Universitat de Lleida

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INMOOV ROBOT: BUILDING OF THE FIRST OPEN SOURCE 3D PRINTED LIFE-SIZE ROBOT

Grau en Enginyeria Mecànica UdL
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1 OBJECTIVES

The objective of this project is to contribute in the printing and assembly of a life size robot at the Vaasa University of Applied Sciences. I had the opportunity to join this project, working together with Doctor Rayko Toshev and the other Erasmus student Alexandru Galben in this long going joint project to build the first open source 3D printed life size robot. The objective was to build this robot in less than 3 months while learning to print with 3D printers and follow all the guidelines written by the creator of this project Gael Langevin.

2 INTRODUCTION

The topic of this degree thesis is about my participation in the building of the InMoov robot at the Technobothnia laboratory in Vaasa, Finland. Following you will be able to find all the information regarding the robot itself, the state of the design right now, the state of the robot in which I participated, and the part of the building process in which I was involved.

This project started at the beginning of the academic year 2015-2016 by two students from Saudi Arabia, who were doing their Erasmus at Vaasa, during the first semester they printed a major part of the robot using two 3D printers: the Minifactory 3 and the Makerbot Replicator all of them located at the Technobothnia which has all its facilities available for students to complement their training.

On the second semester, myself and Alexandru Galben, another Erasmus student took this project and continued working on it. Although a good part of the robot was already assembled, we had to start from scratch since all the mechanical components necessary for the movement of the robot were missing, and therefore we had to disassemble it first.

As I write this, the robot is not finished yet, but I am happy that we managed to make a huge progress in its building, and we trust that our professor at the laboratory Dr. Rayko Toshev will be able to finish the remaining parts this summer in order to make it work as it should.

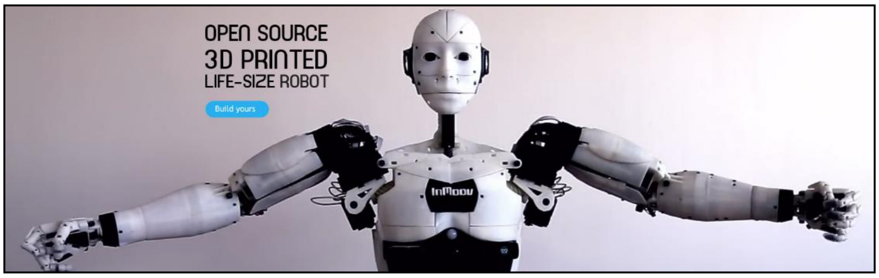

Figure 1. Presentation picture of the InMoov robot.

3 TECHNOBOTHNIA EDUCATION AND RESEARCH CENTRE

This joint project has been conducted in the Technobothnia facilities, inside the Additive Manufacturing laboratory. Technobothnia is an education and research centre located in Vaasa inside an old cotton factory. It was founded as an answer to increase the cooperation between the future engineers studying in the city, as well as benefitting to their education. This building is being jointly used by University of Vaasa, Vaasa University of Applied Sciences and Novia University of Applied Sciences.

This state-of-the-art building offers equipment in the areas of electrical, mechanical, construction engineering, and environmental, and information technology. It also offers services in testing and measuring as well as education in three different languages: Finnish, Swedish and English.

Figure 2. Technobothnia building.

4 GAEL LANGEVIN

4.1 Birth of the Project

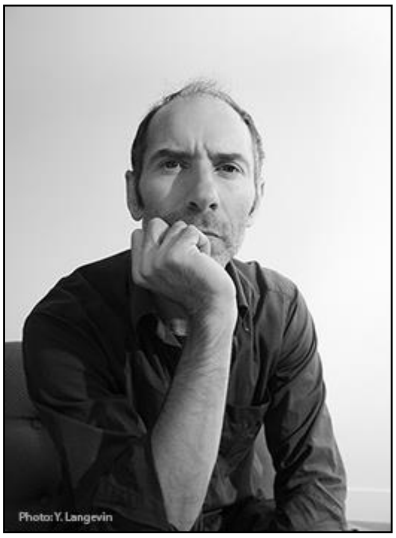

Figure 3. Gael Langevin.

Gael Langevin is the man behind this robot. He is a French sculptor and designer. His workshop is located in Paris, and he has been working for the biggest brands for more than 25 years. 4 years ago, January 2012 he started getting into robotics. The InMoov robot was born as a prosthetic hand project after he bought his first 3D printer for his work. After he released it to the public as open source, the feedback from the community helped and motivated him to continue with the robot.

This way InMoov was born as the first open source 3D printed life-size robot. The idea behind the design of each piece is to be able to print it in a small 3D printer with a 12x12x12 cm printable area, conceived as a development platform for universities, laboratories, hobbyist and makers. This system, based on sharing through a community gives him the honor to be reproduced in countless projects throughout the world. An estimation made by Gael himself numbers the amount of InMoov robots being built across the world at about 150 at different stages of the process. The feedback also helps in order to improve already existing parts of the robot, by either suggesting the improvements on the official InMoov website (inmoov.fr) or by going a step further and designing the parts themselves with the appropriate modifications.

The project itself it's still an unfinished work, since Gael wants to finish the whole robot adding legs to it, and the ability to walk. This will be the trickiest part of the robot design and functioning. Gael himself didn't know anything about robotics before starting with this project, he has been learning about it as he was working on this project. Before starting the InMoov, he had already designed some robotic parts although they were never really functional, but just aesthetic. In the designing of this robot he has gone a step further having to think about all the parts involved in giving it the functionality and movement he was looking for. As this is being written there are already 228 different pieces designed for the robot, and more to come. All of its functions are controlled using a software called MyRobotLab, a package developed by Greg Perry and the community.

All the downloadable parts from the official InMoov website are designed by Gael himself using and open source software called Blender. After finishing each part, is released under a License CC BY-NC 3.0 (Creative Commons attribution-non-commercial) so "InMoov" is a trademark. This design is based on a human figure to make sure it stays in the lines and shapes, although it's a secret on whom is based.

4.2 Getting started with the Project and Functionality

To build this robot yourself all you need to start with is a 3D printer, and around 1000$ worth of material. This includes the printing plastic, 32 hobby servos to get the robot moving, as well as two Arduino Mega boards, cables, screws, fishing line, and the electronical boards purchasable from the InMoov website. To get started you will also need the following tools: a computer, a drill, sand paper, glue, screwdrivers, threading tools (3, 4, 5, 8mm) and a cutter.

InMoov can listen to voice commands, talk and move. Its gestures can be very human-like. He can see, search for people and objects, he can track them in space and variable environments through his eyes (cameras). He can detect when there is movement at a certain distance and start a welcome sequence followed by random actions depending on your responses. He has a Kinect which lets us do gesture recognition. InMoov shares its scripts with all the other InMoov robots, which means they learn from each other, yet on a very basic level. All of this is a work in progress which evolves everyday as the community grows.[1]

[1] Langevin, G. September 2015. Robots and Androids. Online Blog. http://www.robots-and-androids.com/Gael-Langevin-and-InMoov.html

5 PART PRINTING

To get started with the robot building, first you will need to have all the parts printed. Regardless of the printer that you are using, any that has more than 12x12x12 centimetres of printing surface will work for this purpose.

There are some parameters though that you can specify in every software of a 3D printer, and that you need to be aware of in order to print the pieces correctly, and be sure that they won't break down while the robot is functioning.

