Final Evaluation Report for a project in the context of "Innovatives Studium 2016"

Prof. Dr. Moritz Diehl,
Lehrstuhl für Systemtheorie, Regelungstechnik und Optimierung
IMTEK, Technische Fakultät,

Embedded Control Project

where Cyber Physical Systems meet Model Based Development

The aim of the Embedded Control Project (ECP) was to let international master students experience the full cycle of control system design for cyber physical systems in a modern model based setting.

Summary of the ECP in 2016/2017

There were 15 students doing project work during the course of 4 months, from October 2016 to February 2017. Each group of three students started with a brainstorming and then chose one specific idea to build an automated system from scratch. Each group had one tutor who closely followed their work, giving help and being available for discussions. The instructor, five tutors, and a master engineer held weekly meetings to address problems that arose during the students' projects. There were six course-wide meetings during the course: the Kick-off meeting (20.10.2016), a Security instructions & Tutorial (27.10.2016), Project plan presentation (03.11.2016), Interim presentation (15.12.2016), Project presentation (10.02.2017) and Final demonstration (15.05.2017). The public was invited to the last two events. At the end of the course, each group had finished building one system and programmed the control algorithm on the PC and embedded controllers.

Reflection

What went well?

1. All the five groups have worked well and hard to implement their ideas, and consequently they obtained extensive experience on the development process: from conceptual design to hardware selection and construction with metal machining, 3D printing, electronic schematic and PCB making, and to system modelling, analysis, then control algorithm implementation and tuning. Several small iterations were necessary during the development, going together with the students throug the "plan–do–check–act" cycle, and optimizing their designs.

2. By the end of the course, each group had successfully built its own system and presented its project with a real model demonstration. Four teams were be able to verify the realizability of their ideas, while one group's original dream was not attained despite several conceptual changes, due to one actuator's insufficient power. All students figured out the strengths and drawbacks of their systems in order to adapt the control algorithms accordingly. Two groups

facing issues in modelling the systems have decided to use the propotional-integral-derivative controller for low-fidelity models, because this saved the time effort to obtain model-based controllers.

What did not go so well?

1. At the planned final reporting date, 4 out of 5 groups still had not finished their projects, due to too many troubles they encountered during either mechanical and electronic system construction, or software development and integration. This issue reflected the large amount of work students needed to put in their projects, partly influenced by the variety of technical fields that were involved in the development process. They successfully delivered their project after two weeks of extension, however, most students thought the effort was worth far more than the 6 ECTS they received for the course.

2. When we prepared for the course, we intended to help students face three challenges during control system design:

a) choosing the sensor- and actuation components and setting up their embedded system communication interfaces,

b) mathematical modelling of the system and choice of control methodology, and

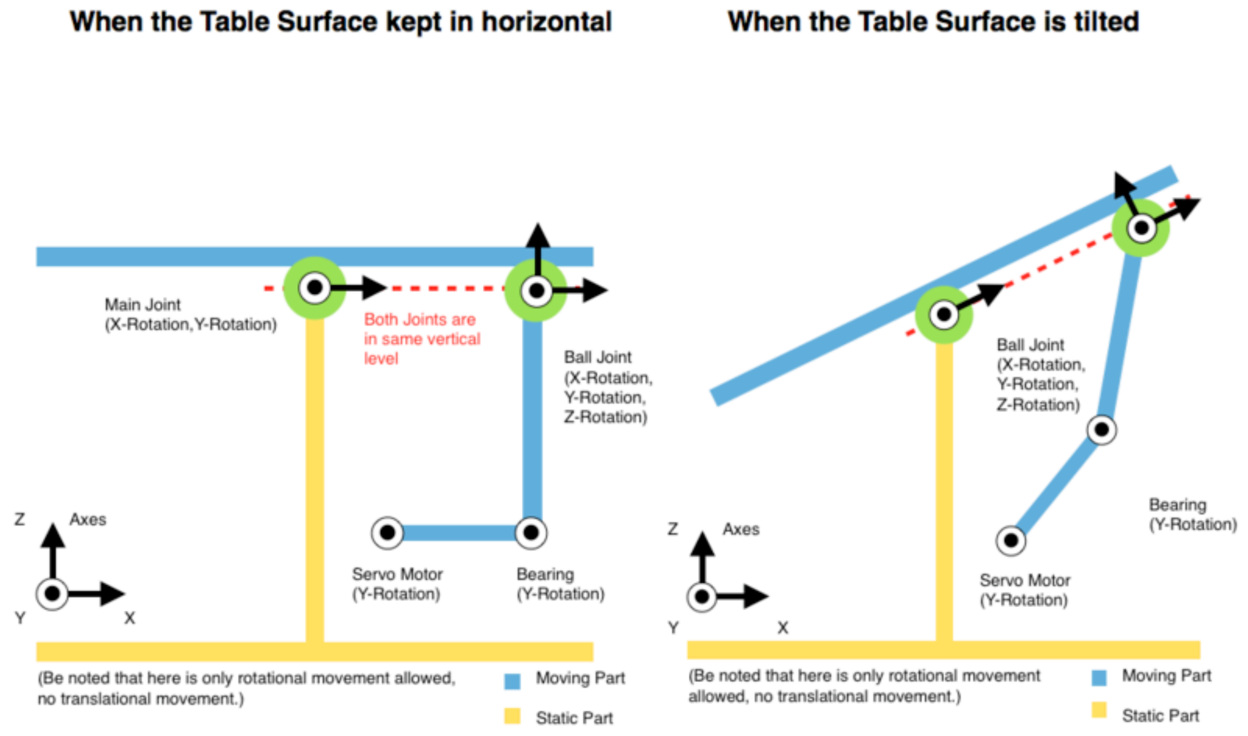
c) choosing the real-time hardware for computations and communications, setting it up and implementing the controllers on this hardware.

We expected that Step a) would be addressed quickly, and Step c) can also be accelerated, so that students could iterate several loops for doing Step b) and Step c) to refine the model and the control methodology. Indeed, most groups finished Step a) in short time with the guidance of the instructors. Step c), however, was quite challenging to students, particularly the communications between Matlab/Simulink and embedded controllers was not smooth. This issue has led to less time for Step b), hence most students did not go through a complete mathematical modelling and model-based design process, and instead, they ended up using the classic propotional-integral-derivative control approach. After the course, we discussed with support engineers from The Mathworks, and realized that although Simulink could work with the embedded controllers Arduino Due we used, its support for third-party peripherals (e.g. sensors and actuators) was limited. Therefore, a smooth development workflow from Simulink running on PC to embedded controllers could not be achieved, preventing us from using the setups created in the ECP for future control system design courses which mainly focus on Step b).

