
PARALLEL MANIPULATOR WITH FIVE DEGREES OF FREEDOM – FINAL REPORT

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Intermediate Project

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Abstract

The aim of this project was to design and implement mechanical construction as well as electronic components for the parallel delta robot. Additionally, the objective assumed also implementation of the simple application with GUI which will allow to remotely control the robot's movement in each joint. After finishing all these separated tasks, the evaluation process was to test control of the robot simple movement through the application on PC.

1 Background of the project

The further target for the construction made during this project will be a platform for an autonomous dental lamp, which will be able to react on the patient movement in order to set an optimal position of the light source and direction of the light, avoiding collisions with the doctor or another objects in the work space. For that reason, the construction in this project will be equipped with few proximity sensors and a time-of-flight depth camera, which will allow manipulator to detect the human face, its characteristic features, and read the distance from obstacles in the neighbourhood of the effector.

Project was based on the earlier version prototype designed and made by myself, which is presented in the figure 1. Conclusions gathered from that construction provided me an important "know-how" which was necessary to make some choices of solutions, which occurred during realization of the project. Although some external sources were necessary for facing the objectives, and preparing the project for further more complicated stages.

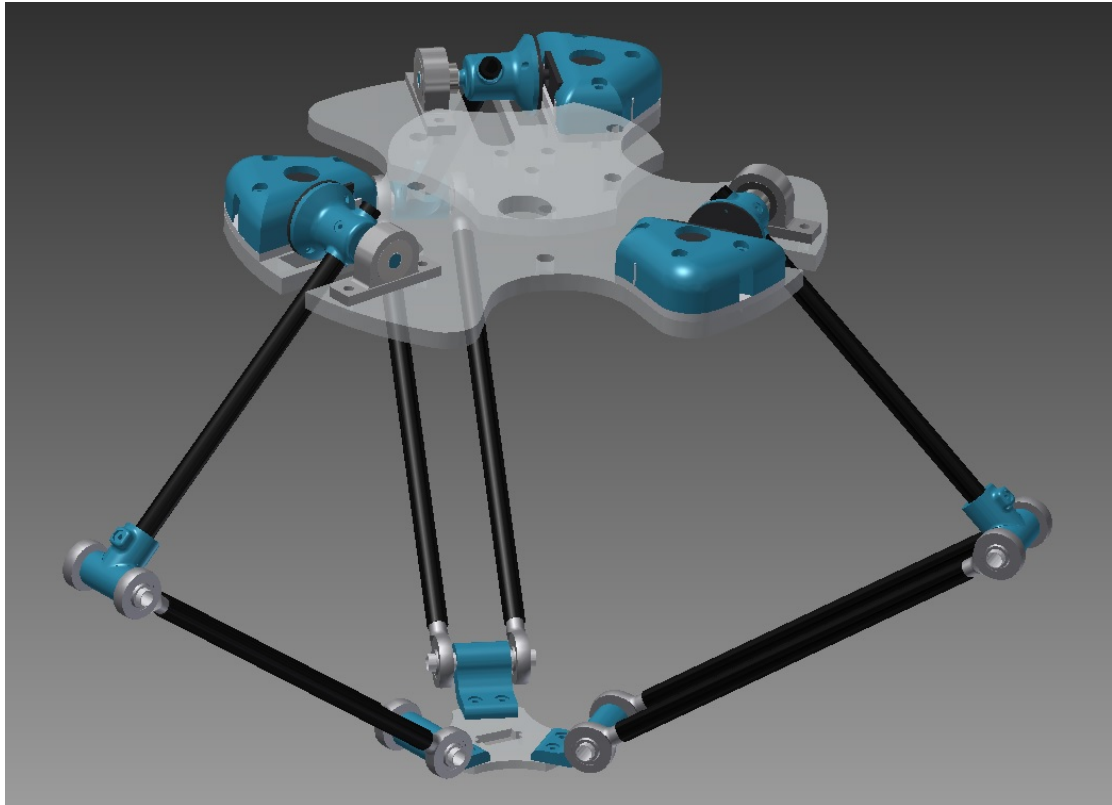


Figure 1: First prototype of the manipulator. New construction was significantly changed

I chose the parallel construction as a platform for such project, because the conclusion from performed research was that this kind of manipulator is the easiest construction to build, due to relatively small issues with the stiffness or torques, while all assumptions and constraints were maintained.