The following specifications are the ones that we have used to print all the pieces of the robot except for the parts called piston. These parts require more infill (75-100%) to be resistant enough. Also, the parts called worm will need support activated in order to be printed correctly. For the rest of the parts the specifications are as it follows:

- Infill: 30%
- Nº of shells: 3
- Layer thickness: 0.3 mm
- Raft: None
- Support: None

Following I've completed a table with the estimated printing times of all the pieces designed so far, so it's easily seen how long this project can take. Just the printing alone adds up to an estimated combined total printing time of 16.605 hours. In my case, I've had at the disposal of the project two different printers, which helped to reduce the amount of time needed to print everything substantially.

Body part	*File name*	*Estimated print time (min.)*
Right Hand	Arduinosupport.stl	20
Right Hand	Auriculaire3.stl	20
Right Hand	Bolt_entretoise5.stl	40
Right Hand	Cableholder1.stl	5
Right Hand	Cableholderwrist1.stl	5
Right Hand	Coverfinger1.stl	5

Right Hand	Index3.stl	20
Right Hand	Majeure3.stl	20
Right Hand	Ringfinger3.stl	20
Right Hand	Robcap3V1.stl	70
Right Hand	Robpart2V2.stl	240
Right Hand	Robpart3V3.stl	240
Right Hand	Robpart4V3.stl	240
Right Hand	Robpart5V2.stl	300
Right Hand	Rotawrist1V2.stl	150
Right Hand	Rotawrist2.stl	120
Right Hand	Rotawrist3.stl	30
Right Hand	Stand1.stl	15
Right Hand	Stand2.stl	30
Right Hand	Thumb5.stl	20
Right Hand	Topsurface4.stl	200
Right Hand	Wristgears3.stl	20
Right Hand	WristlargeV3.stl	180
Right Hand	WristsmallV3.stl	90
Left Hand	Auriculaire3.stl	20
Left Hand	Bolt_entrtoise4.stl	40
Left Hand	Cableholder1.stl	5
Left Hand	Cableholderwrist1.stl	5
Left Hand	Index3.stl	20
Left Hand	Leftarduinosupport.stl	20
Left Hand	Leftcoverfinger1.stl	5
Left Hand	Leftrobcap3V1.stl	70
Left Hand	Leftrobpart1.stl	240
Left Hand	Leftrobpart2V2.stl	240
Left Hand	Leftrobpart3V3.stl	240
Left Hand	Leftrobpart4V3.stl	240
Left Hand	Leftrobpart5V2.stl	300
Left Hand	Leftrotawrist1V2.stl	120
Left Hand	Leftrotawrist2.stl	30
Left Hand	Leftstand1.stl	15
Left Hand	Leftstand2.stl	30
Left Hand	Leftthumb5.stl	20
Left Hand	Lefttopsurfae4.stl	200
Left Hand	LeftwristlargeV3.stl	180

Left Hand	LeftwristsmallV3.stl	90
Left Hand	Index3.stl	20
Left Hand	Majeure3.stl	20
Left Hand	Ringfinger3.stl	20
Left Hand	Rotawrist3.stl	30
Left Hand	Wristgears3.stl	20
Right Upper Arm	Armtopcover1.stl	200
Right Upper Arm	Armtopcover2.stl	160
Right Upper Arm	Armtopcover3.stl	240
Right Upper Arm	ElbowshaftgearV1.stl	60
Right Upper Arm	GearholderV1.stl	20
Right Upper Arm	GearpotentioV1.stl	10
Right Upper Arm	HigharmsideV1.stl	100
Right Upper Arm	LowarmsideV1.stl	50
Right Upper Arm	PistonanticlockV1.stl	100
Right Upper Arm	PistonbaseantiV1.stl	100
Right Upper Arm	ReinforcerV1.stl	60
Right Upper Arm	RotcenterV2.stl	300
Right Upper Arm	RotgearV3.stl	130
Right Upper Arm	RotmitV2.stl	180
Right Upper Arm	RotpotentioV2.stl	20
Right Upper Arm	RottitV2.stl	140
Right Upper Arm	RotwormV5.stl	60
Right Upper Arm	ServobaseV1.stl	70
Right Upper Arm	ServoholderV1.stl	110
Right Upper Arm	SpacerV1.stl	20
Left Upper Arm	Armtopcover1.stl	200
Left Upper Arm	Armtopcover2.stl	160
Left Upper Arm	Armtopcover3.stl	240
Left Upper Arm	ElbowshaftgearV1.stl	60
Left Upper Arm	GearholderV1.stl	20
Left Upper Arm	GearpotentioV1.stl	10
Left Upper Arm	HigharmsideV1.stl	100
Left Upper Arm	LeftrotcenterV2.stl	300
Left Upper Arm	LeftrottitV2.stl	140
Left Upper Arm	LowarmsideV1.stl	50
Left Upper Arm	PistonanticlockV1.stl	100
Left Upper Arm	PistonbaseantiV1.stl	100

Left Upper Arm	ReinforcerV1.stl	60
Left Upper Arm	RotgearV3.stl	130
Left Upper Arm	RotpotentioV2.stl	20
Left Upper Arm	RotwormV5.stl	60
Left Upper Arm	ServobaseV1.stl	70
Left Upper Arm	ServoholderV1.stl	110
Left Upper Arm	SpacerV1.stl	20
Right Shoulder	ClavibackV1.stl	180
Right Shoulder	ClavifrontV1.stl	180
Right Shoulder	PistonbaseV4.stl	100
Right Shoulder	PistonclaviV2.stl	100
Right Shoulder	PivcenterV1.stl	300
Right Shoulder	PivconnectorV1.stl	60
Right Shoulder	PivgearV3.stl	130
Right Shoulder	PivmitV1.stl	180
Right Shoulder	PivpotentioV2.stl	10
Right Shoulder	PivpotholderV2.stl	50
Right Shoulder	PivtitV1.stl	140
Right Shoulder	PivwormV2.stl	60
Right Shoulder	ServoholderV1.stl	110
Right Shoulder	ServoholsterV1.stl	100
Left Shoulder	ClavibackV1.stl	180
Left Shoulder	ClavifrontV1.stl	180
Left Shoulder	PistonbaseV4.stl	100
Left Shoulder	PistonclaviV2.stl	100
Left Shoulder	PivconnectorV1.stl	60
Left Shoulder	PivgearV3.stl	130
Left Shoulder	LeftpivcenterV1.stl	300
Left Shoulder	LeftPivmitV1.stl	180
Left Shoulder	LeftpivpotholderV2.stl	50
Left Shoulder	LeftpivtitV1.stl	140
Left Shoulder	PivpotentioV2.stl	10
Left Shoulder	PivwormV2.stl	60
Left Shoulder	ServoholderV1.stl	110
Left Shoulder	ServoholsterV1.stl	100
Torso	Homplateback-V1.stl	110
Torso	Homplateback+V1.stl	110
Torso	Homplatebacklow-V1.stl	100

Torso	Homplatebacklow+V1.stl	100
Torso	Homplatefront-V1.stl	100
Torso	Homplatefront+V1.stl	100
Torso	ServoholsterV1.stl	100
Torso	SternumV1.stl	100
Torso	ThroatlowerV1.stl	100
Neck	FaceholderV4.stl	60
Neck	GearholderV1.stl	120
Neck	MaingearV1.stl	70
Neck	NeckboltsV2.stl	60
Neck	NeckhingeV1.stl	140
Neck	NeckV1.stl	300
Neck	RingV1.stl	30
Neck	ServogearV1.stl	70
Neck	SkullservofixV1.stl	160
Neck	ThroatholderV2.stl	40
Neck	ThroatholeV3.stl	90
Neck	ThroatpistonbaseV3.stl	180
Neck	ThroatpistonV3.stl	130
Jaw	JawhingeV1.stl	40
Jaw	JawhingeV3.stl	40
Jaw	JawpistonV1.stl	35
Jaw	JawsupportV1.stl	60
Jaw	JawV4.stl	210
Skull and Face	EyeglassV2.stl	150
Skull and Face	LowbackV3.stl	240
Skull and Face	SidehearV3.stl	130
Skull and Face	TopbackskullV1.stl	260
Skull and Face	TopmouthV2.stl	200
Skull and Face	TopskullleftV2.stl	300
Skull and Face	TopskullrightV2.stl	300
Eye mechanism	EyecameraV3.stl	70
Eye mechanism	EyemoversideV3.stl	10
Eye mechanism	EyemoverupV3.stl	10
Eye mechanism	EyesupportV3.stl	70
Eye mechanism	EyetonoseV4.stl	30
Ears	EarrightV1.stl	130
Ears	EarleftV1.stl	130

Table 1. Printing times list.