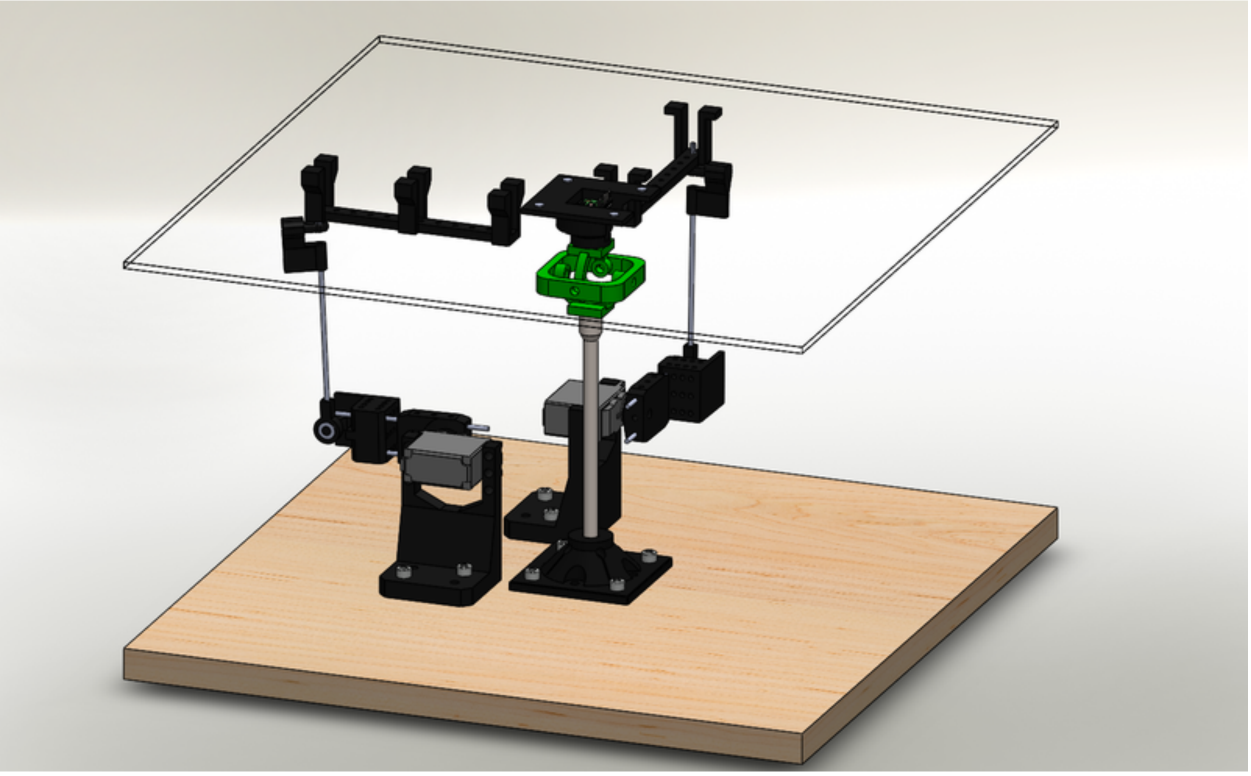
Some pictures collected from the course ECP:

1. Process from conceptual design to implementation

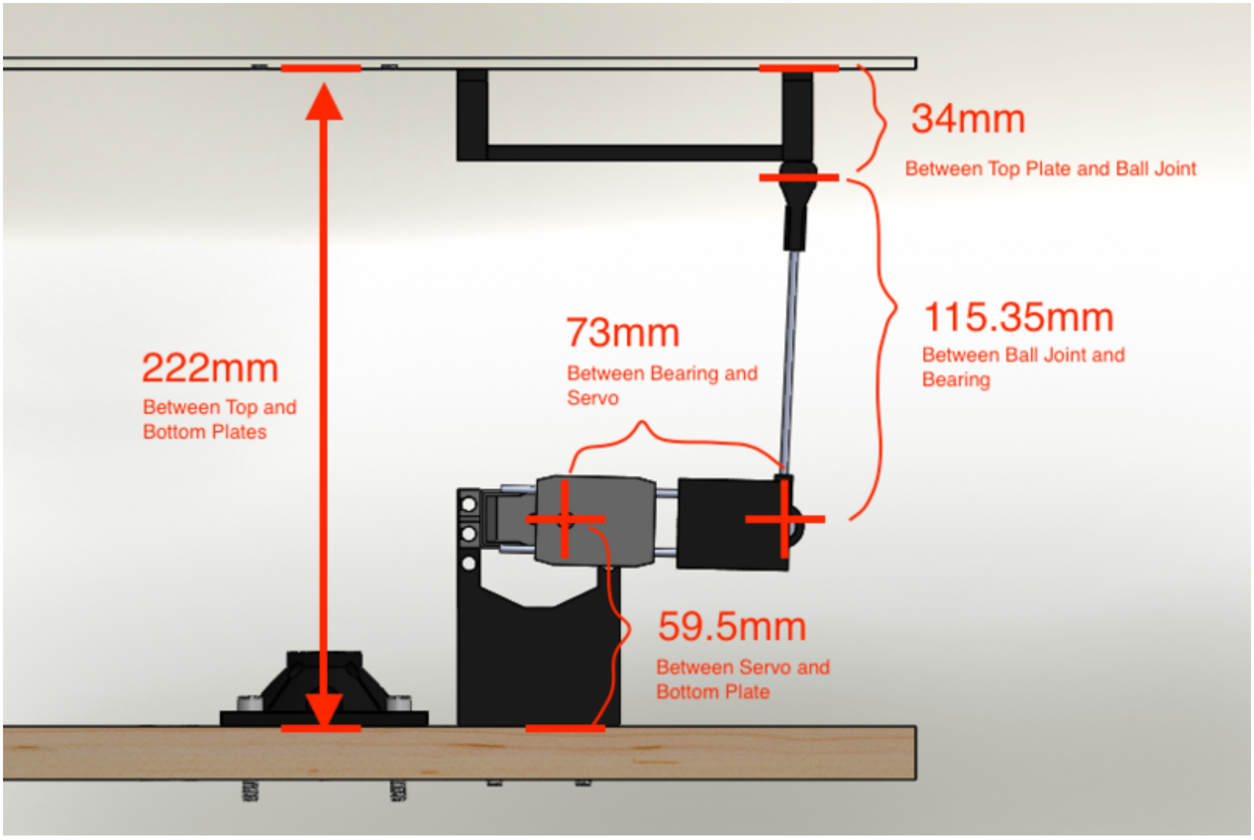
These pictures show the series of tasks that one group has done during the process of design and building a "Balancing table" in the ECP course.