2 Specification for robot modules

Difficulty of specifying project requirements and defining goals is in the complexity of this task. The easiest way to present it, is to consider each module separately. In most of the time spent on working, application, electronics and mechanics were formed independently, only the last part which was assembly all together and evaluation, was the moment when the robot was in the one piece. However, it was important to assume some constraints and specification which had to be met in order to realize correctly the further task for this robot:

- The robot must have construction allowing to hang it under the ceiling,
- workspace for the robot must be more or less cube with one meter length of the edge,
- robot must be able to perform fluent movements with all possible parts mounted on the effector (enough torque),
- robot must behave safe after sudden power loss, it should stay in its configuration,
- robot must be able for wireless data exchange with the server (especially movement commands),
- construction must allow for movement in 5 dof (all possible configurations excluding the rotation of the camera image around the viewing axis).

Additionally, we assumed that these goals should be achieved in the end of the project:

1. **Electronics**

The electronic part of the robot consists of four modules, each powered by microcontroller STM32, and communicated together over the I^2C bus. One module will be responsible for remote communication with the server, resending messages to the rest modules and controlling two servos in the effector. The rest three modules will control the three parallel joints, following given trajectory of the computed angles.

2. **Project of mechanics**

This version in opposite to the previous prototype will use the transform of the motor shaft rotational into translational movement to strongly improve the value of the final torque. It was made in order to operate with quite long arms and a significant mass concentrated on the effector module. To move in the joints, three DC motors were used, and additionally two mini servos in the effector to provide possibility for changing the orientation of the camera and light viewing.

3. **Application with the GUI**

Application on PC, which handles the depth camera with the dedicated SDK, acquires data from proximity sensors and fuses them with camera image to

obtain information about neighbourhood of the robot. Sends information to the robot about the movement which can be set manually or further as a result of the autonomous mode. Application were designed in QT framework and works on the computers with Windows operating system.

To ensure proper project management, I used the waterfall metodology with critical buffers, represented as the Gantt diagram prepared in GanttProject. The project was split into whole semester and the plan is shown in the picture below:

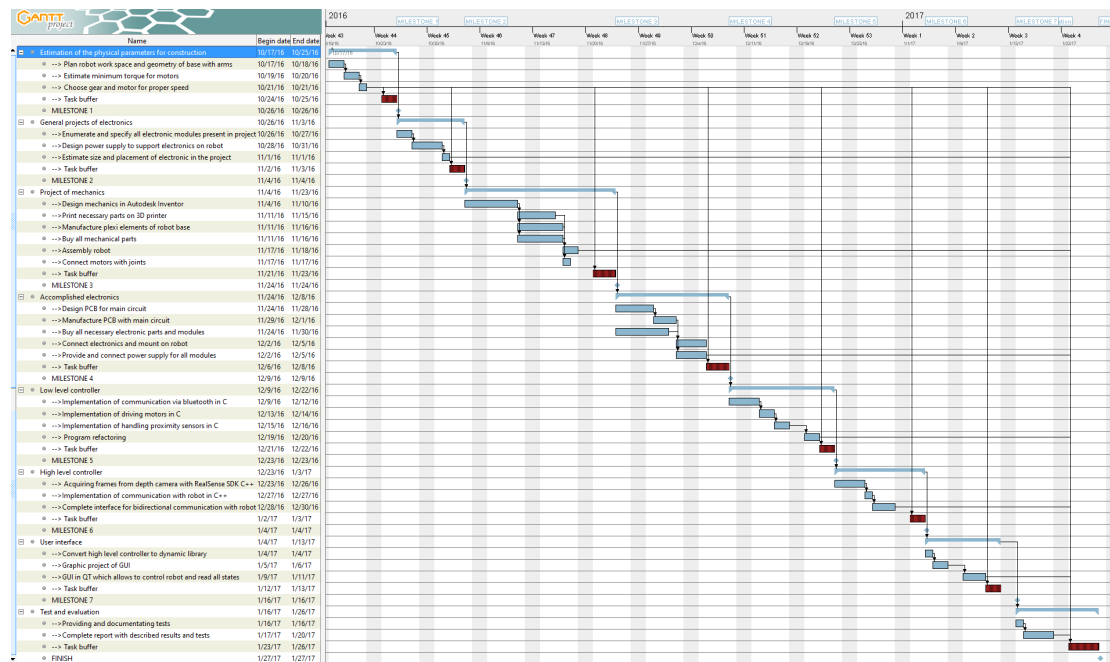


Figure 2: Timetable for this project realized as Gantt diagram in GanttProject program

3 Results

The first stage of realisation was designing parameters in order to maintain the specification. Using tools for simulation and visualization (for more details see section 5) geometry of the robot was computed as follows:

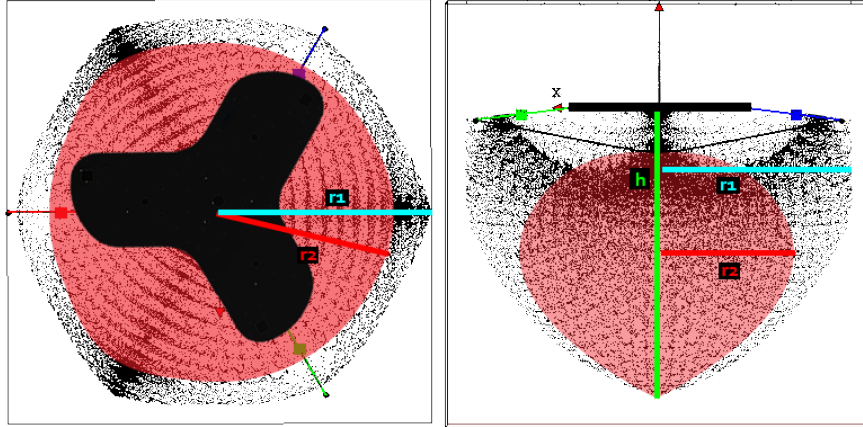


Figure 3: Visualization of the robot workspace for computed geometry

where length of arms have following values:

length of upper arm=

length of lower arm=

In case of designing mechanics, first task was to make project of the joint mechanism. The issue was to make such gear that will be able to multiply nominal torque of the motor tens time, to make it able to operate with quite long arms. The project was firstly designed in Inventor (figure 4), then made as shown in the figure 5.

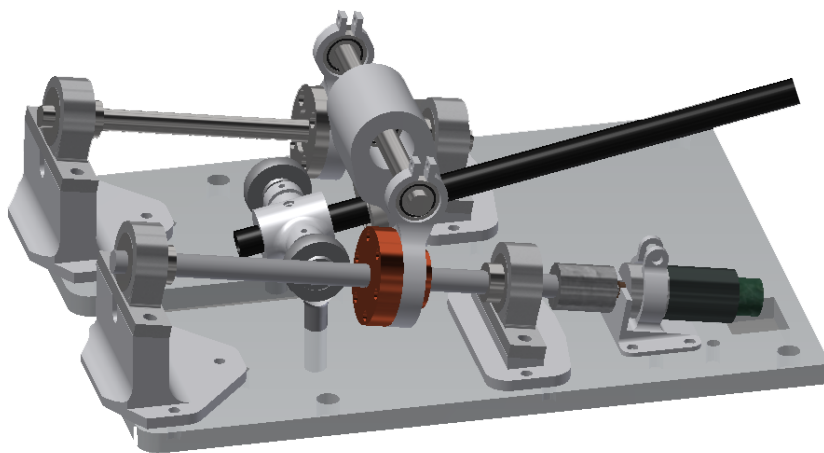


Figure 4: Project of a single robot joint with the translational screw



Figure 5: Realization of the single robot joint

Because the project was made from scratch, it was necessary to design model of the robot before its physical implementation. Results of making project in 3D are visible in figures 6-7.