6 FULL BUDGET FOR THE BUILD

When deciding to build the InMoov, one of the most important things to take in consideration is the full list of materials that are going to be necessary to build it. It will be important as well to think about the money that will cost all of it.

Following there's a complete list of pieces and approximate prices of each part divided into body parts, since not always the robot is going to be built all at one time.

6.1 Hands and Forearms

All the materials included in this section are meant to be for the build of both arms.

10x Servos HK15298B	190 €
2x Servos MG996R	23 €
90kg Fishing line	27 €
1x Copper Plate	12 €
1x Liquid Silicon Charge	3 €
1x 300mmx300mm Antistatic Foam	7 €
Total	262 €

Table 2. Hands and Forearms materials prices.

6.2 Arms and Shoulders

All the materials included in this section are meant to be for the build of both arms.

8x Servos HS805BB	210 €
1500gr Natural ABS	49 €
Total	259 €

Table 3. Arms and Shoulders materials prices.

6.3 Head and Torso

The robot requires just one battery to work, but for the sake of extending the autonomy of InMoov you should at least have 2 or 3, and it should be good to run for a few hours. The cameras listed below will have to be dismantled, since only the camera lens and the important parts are remaining.

2x Servos HS805BB	55 €
1x Servo HK15298B	20 €
3x Servos DS929HV	50 €
1x Kinect Xbox One	145 €
2x Hercules HD Twist	36 €
3x Battery 6V 12A + Charger	80 €
2x Speakers 4Ω 6W	18 €
1x PIR Sensor HC-SR501	2 €
2000gr Natural ABS	60 €
Total	466 €

Table 4. Head and Torso materials prices.

6.4 Stomach

2x Servos HS805BB	55 €
2x Servos VSD-11AYMB	40 €
Total	95 €

Table 5. Stomach materials prices.

6.5 Miscellaneous

2x Arduino Mega	21 €
50x Allen Screw M3x20mm	7 €
50x Allen Screw M4x20mm	4 €
15x Allen Screw M8x100mm	11 €
100x Phillips Flat-Head Wood Screw M3x12mm	6 €

50x Phillips Flat-Head Wood Screw M4x20mm	5 €
2x Bolts M8x85mm	4 €
2x Bolts M8x70mm	3 €
1x Ribbon Cable 10 PIN 10cm	6 €
4x Ribbon Cable 10 PIN 30cm	24 €
1x Ribbon Cable 10 PIN 35cm	6 €
1x Ribbon Cable 10 PIN 55cm	6 €
1x Automotive Switch	6 €
1x Can of White Grease	10 €
Total	119 €

Table 6. Miscellaneous materials prices.

6.6 Total Budget

With all the costs of parts explained previously, we can now you have a very good approximation of how much it will cost an InMoov robot of your own. The total price of purchasable materials for the build adds up to about 1.201 € as it can be seen on table 7.

Hands and Forearms	262 €
Arms and Shoulders	259 €
Head and Torso	466 €
Stomach	95 €
Miscellaneous	119 €
Total	1.201 €

Table 7. Total Budget.

6.7 Additional Tools

When building the InMoov you don't have to just think about the materials to buy, but also you need to have in mind all the tools that will be necessary during the process. Since the project is conceived as a development platform for universities, laboratories, hobbyist and makers it is based on the idea that people trying to replicate the robot will already have the tools necessary, but just in case some is missing, here is the list with all the devices that are going to take part in the build of InMoov.

- 1 PC running Windows XP or higher with MyRobotLab installed.
- 1 bluetooth wireless headphone with microphone.
- Screwdrivers sizes M3, M4 and M8.
- Drill with sizes from M1 to M10.
- Silicon gun.
- Tweezers.
- Soldering material.
- Sand paper.
- Lime.

All of this equipment is commonly found in a workshop, but in the case that someone without the tools wants to build it, it will also be necessary to consider the money to buy everything, or the missing tools.

7 SERVOS

Servo motors are a really important part of the InMoov. The robot it's made up of 30 servos. All of the give the robot its full ability of movement. They come in different sizes and powers, and are very useful in our project. When successfully assembled and working, all of these servos will provide InMoov with a human-like movement.

7.1 Description

A modelling servo, usually just called servo is an actuator device with the ability to locate itself in any position within the operating range, and to stay stable at that exact same position. A typical servo consists of a direct current engine, a train of reduction gears and a control circuit. Its working range is usually less than a 360 degree turn.

This kind of servos are usually found in radio controlled vehicles and robotics, although its use is not exclusively limited to those.

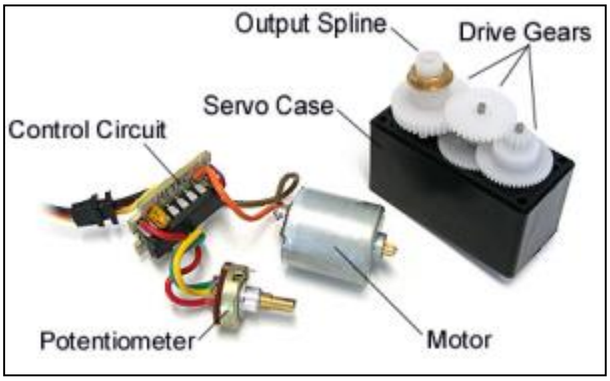

Figure 4. Parts of a servo.

7.2 Internal Structure and how it Works

The main component of a servo is a direct current engine, which acts as an actuator of the device. When applying a voltage between its two terminals, the engine will spin in a direction at high speed, but producing a low amount of torque. To maximise this torque it has group of reduction gears, with reduce the speed and amplify the torque.

The device utilises a control circuit to ensure that the engine stays at the desired position with the help of a potentiometer.

The reference point, or setpoint is the value of the desired position. This point is indicated by a square control signal. The pulse width of the signal indicates the angle position. A wider pulse means a higher angle.

Initially, an error amplifier calculates the value of the position error, which is the difference between the setpoint and the current position of the engine. A bigger position error will mean that the offset between the desired position and the current position is bigger, therefore making the engine spin faster in order to achieve that position. A smaller position error will mean the engine is closer to the desired position, making the engine spin slower. Once the engine reaches the desired position, this position error will be zero, making the engine to stop.

For the error amplifier to be able to calculate the position error it must subtract two analogic voltage values. The setpoint control signal is converted then in an analogic voltage value using a converter with reads the width pulse as a voltage. The value of the engine position is obtained using a potentiometer mechanically coupled to the reduction gears of the engine. When the engine will spin, so will the potentiometer, varying the value of the voltage that the error amplifier receives. Once obtained this position error, it is amplified and sent to the engine terminals.