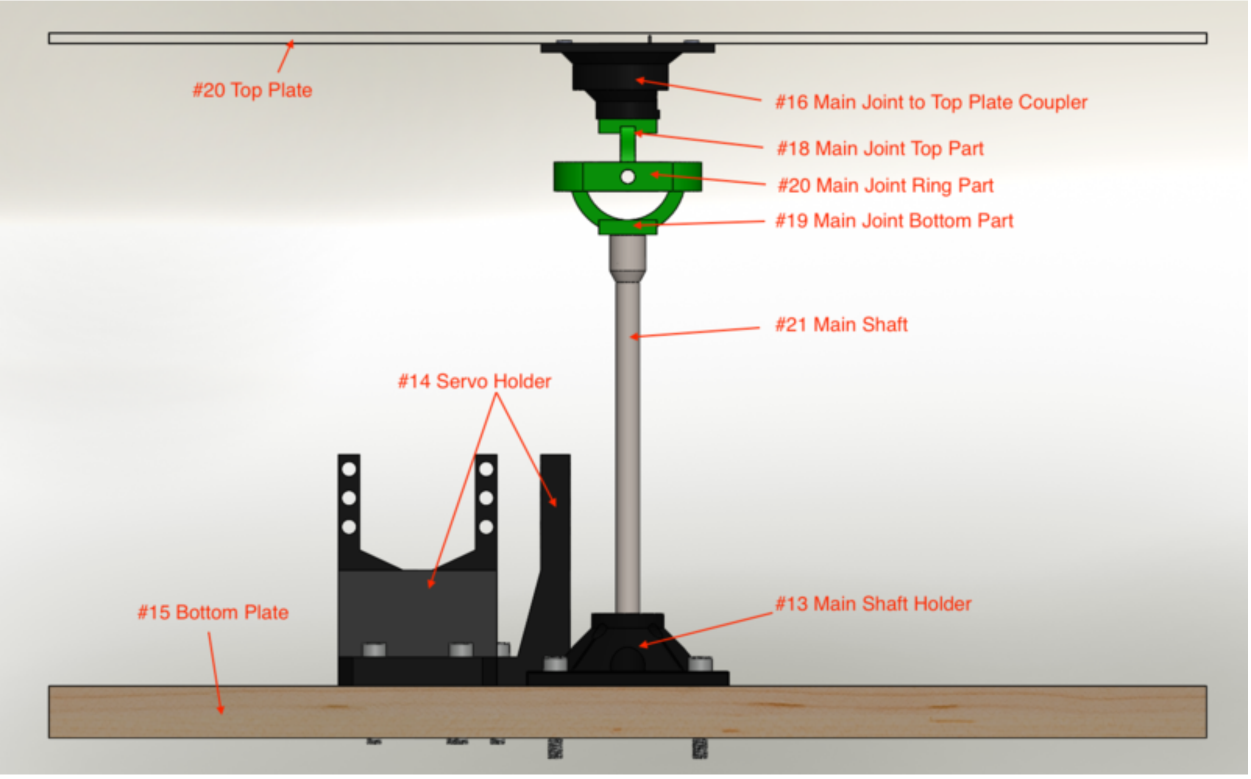
System Concepts



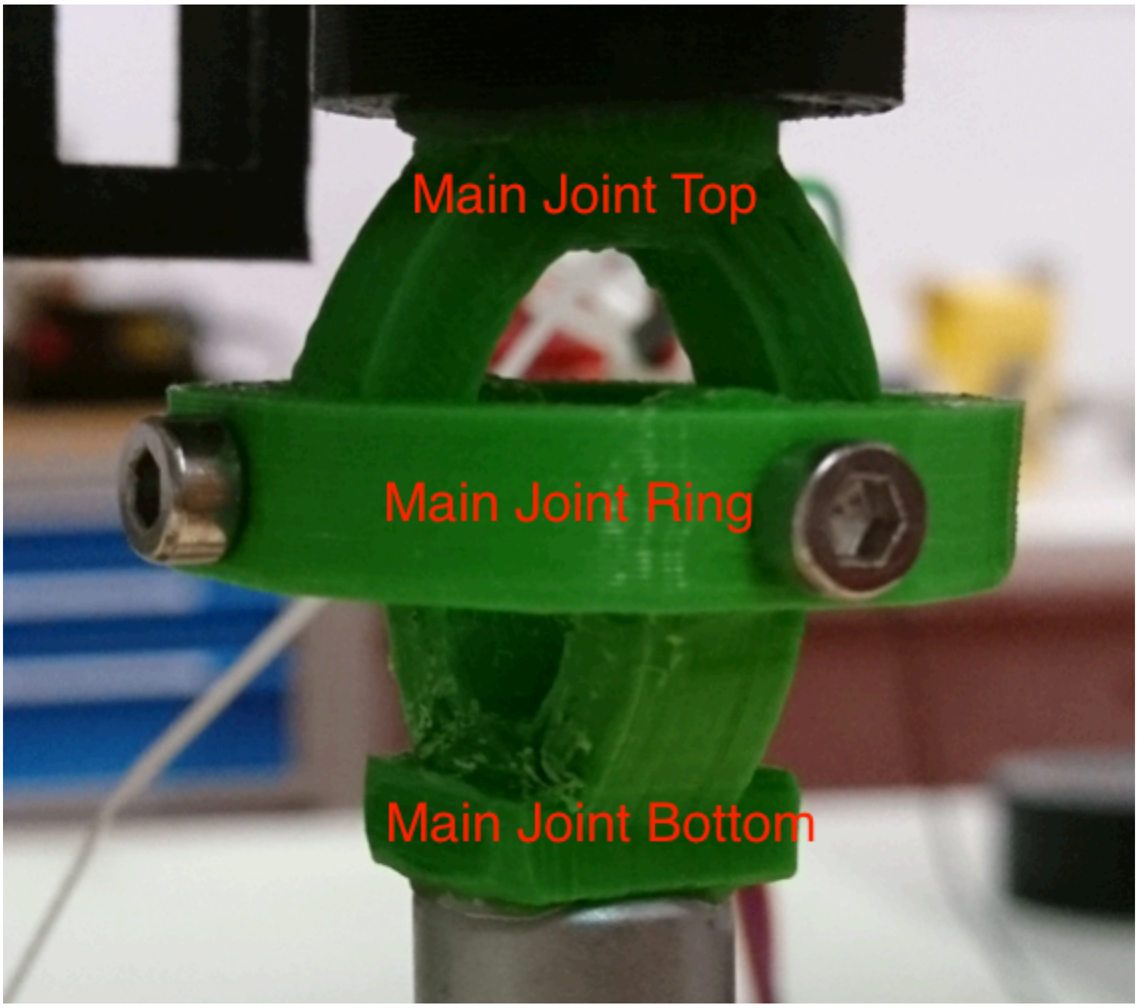
Mechanical Assembly in Solidworks



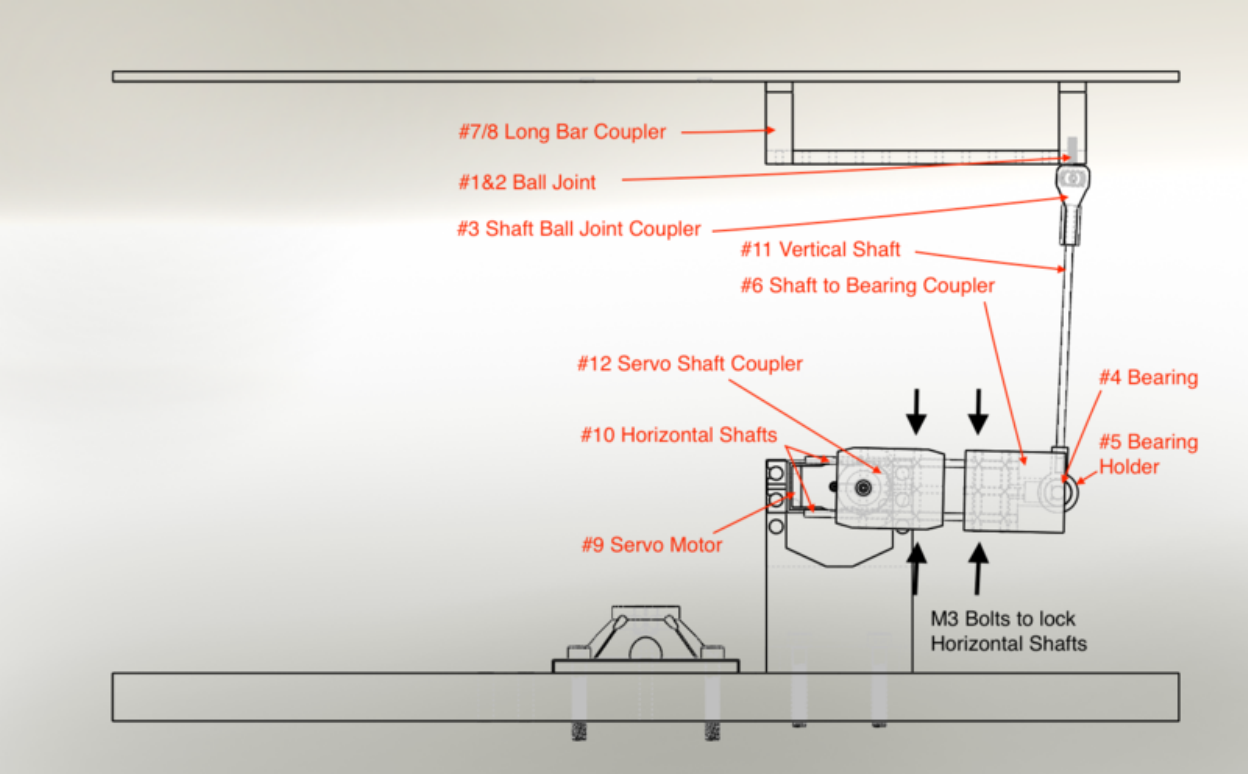
Dimensions of Actuating Shafts and Vertical Height