Figure 6: Project of the robot's body - view from the top

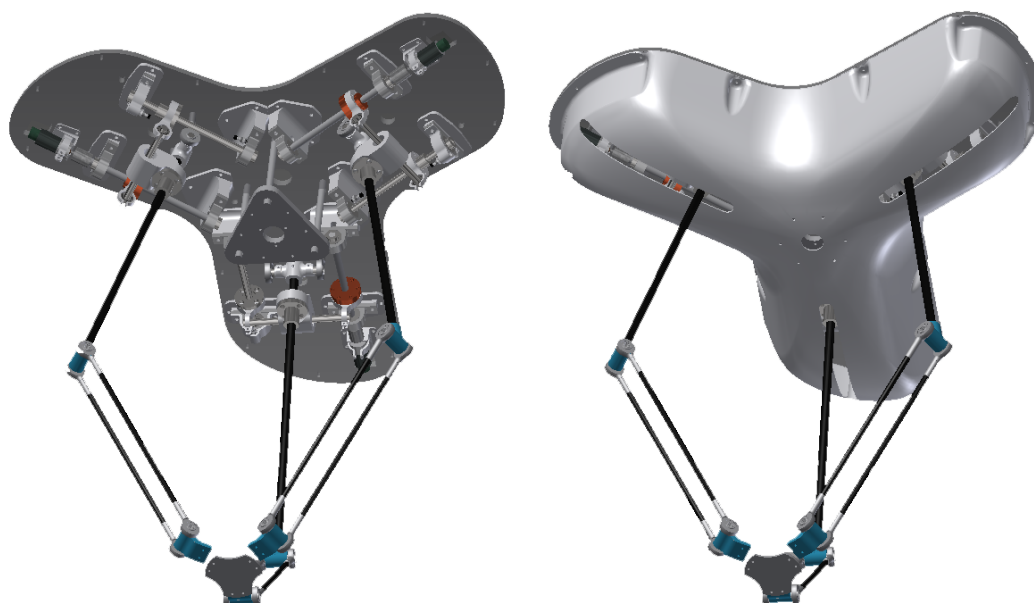


Figure 7: Project of the robot's body - view from the bottom

After the assembly process, there was a problem with the robot placement, so temporary it was used in the inverse pose, with the base in the bottom. Below we can see some pictures which presents the view of fully assembled robot:

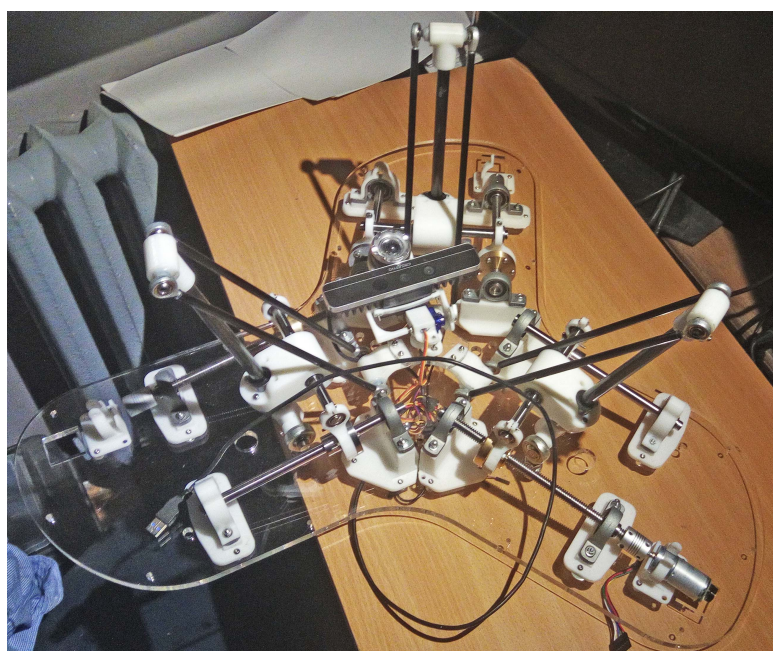


Figure 8: Realization of the robot - fully assembled - view 1

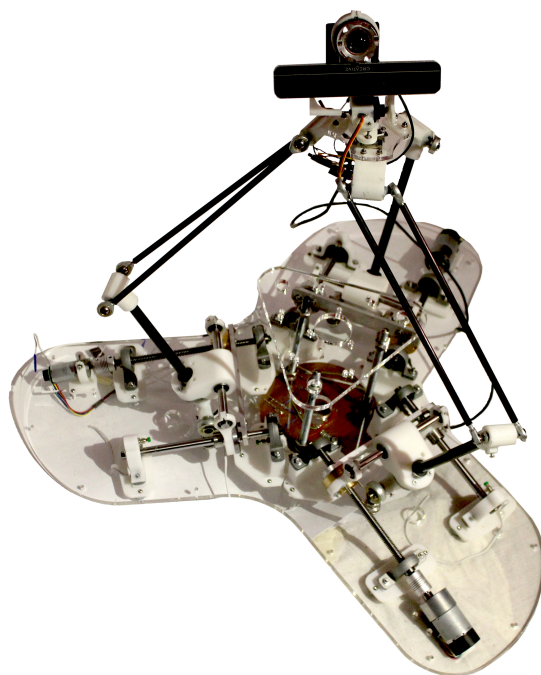


Figure 9: Realization of the robot - fully assembled - view 2

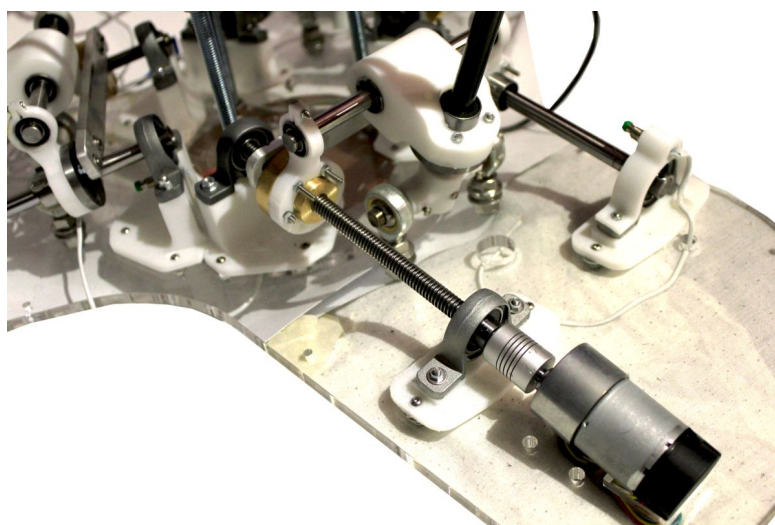


Figure 10: Realization of the robot - fully assembled - view 3

Most of the parts were printed from the HIPS (High Impact Polystyrene) material, and the base was laser cut from the plexiglass. Unfortunately some problems encountered with ordering the thermoformed case, so up to the project deadline, we can see that the robot looks like on the visualizations without the plastic case.

Another problems occurred with the I^2C communications, due to electromagnetic disturbances, hence the electronics were not fully complete and robot could be controlled only by directly powering the motors in each joint. The view of prototyped main module electronics, and joint module electronics is shown in the picture 11 and 12.