7.3 Alternative Servos for the InMoov

The servos specified in the budget list are the ones which were used by Gael Langevin and myself. There is the possibility though, to use different servo engines and still have a fully functional and correctly working InMoov. The possible replacements for these servos are:

For the hand:

- TGY-5521MDHV (24kg of torque, should fit)
- JX PDI-6221MG (20-36kg torque, should fit)
- RS-550MGC-HV (11.2kg torque, should fit)
- HS-311 (3.5kg torque, should fit)
- XQ-S4020D (21.5kg torque, should fit)

For bicep, shoulder and torso:

- SV-0235MG (35kg torque, should fit)
- TS-80 2BB (24kg torque, identical to HS805BB)
- CYS-S8218 (40kg torque, does not fit, needs adjustment)
- HK15338 (25kg torque, should fit)

For the eyes:

- MG91 (2.6kg torque, should fit)

For low stomach:

- SV-0235MG (35kg torque, fits with no modifications)
- CYS-S8218 (40kg torque, fits with no modifications)

7.4 Hacking a Servo

For the building of the InMoov, there are a lot of servos involved. Some of them will need to be hacked in order to remove the potentiometer from inside and place it in an articulation of the robot. This is done in order to send to the servo's con-

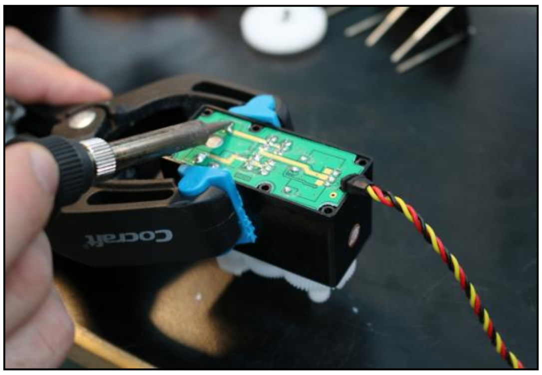

Figure 5. Unwelding engine terminals from control board.

trol board the exact position of the articulation and regulate it according to that reference. The procedure to "hack" the servo is done as following.

First of all you have to open the servo and unweld the electrical engine terminals from the control board. This way you are able to completely open the servo.

Following you will have to remove the potentiometer from the train of gears which is as simple as pulling it. You will also have to remove the plastic stop that prevents the servo from doing more than a complete turn. To do so you will need some precise cutting tool to be able to cut that plastic appendix without damaging the rest of the gear.

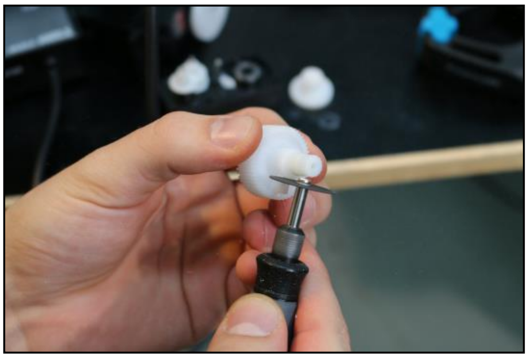

Figure 6. Removal of the stop from the plastic gear.

Figure 7. Hacked servo with the longer potentiometer coming out.

Finally we will enlarge the hole from where the servo cables come out to allow the potentiometer cables to go through, and we will cut this cables to enlarge their length by adding additional cable in the middle. We also have to bear in mind that for the left arm, and left torso servos we will have to reverse the positive voltage terminal and the ground terminal (usually the red and the black cables), except for the bicep servo.

Following on Figure 8 you can see the purpose of hacking a servo, with the potentiometer of the servo placed inside a gear to monitor its position.

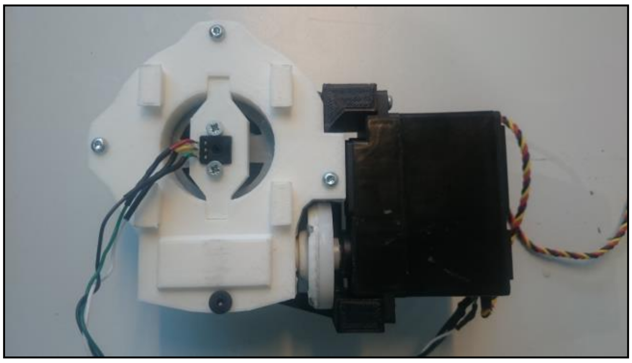

Figure 8. Placement of a potentiometer inside a gear.

8 ROBOT CONSTRUCTION

The whole participation with the build of the InMoov robot has been possible thanks to the Vaasa University of Applied Sciences. The idea was to contribute to the assembling of it and to make it work as expected. I and my laboratory partner Alexandru Galben have been able to fully assemble both complete arms of the robot, and part of the torso. Following are the instructions of all the steps that we had to make in order to ensure the correct functioning of the mentioned parts.

8.1 Hands

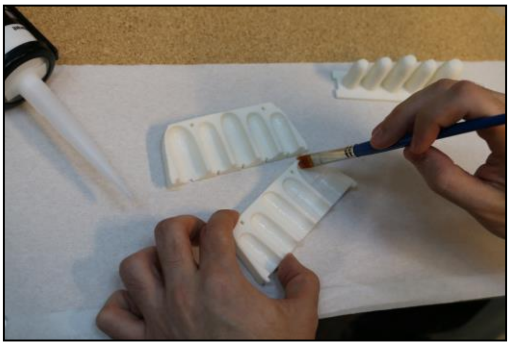

Figure 9. Applying soap on the fingertips mold's surface.

To begin with, we started working on the robot hands. To ensure a better grip for the robot, the finger tips had to be made out of silicone. For it, we firstly had to print out the molds for the fingers. Once printed the mold has to be assembled and covered with wax, vaseline or dish soap.

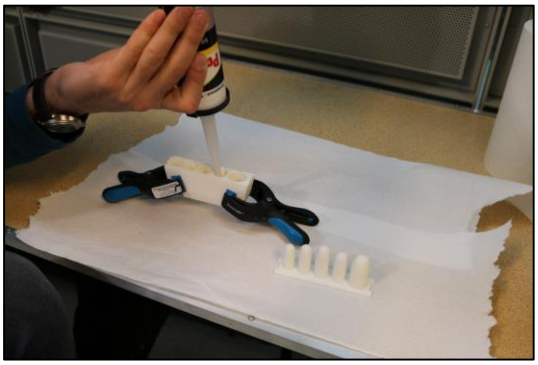

Figure 10. Pouring silicone inside the fingertips mold.

In our build we used some hand washing soap. This will helps once the silicone is dry and has to be separated from the surface of the mold.

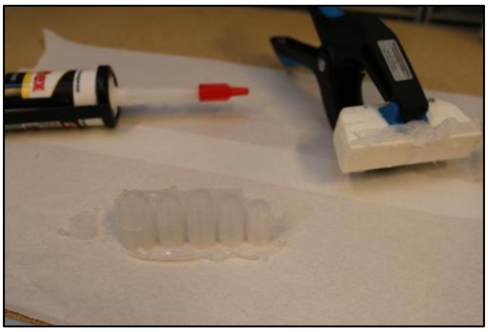

Figure 11. Finished fingertips next to closed mold.

Some minutes after applying the soap, you are ready to pour silicone inside the mold. To be sure you are adding the correct amount, you should fill each finger up until the middle, and then introduce the other half of the mold carefully. Since there will be some extra silicone that will be exiting the mold from the top, some side holes are made exactly for that. Wait the curation time specified for the silicone used before removing the mold. Open it carefully with a screwdriver and remove the finger-tips.