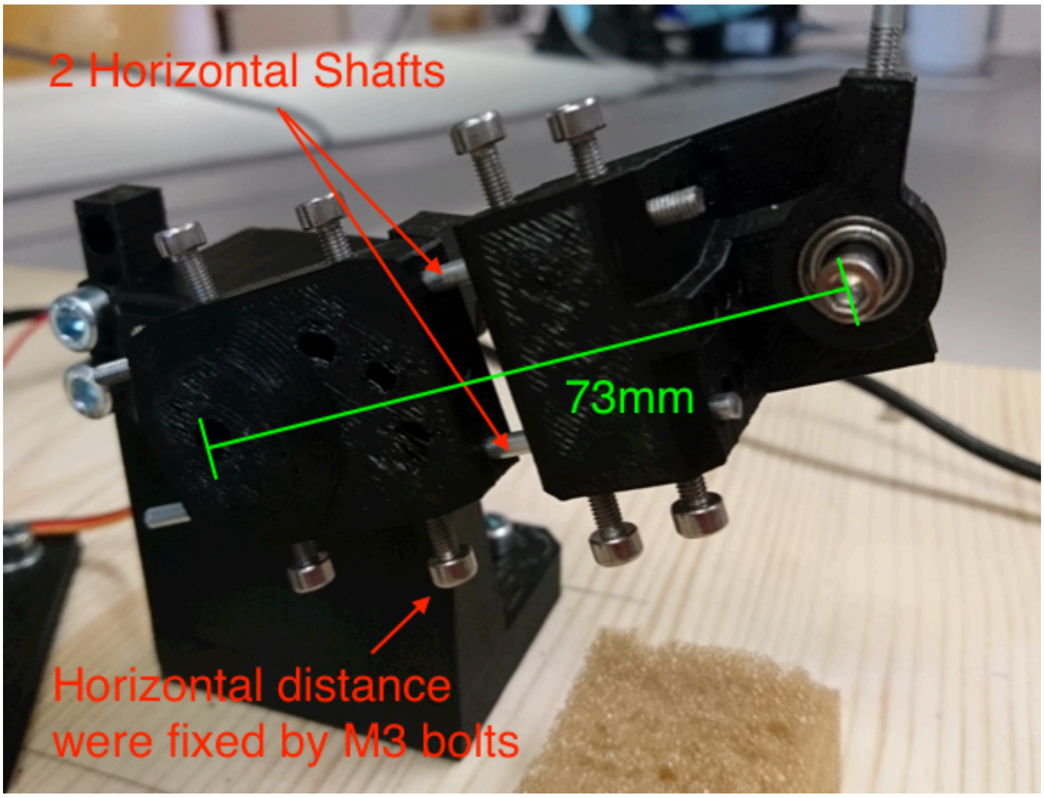
Passive Parts



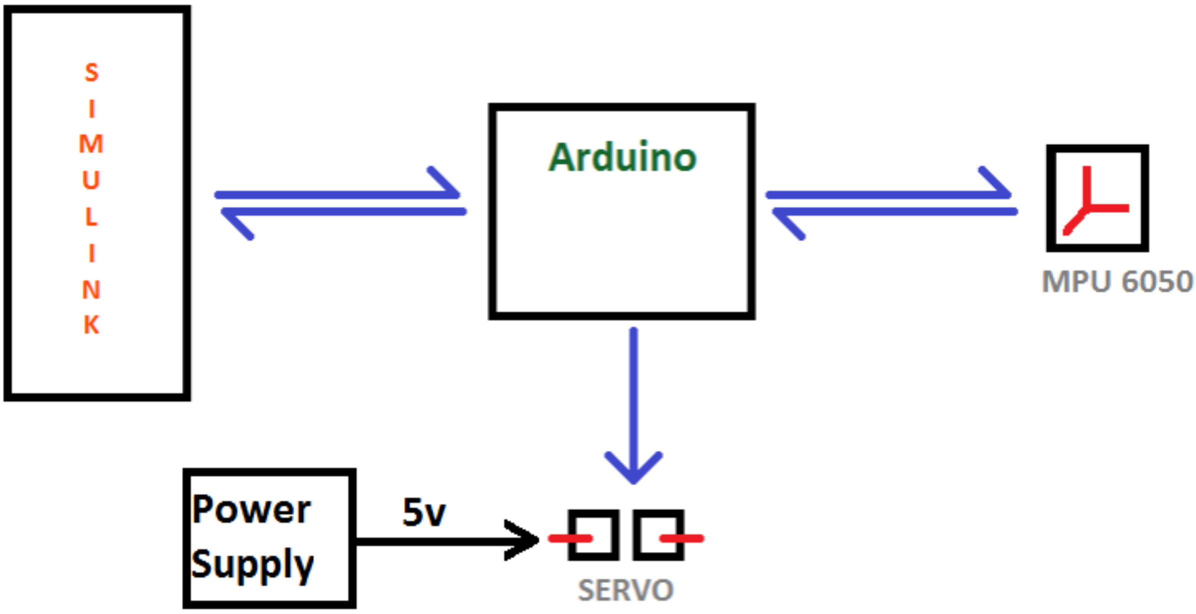
3D printed Main Joint



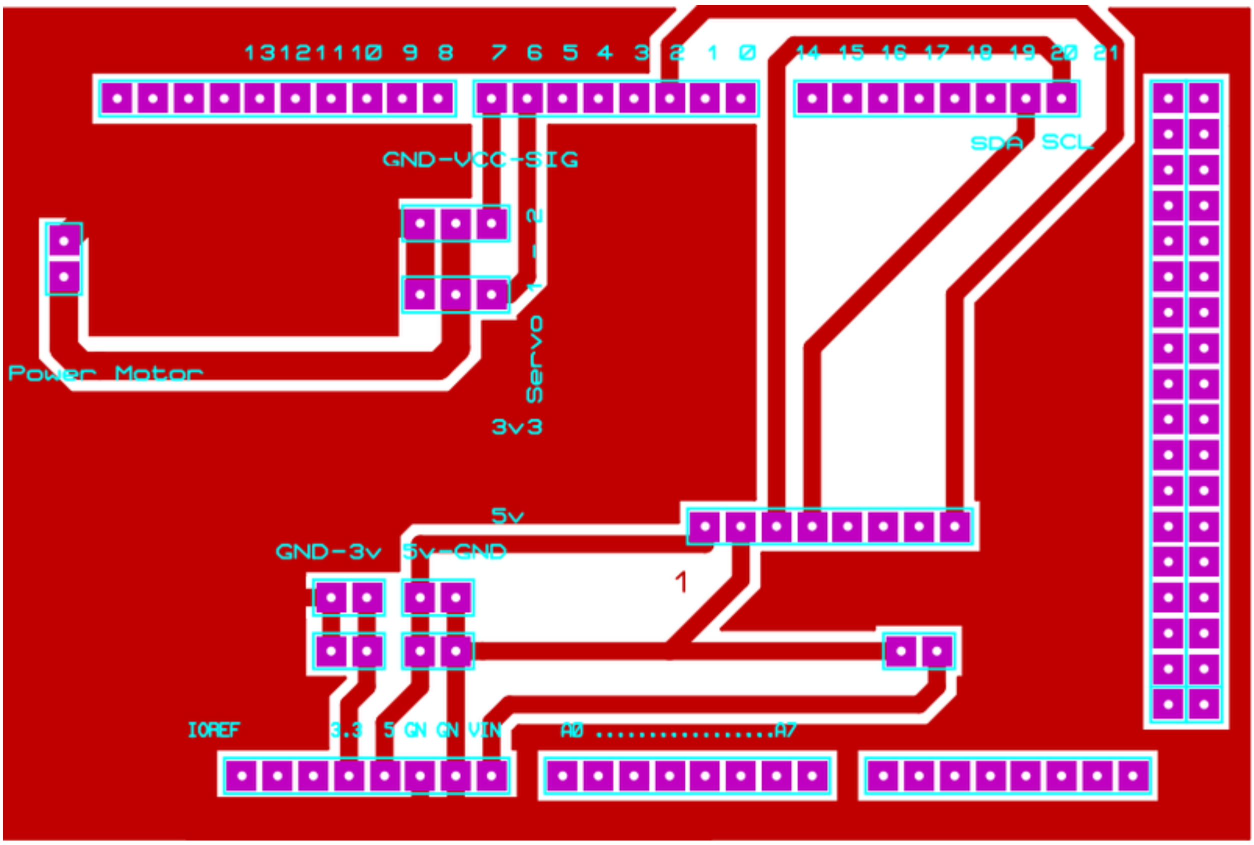
Actuation Parts



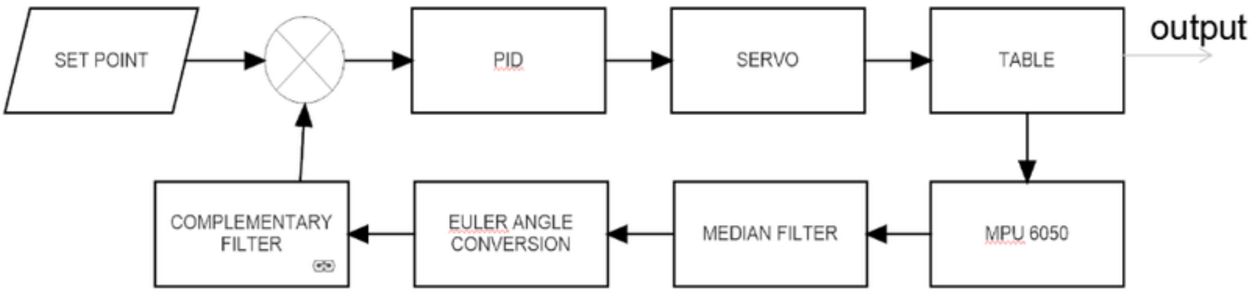
Fixing Horizontal Shaft



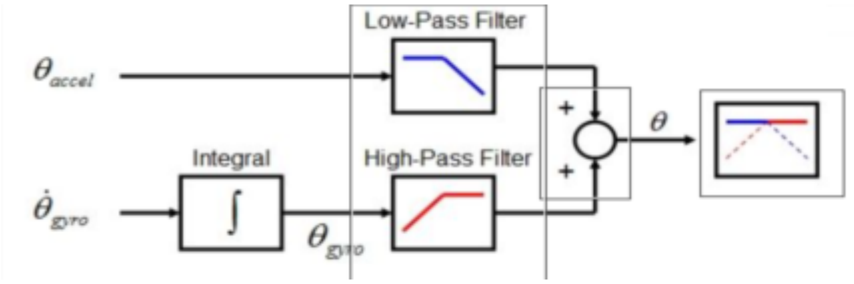