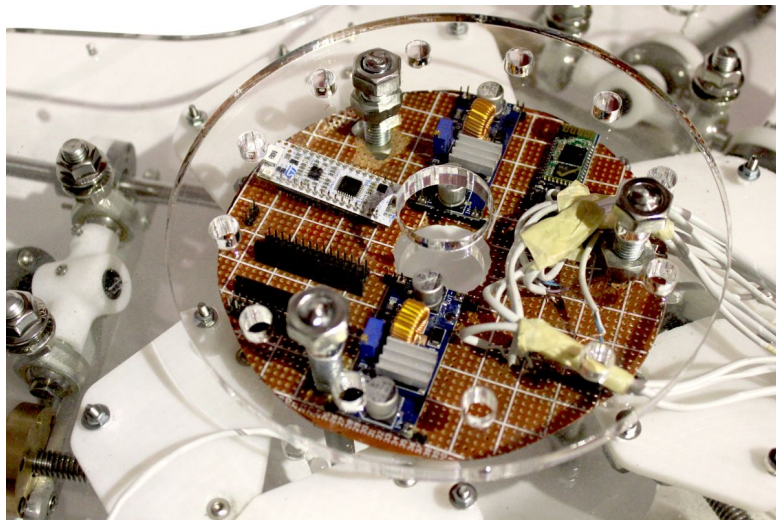


Figure 11: View of the main module electronics

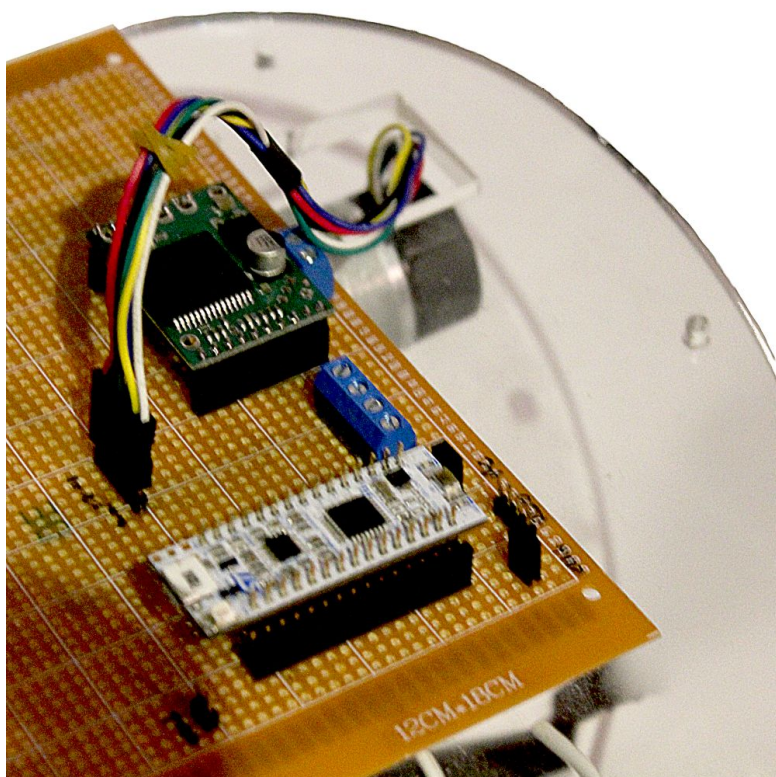


Figure 12: View of the joint module electronics

The last part of the work made in this project was application on PC. As it was mentioned before, the GUI was created using QT framework. The program includes two important modules, written additionally by me in Visual Studio and compiled as external dynamic libraries. First one is the module for serial communication with the robot, using virtual COM port representing bluetooth connection. Second important module is the module based on RealSense SDK, which is the interface in connection with the depth camera. The view of the compiled working program is shown in the figure 13.