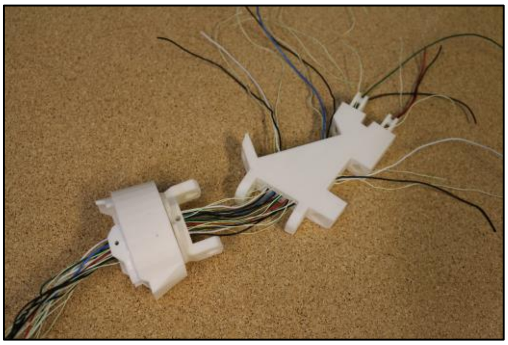

Figure 12. Base and palm of the hand with all the cables running through.

Now that we have the fingertips we are going to proceed and assemble the rest of the hands. We have to take in considera-tion that trough the fingers there is going to be not just the tendons pulling the fin-gers, but also the cables responsible of transmitting the signal sent by the sensors, that will be located on the fingertips. Bearing that in mind we should be pulling the tendons and cables through the fingers while we are assembling them.

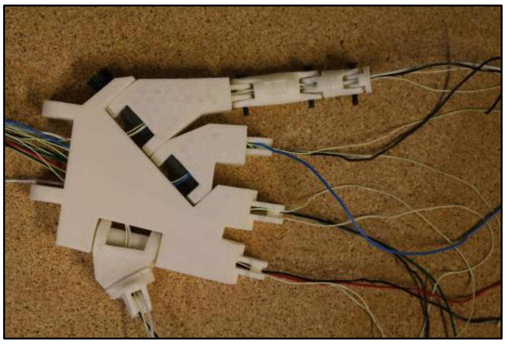

Figure 13. Assembling fingers on at a time.

To make the job easier, you should group the two cables and two tendons that run through each finger all together and as-semble one finger at a time. Start by pull-ing all the cables and tendons through the wrist part and the palm of the hand. Then pull carefully through each finger taking in consideration that the tendons should go one on the upper part of the finger and one on the lower part, and the same for the cables.

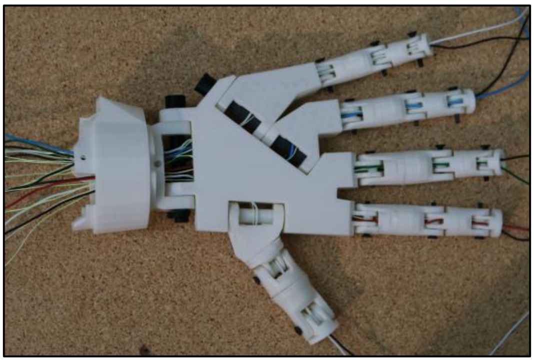

Figure 14. All the fingers of the hand assembled.

To finish with the assembly of the hands we are going to put the sensor on the fingertips. To do so, we are going to cut some small copper triangles, and weld them to the end of both cables of

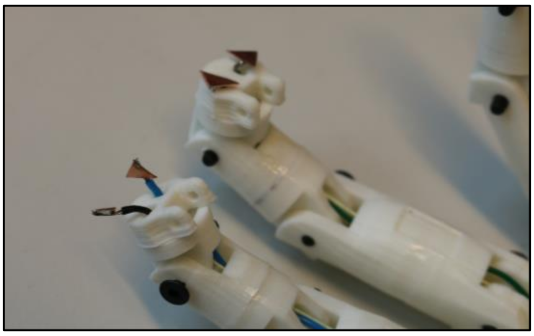

Figure 15. Welded copper triangles to the cable ends of the fingers.

each finger. After this we are going to apply some glue to fix the copper triangles on the flat surface of the finger. Finally some antistatic foam is cut to fit inside the gap that there is at the fingertip. When the fingertip will make contact with something will press the foam, connecting the two cables and sending the signal to stop the finger movement.

Once assembled we will put the covers of the hand to make it look more human-like. The silicone fingertips should also be added now, once we finished installing the sensors. Additionally some rubber surface can be added to the palm of the hand to improve its grip.

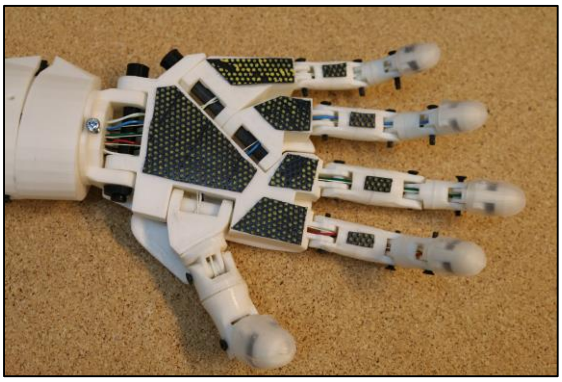

Figure 16. Completely assembled hand.

8.2 Wrist

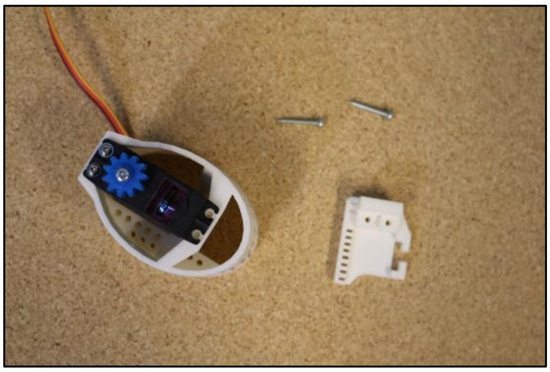

Figure 17. Assembling the wrist.

With the hand ready, we need to provide the wrist with the rotation movement. This part will be attached next to the hand, and before the forearm. This part will count with one small servo inside that will provide the force for the rotation. We will need to first assemble the wrist separately with the servo, a custom printed gear to allow the movement and a perforated plastic plate that will ensure that the cables run straight

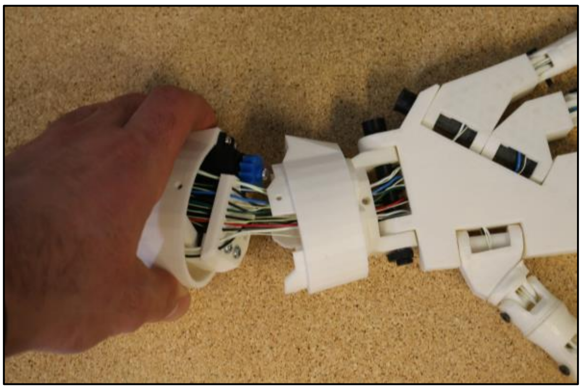

Figure 18. Adding the wrist to the hand.

through the wrist. Once fully assembled we will attach it to the hand. To do so we will run the tendons and cables carefully through the wrist, and add some grease for the lubrication between gears.

8.3 Forearm

Once the hand is finished we are going to attach it to the forearm. To do so, first the forearm parts need to be printed and glued together. To glue plastic together you have to take in consideration which kind of plastic you are working with. In case you are working with ABS you will need acetone, and for PLA you will need epoxy. In our case we worked with ABS, but the process is the same in either case. Pour some gluing material (acetone or epoxy) in a glass, apply some of it on the surface that will be glued with a brush, and hold the pieces together with clamps. It dries pretty quickly, but it is better to let it rest for a day to make sure the union is completely sealed.

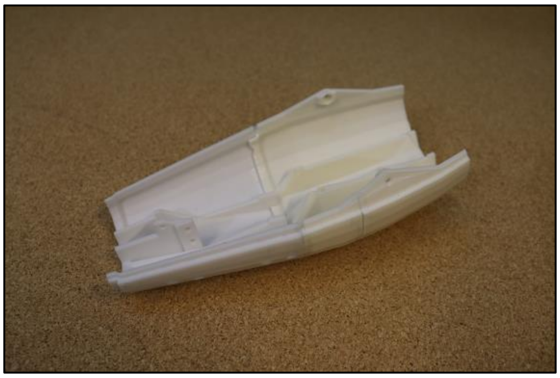

Figure 20. Glued forearm cover.