System setting



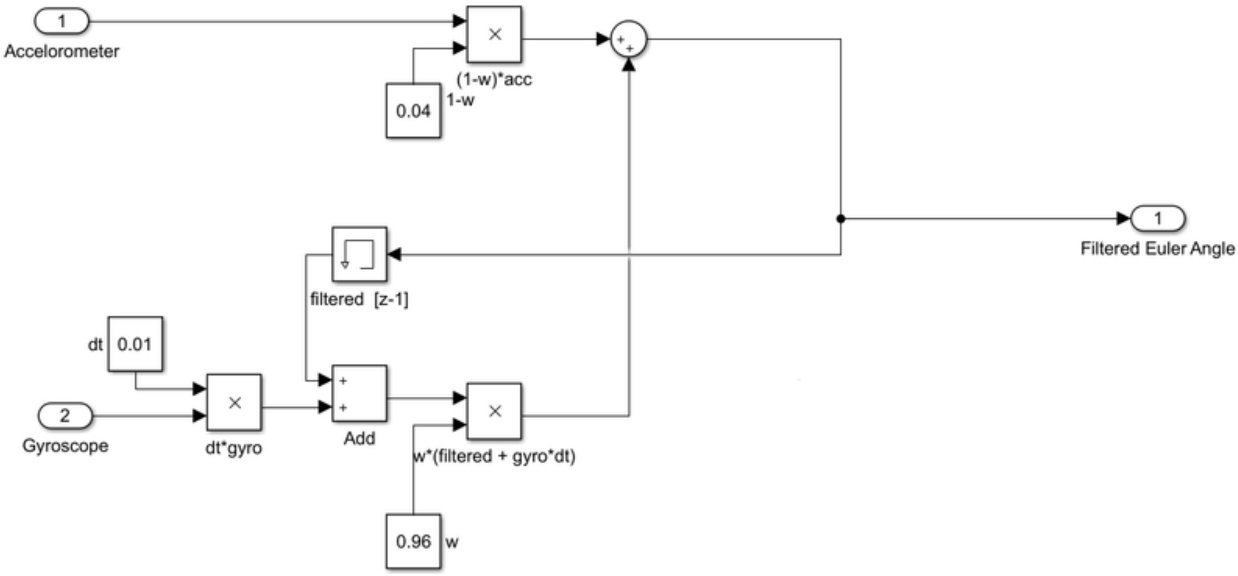
PCB Layout



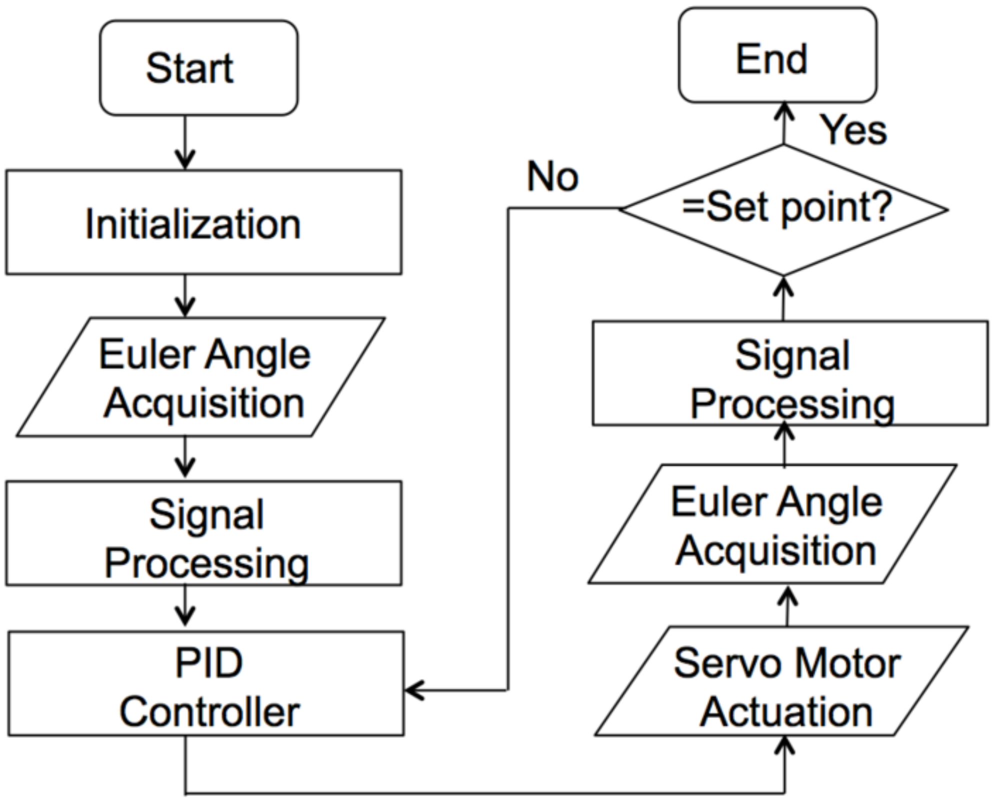
Process Flow chart



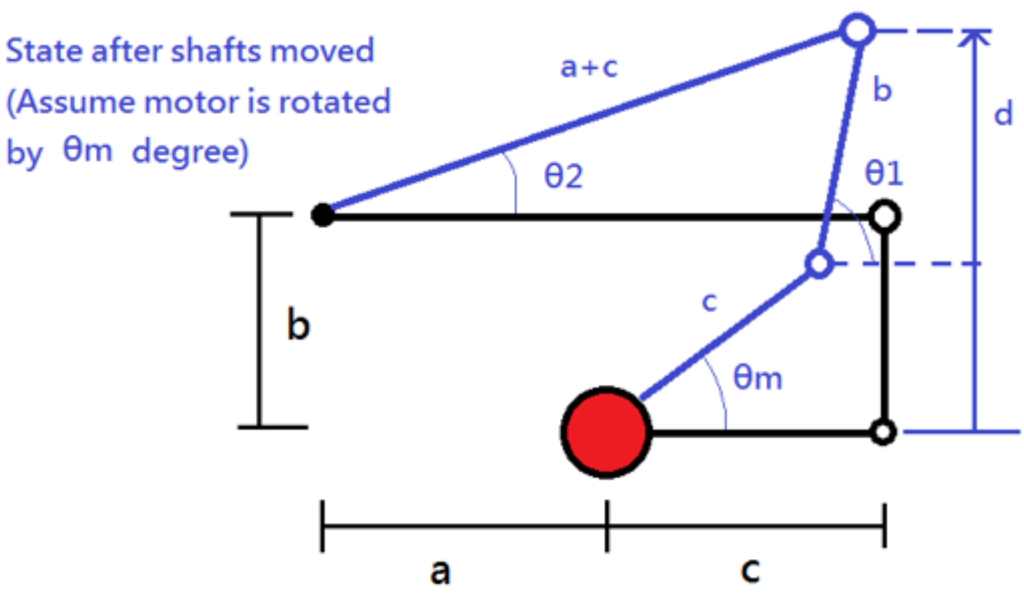
Schematic for complementary filter



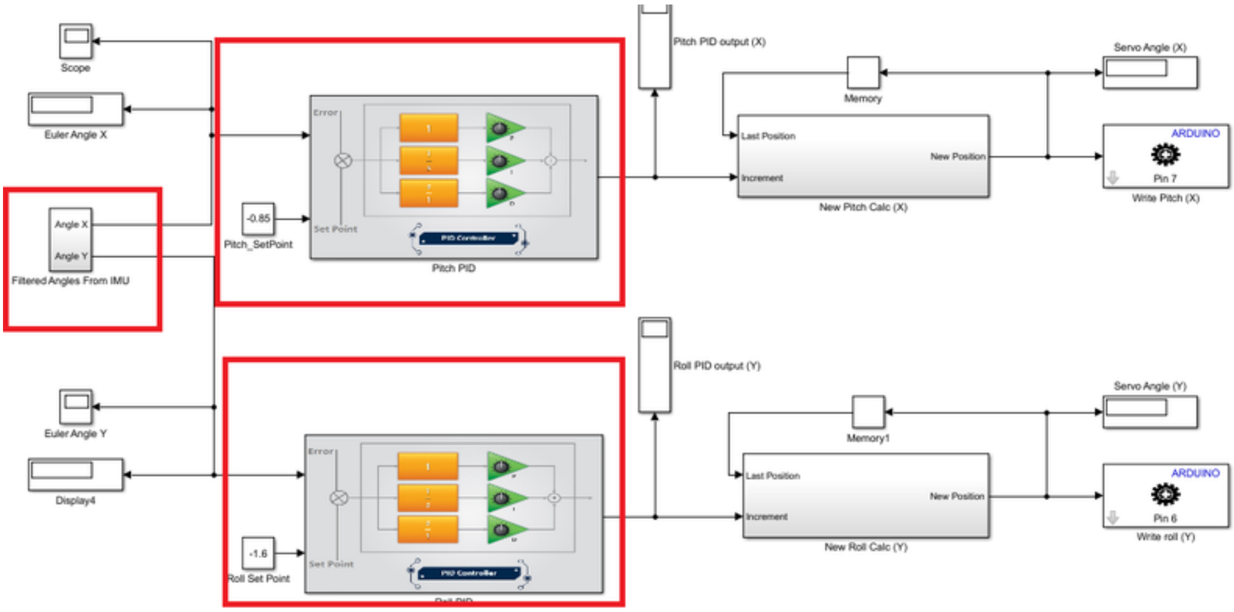
Implementation of complementary filter in Simulink