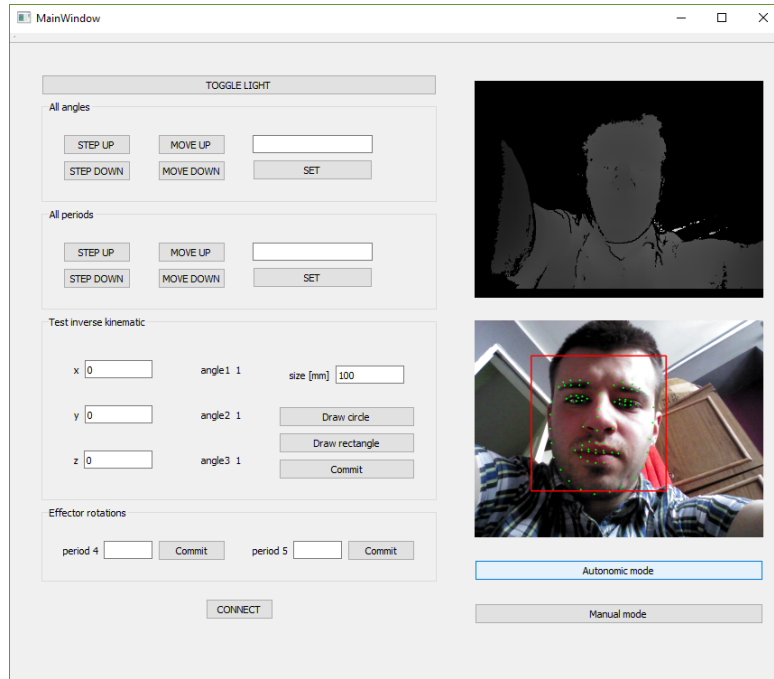


Figure 13: View of the application

The functionality included in the program is following:

- Capture depth and colour data from the depth camera,
- detect face and features like mouth, eyes, etc.,
- control robot's movement in each joint,
- read current robot position in each joint,
- enable switching between working in autonomous and manual mode.

4 Conclusions

Main difficulty in this project was that the final result was strongly dependent on all subtasks (electronics, mechanics, application). Therefore small delay in one of those parts causes delay in whole project. This is the reason why finally it didn't work as should. However, almost all goals were achieved, and project will be soon completed.

5 Tools and references

Applications used for project realization:

- **Autodesk Inventor** for designing mechanical constructions, with respect to all real physical parameters.
- **Matlab** with **Simulink** to provide, simulate and assess such issues like kinematic matrices, work space borders and drive actuators.
- **CadSoft Eagle** for planning and development of electronic circuits
- **Git** repository on **Bitbucket** server for version control system
- **Keil** working with **STM32Cube MX** programming environment for microcontroller software written in C
- **RealSense SDK** dedicated framework to use with sensor Creative f200
- **QT framework** for fast and easy created GUI
- **Microsoft Visual Studio 2015** for writing and building C++ dynamic libraries used in project.

Some of these program are not free licensed. If we want to work with them, we need to buy an original copy. As it was mentioned above, the robot will be based on earlier version of prototype. However experience gathered from that construction will be more useful in choosing mechanical solutions. For the rest areas, almost everything will be significantly more complex or quite new. For that reason, some additional sources of knowledge will be surely used in this project:

1. Manuals on <https://www.knowledge.autodesk.com/support/inventor-products>
2. Datasheets on <https://www.st.com/en/microcontrollers>
3. Materials on <https://www.software.intel.com/en-us/intel-realsense-sdk-support>
4. P. Horowitz, W. Hill (2014) *Sztuka elektroniki cz 1 i 2*
5. K. Tchoń, A. Mazur, I. Duleba, R. Hossa, R. Muszyński (2000), *Manipulatory i roboty mobilne*
6. Hamid D. Taghirad (2013), *Parallel Robots: Mechanics and Control*
7. Stamper, R. E. (1997). *A three degree of freedom parallel manipulator with only translational degrees of freedom*