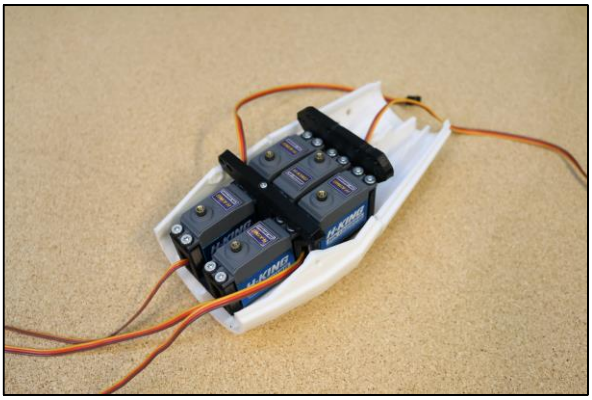

Figure 19. Servos attached to the forearm.

Now that the base of the forearm is finished the servos will need to be placed inside. This servos are the ones who will make each finger move. You first need to screw in the mount of the servos, and then screw each servo in place. Once all servos are in place we will attach custom printed gears on top of them which will help to pull the fingers correctly. Just one screw is necessary to attach these gears.

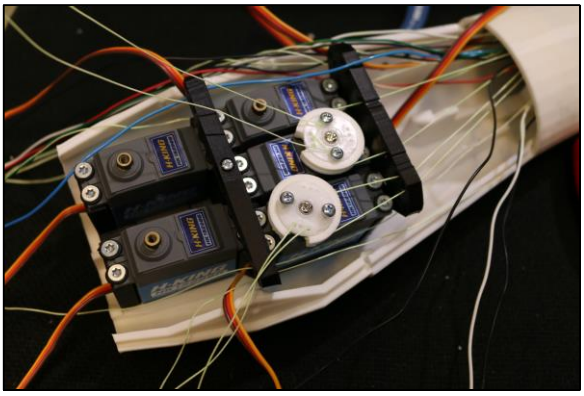

Figure 21. Putting the gears on the servos.

After we are going to assemble to forearm part to the wrist with glue. Last and most important you are going to run the tendons through the servo gears, carefully, making sure that there's enough tension at the lines to allow the correct movement of the fingers. We attached each servo to and Arduino Uno board and the power supply to test each time until the correct positioning and tension was accomplished. It took several tries to achieve the perfect tension to make the fingers move smoothly in both directions (closing and opening). You need to remember to place the servos at the default 0º position, and place the fingers straight before attaching the tendons.

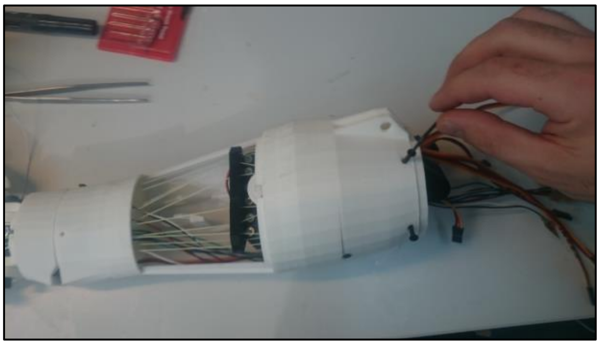

Figure 22. Final assembly of the forearm.

8.4 Bicep

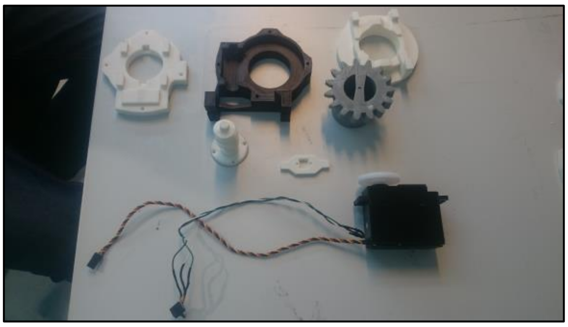

Figure 23. Shoulder parts before assembly.

To complete the arm, last missing part is the bicep. This part contains two servos responsible for the rotation of the whole arm, and for the movement of the elbow articulation.

For the assembly of the bicep part, we are going to begin with the upper part responsible for the rotation of the complete arm. Since this part has worm drive gear arrangement, a special effort will be needed when polishing the parts after printing. During this build, all of the printed parts have been modified after the printing due to the printer tolerance between the model and the final printed product. Especially with this type of gear arrangement, it needs some further polishing to ensure the smoothness of the movement.

Figure 24. Assembling the shoulder.

Once the gears are perfectly working, we will screw in the servo, putting the potentiometer of the servo in the middle of the worn gear. This potentiometer is usually located inside of the servo, but in this case it will need to be previously remove it from the inside and extend it using some 20 centimeters of extra cable as it is explained at section 6.4 Hacking a Servo.

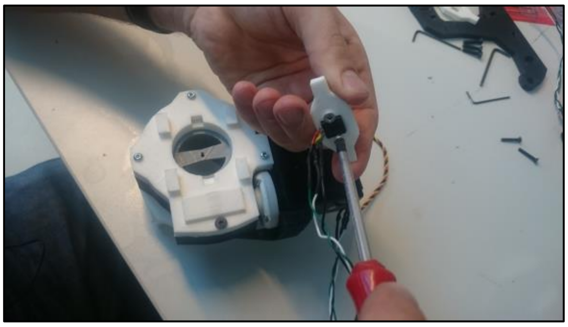

Figure 25. Potentiometer attachment to the middle of the gear.

We will then proceed to put the top to the worm drive gears after applying some grease between them. A test of the servo should be done before continuing with the assembly to assure the correct functioning of it and to stablish the neutral position (usually located around 90º). Now all the plastic printed parts which form the structure of the bicep will be added to the previous part like shown in the figure 26.

Figure 26. Bicep assembly.

Before attaching the last servo we will assemble this next to the forearm using a printed plastic screw to hold them together. Once the arm is fully assembled we can then attach the bicep servo in its place, with its potentiometer at the elbow articulation. Finally a careful test should be conducted to find out the limits of the articulation, and therefore limit the movement of the servo. This result may vary in each case. The figure 27 shows how it looks once the bicep part is finished.

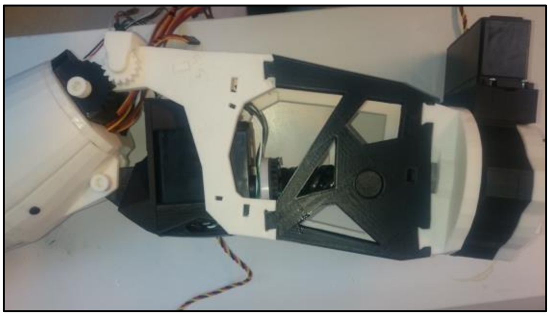

Figure 27. Finished bicep without the cover.

Last only the covers of the bicep should be added to finish it. The exact same process will be used for both arms. Further explaining and pictures can be found at http://inmoov.fr/ and https://www.wevolver.com/gael.langevin/inmoov-robot/main/description/.