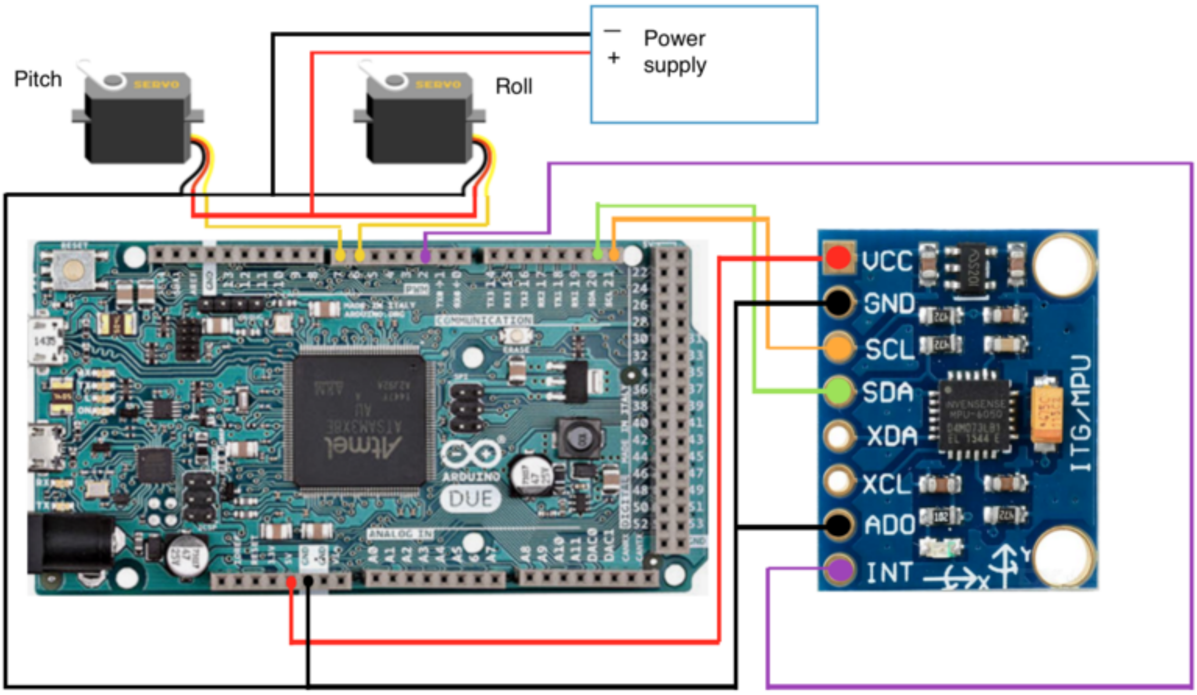
Program Flowchart



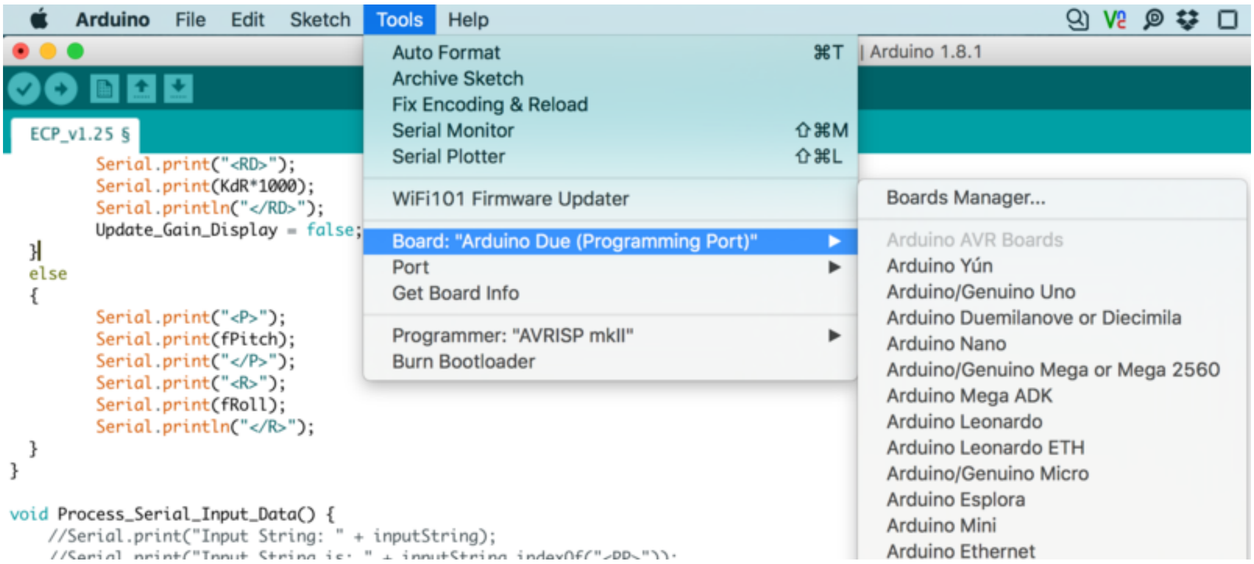
Analysis of Stationary Model of Table - Tilting angle and Servo Angle



