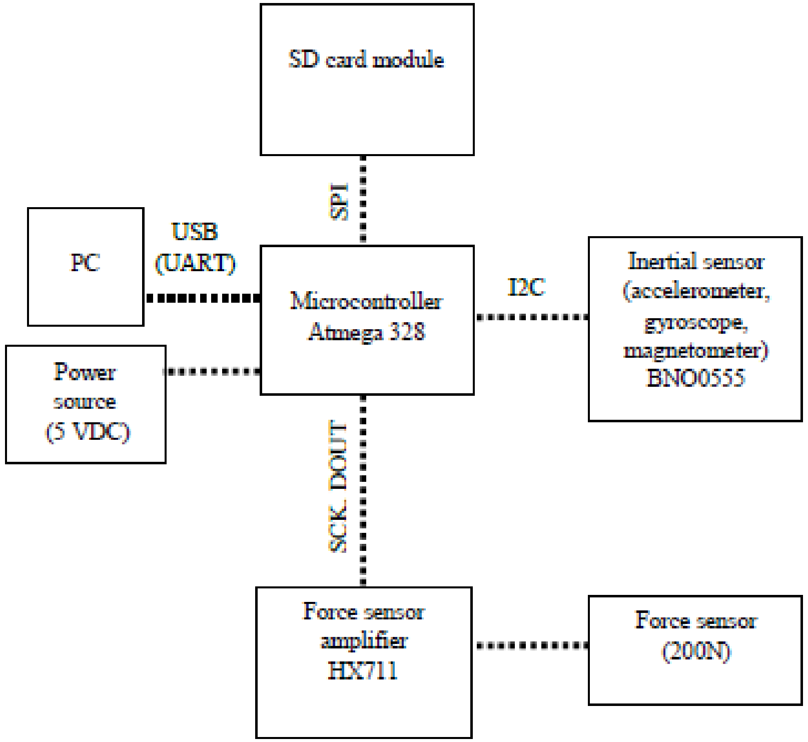

Figure 32 The schematic diagram of the electronic part of the prosthesis

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The following main changes have been introduced to the design:

- the forearm was modified to enable mounting of the microcontroller, inertial sensor and SD card module inside cavities of the forearm – insets were created with holes, for self-tapping purposes (Figure 33)
- at the joint of forearm and CRS socket, insets were added for mounting of the force sensor (beam) – the place (elbow) was selected to easily detect the torques and forces during the bicycle ride
- a number of assembly holes and cable feedthroughs were added to enable unproblematic assembly of the electronic part inside the prosthesis.

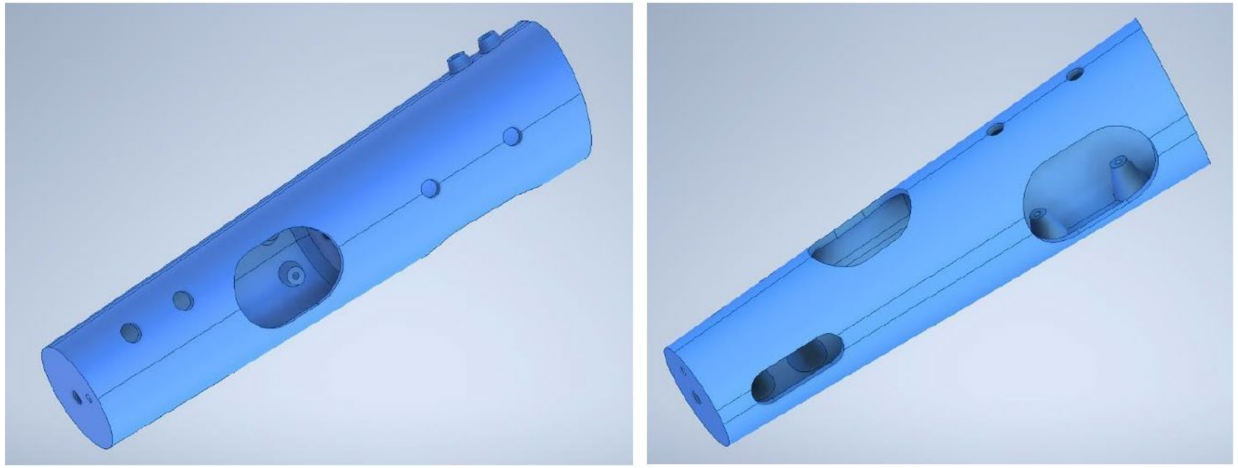

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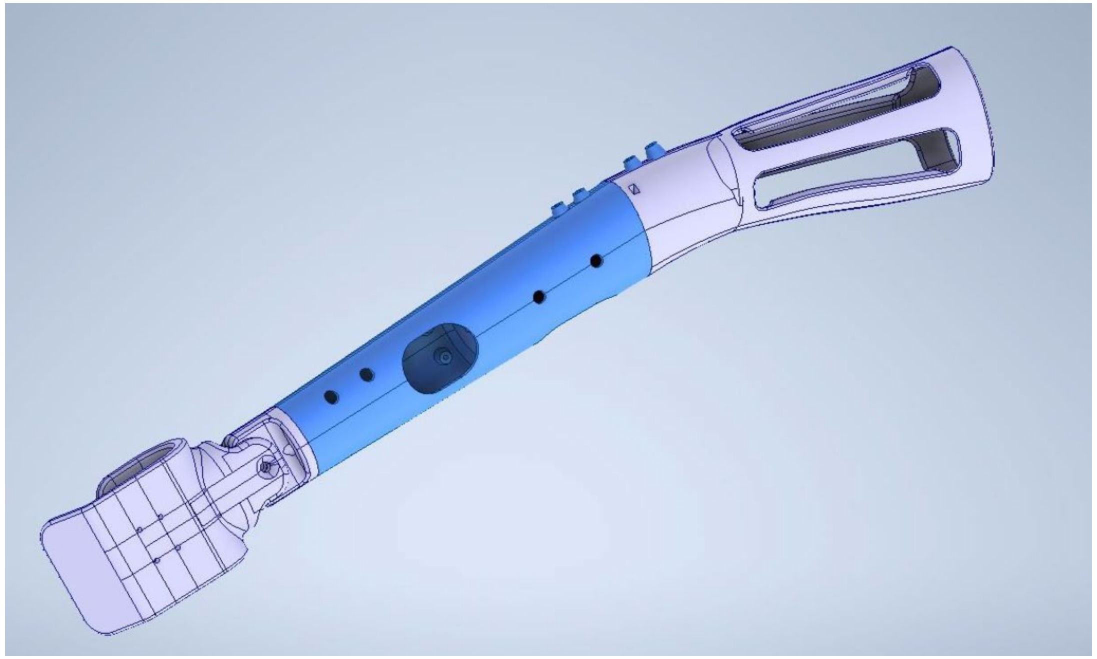
Figure 34 Final CAD model of the biomechatronic bicycle prosthesis



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Summary

In this toolkit, it was shown how a modular model of a low-cost 3D printed bicycle prosthesis can be designed and then converted into a simple biomechatronic device, equipped with sensors for biometrics of the bicycle ride activity.
The toolkit is a part of the set of instructions, focused on the prosthesis model.
The resulting model was 3D printed in further steps and then assembled, tested in laboratory conditions and then in real conditions, with the patient – this is described in other toolkits of the EMERALD project.

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