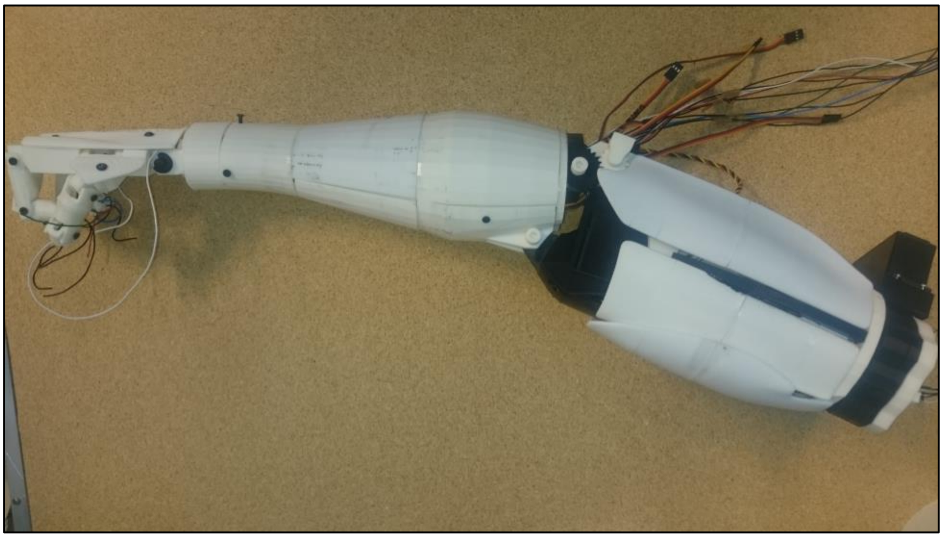

Figure 28. Fully assembled arm.

8.5 Shoulders and Torso

For assembling the next part of the Inmoov you should proceed with same method as the constructor of the project described on his website. In his tutorials Gael

Langevin shows how to build the shoulders and torso simultaneously. For this part you will need 4 servo motors which also need to be hacked as the servos from the bicep part by removing the potentiometer and making the cables around 25 cm longer.

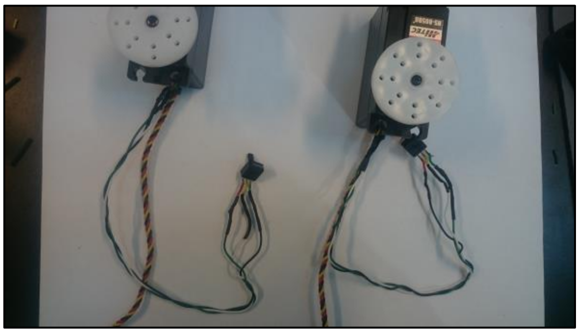

Figure 29. Hacked servos used for the shoulder.

Two servos are used for the shoulder movement and another two are used for the scapula movement. The first step was to hack the servo motors. For the right side of the robot the cables of the potentiometer should the same as it was before extracting it from the servo but for the left side you will have to change the cables from the sides of the potentiometer in order to change the polarity of the servos. It will make the servo to rotate in the opposite way.

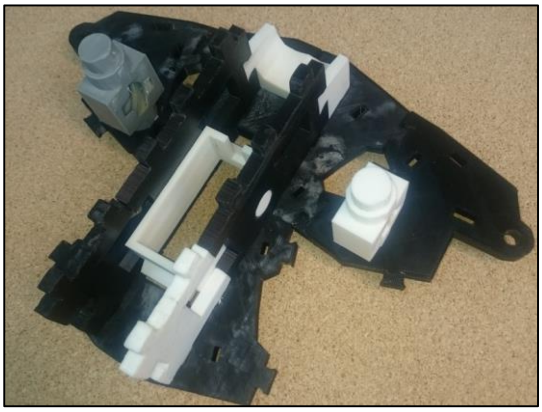

Figure 30. Back part of the torso with the two scapula piston bases.

Next step is to build the shoulder, this part is similar to the upper part of the bicep. It contains the same worm gear mechanism and it needs the same actions as in the bicep part to assemble it.

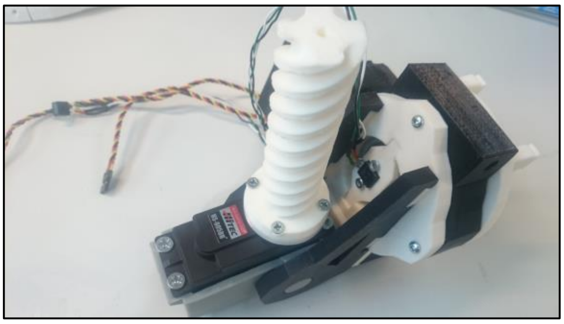

Figure 31. Scapula servo attached next to the shoulder.

The next step is to attach the servo which will create the scapular movement to the shoulder part which later will be attached to the torso.

Next step is to assemble the torso. First we have to mount together all the parts of the back side of torso. This part is quite easy since it’s a lot

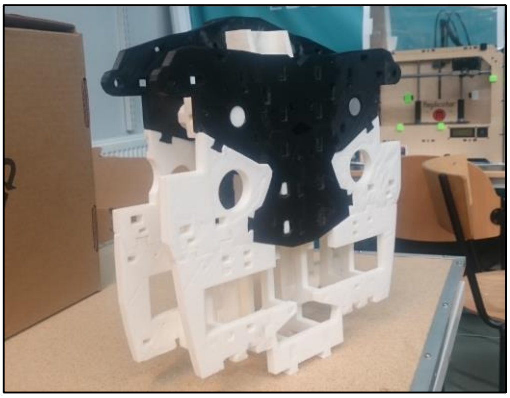

Figure 32. Fully assembled torso.

like assembling a Lego, but the difficult part is that all the pieces will have to be polished with sand paper for quite some time to make everything fit. At the same time the servo holder for the servo motor which will produce the movement of the head moving up/down should be placed inside of the torso and the piston base part for the scapula movement.

Once everything is together we can put the front parts of the torso and start assembling the bottom side of torso which will hold the Kinect.

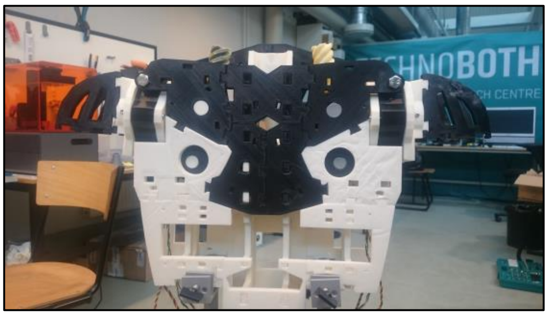

Figure 33. Torso with shoulders and scapula parts.

Now at this point is time to assemble together the shoulder and the torso, but first we have to put a good amount of grease on the piston screws which will move the scapula, and assemble together the shoulders to the torso. We will set the potentiometer for the scapula on the back side of the shoulders connected to the torso.

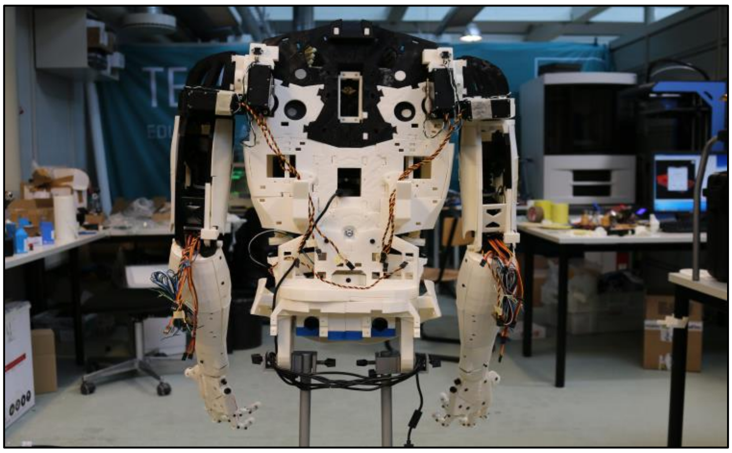

Figure 34. Fully assembled torso and arms seen from behind.