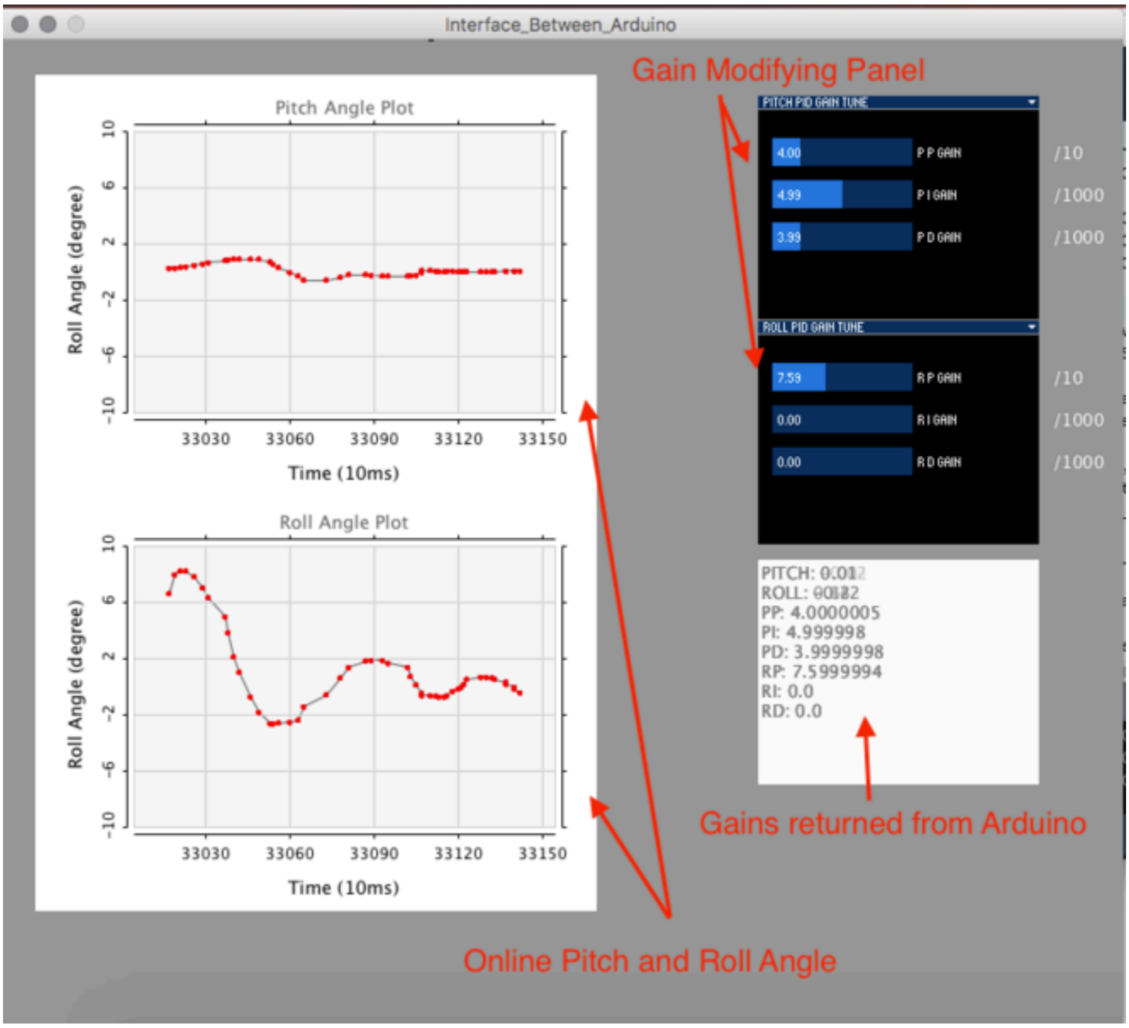
The main view of the controlled system



Electronic controller configuration



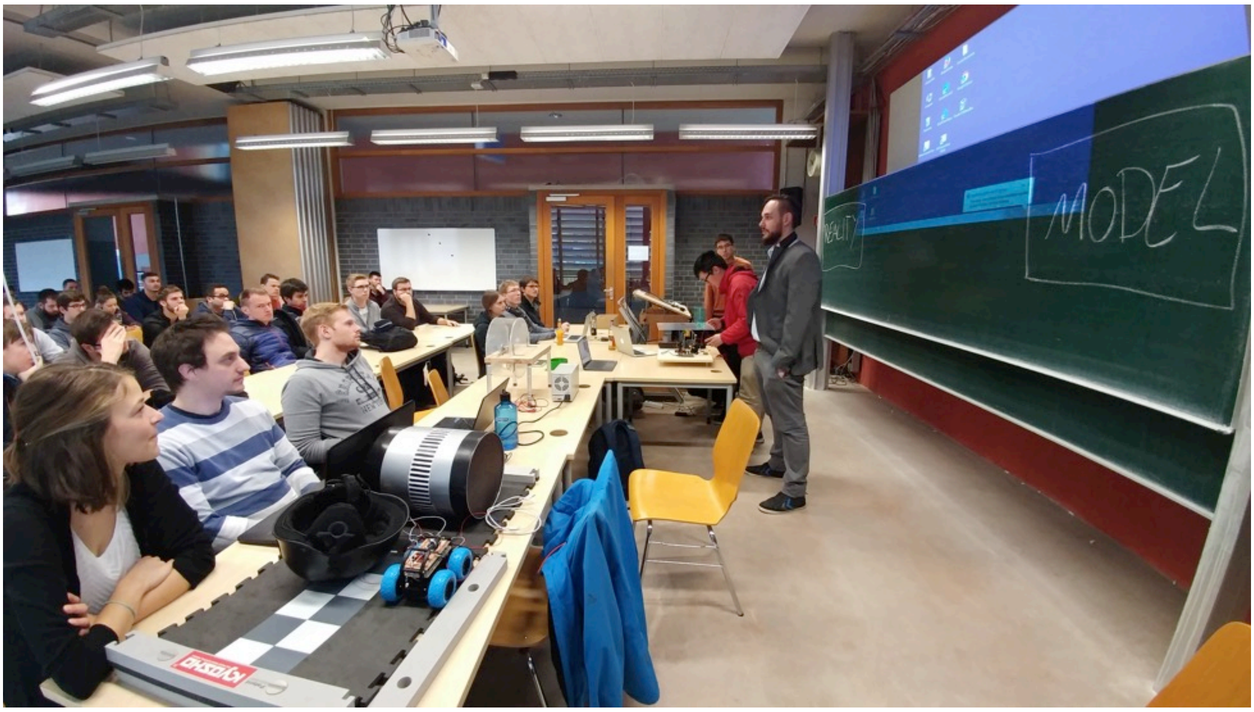
Arduino development