9 ADDITIONAL INFORMATION ABOUT THE ROBOT

Since we were not able to complete the InMoov robot with the limited amount of time that we had, here is some additional information that we left at the university for the next people who will carry on the work from where we left it.

First of all it should be known that although there are already several servos placed they can only be moved one at a time for now, so once the build will be finished everything should be connected to two Arduino Mega that will control all the servos from the robot. Also the robot is still under development, so new parts of the robot will be available in the near future. It's planned to build the low stomach part, and the complete legs of the robot.

The most important thing to have in mind for not breaking the robot is knowing how to set the servos and what their limits are. We already had to reprint some pieces due to mistakes made when setting the servos resulting in broken pieces. Following is the table with all the servos placed so far.

Group	Part Name	Rest Position	Min. Position	Max. Position
Hand	Thumb	0	0	180
	Index	0	0	180
	Middle	0	0	180
	Ring	0	0	180
	Pinky	0	0	180
	Wrist	90	0	180
Arm	Bicep	0	0	85
	Rotate	90	40	180
	Shoulder	90	0	180
	Scapula	95	95	150

Table 8. Servo setting from InMoov hardware map.

10 ELECTRO-MECHANICAL LAYOUT

Once the InMoov robot is finished it still has to be programmed to do all the movements and have all the features that we would like to make him do. For the person who is going to programm it, the following layout is very usefull in orther to know all the servos available and all the signals he is going to have to send and to receive.

Furthermore it's a very organized way to see everything you need to conect to the Arduinos once the built is finished, and how you should do it.

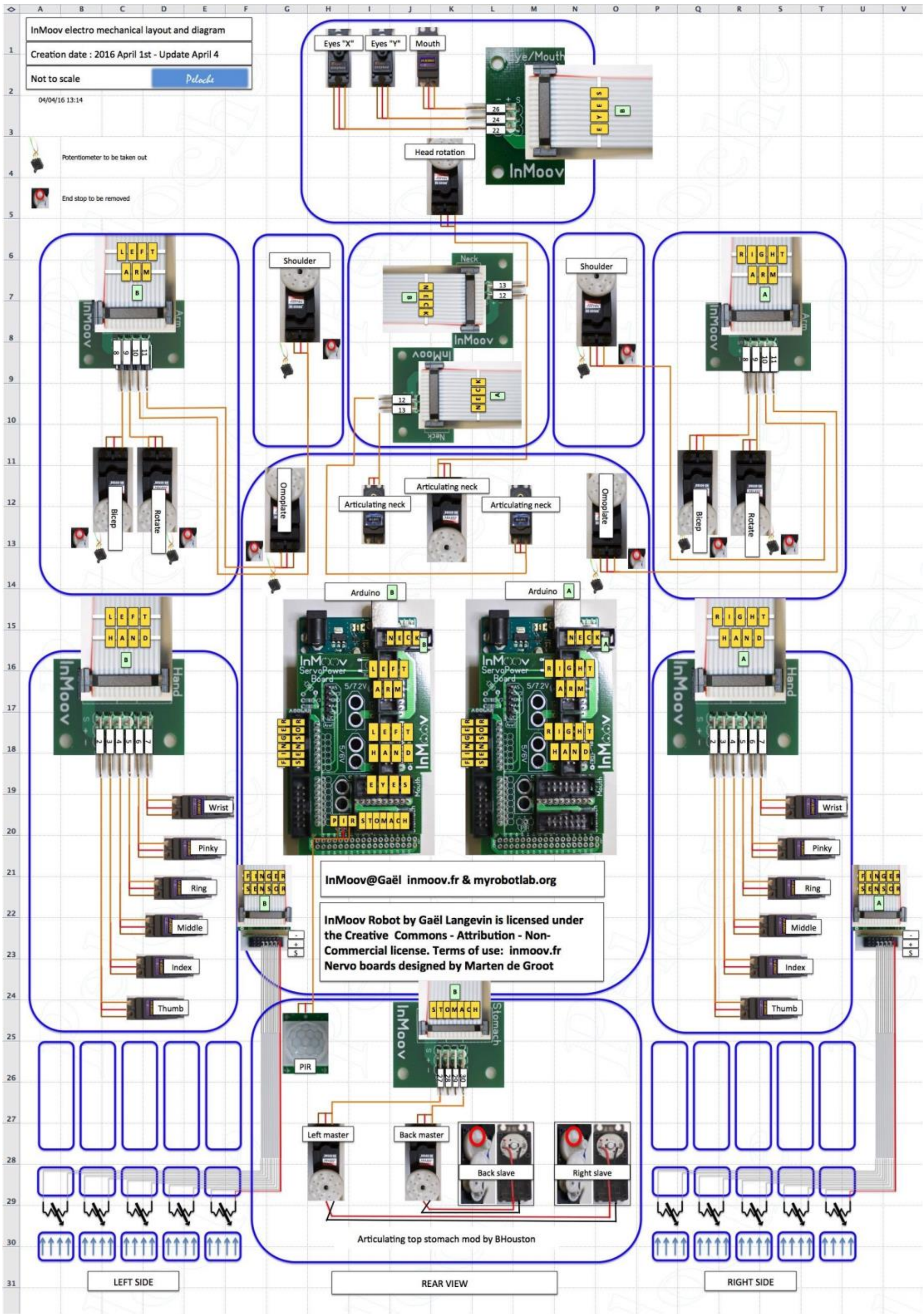

Figure 35. InMoov electro-mechanical layout and diagram.

11 CONLUSIONS

The development of this project has contributed to implement a life size robot at the Vaasa University of Applied Sciences. The initial idea of the project was to build the full InMoov robot in less than 3 months as explained at 1. Objectives. Finally, though, we were not able to finish it due to lack of time and materials.

Almost at the end of the project, we found ourselves with some of the servos necessary for it missing, which were already bought but didn't arrive in time. The project also took us more time than expected. When you read the instruccions at the internet it's all very clear and straight forward, but the truth is that when you start with it not everything is as easy as it looks like. All the pieces are supposed to fit nicely like a Lego, but the measure tolerance of the 3D printer makes it more difficult. As explained along the project all the pieces had to be modified once printer with the use of limes and sand paper since none of the would fit.

Furthermore, in the webpages the explanation, sometimes, leaves you wondering that to do next, and the software MyRobotLab took us sometime to learn how to use it.

Figure 36. Family picture with the robot. From left to right: Alexandru Galben (erasmus student), Lotta Saarikoski (international coordinator), Dr. Rayko Toshev and me.

Anyway, difficulties aside, we were able to complete quite a big part of the project. Once we finsihed Doctor Rayko Toshev kept working on the build, so before leaving Finland we could take some pictures with the almost finished prototype. As you can see in Figure 36, it looks like a finished version, but it's still missing low stomach servos along with the Arduinos to control it entirely, so it could only move one servo at a time.

12 REFERENCES

All the information necessary to build the robot and write this thesis was obtained from the webpages listed below.

https://www.wevolver.com/gael.langevin/inmoov-robot/main/description/http://inmoov.blogspot.fi/

http://inmoov.fr/

http://www.thingiverse.com/

https://groups.google.com/forum/#!forum/Inmoov

http://myrobotlab.org/

http://www.technobothnia.fi/home/

https://www.eiger.io/library

http://www.ebay.es/

https://es.wikipedia.org/wiki/Servomotor_de_modelismo