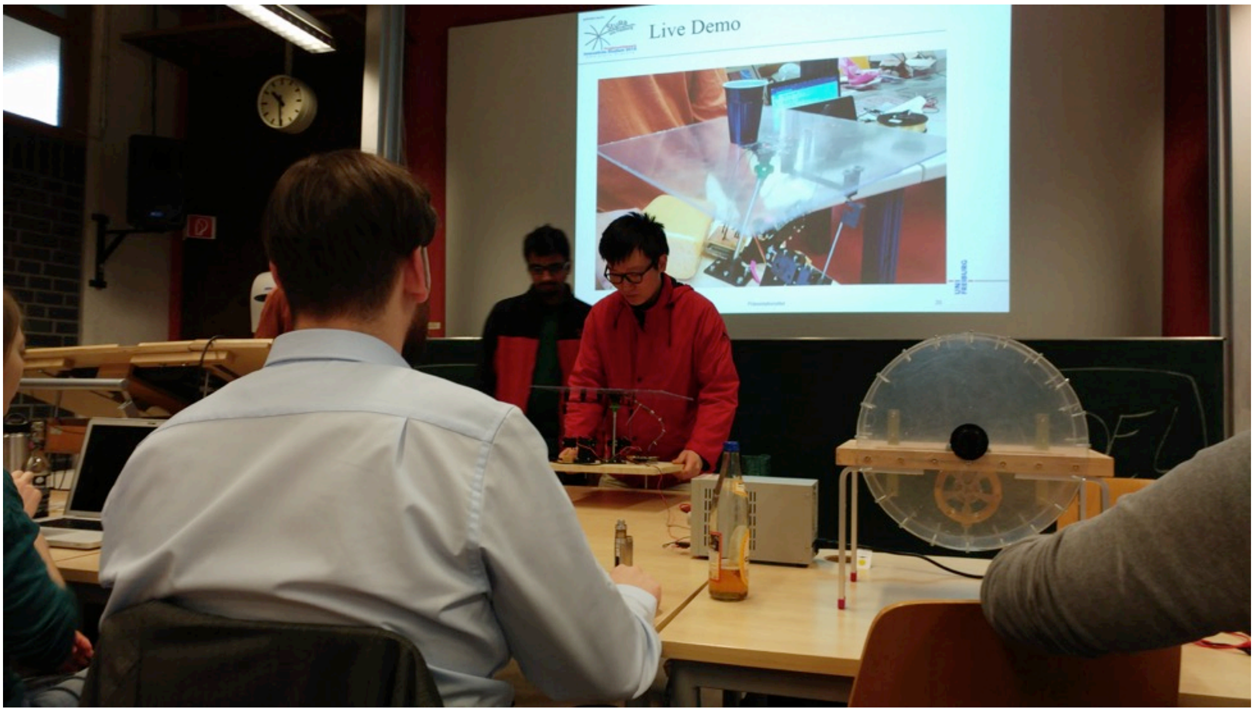
User Interface of the Tune Gain Platform

2. Some photos taken on the presentation day:

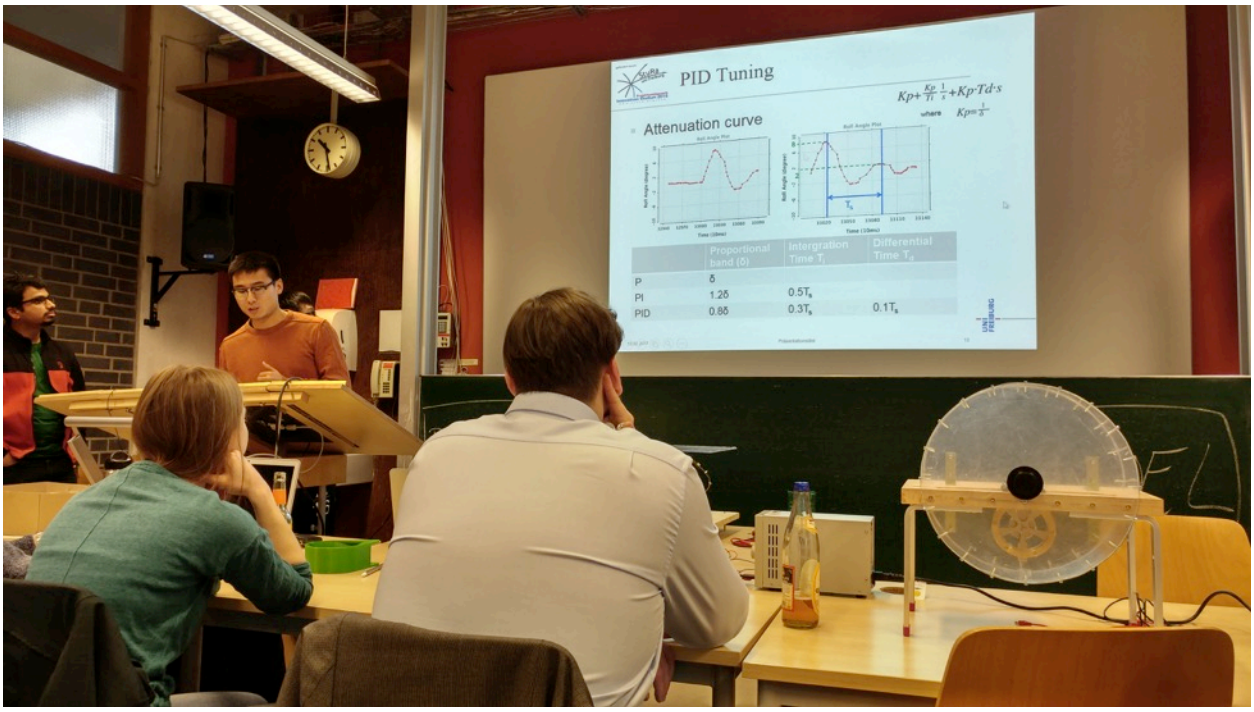
Presenters and audience before the presentations



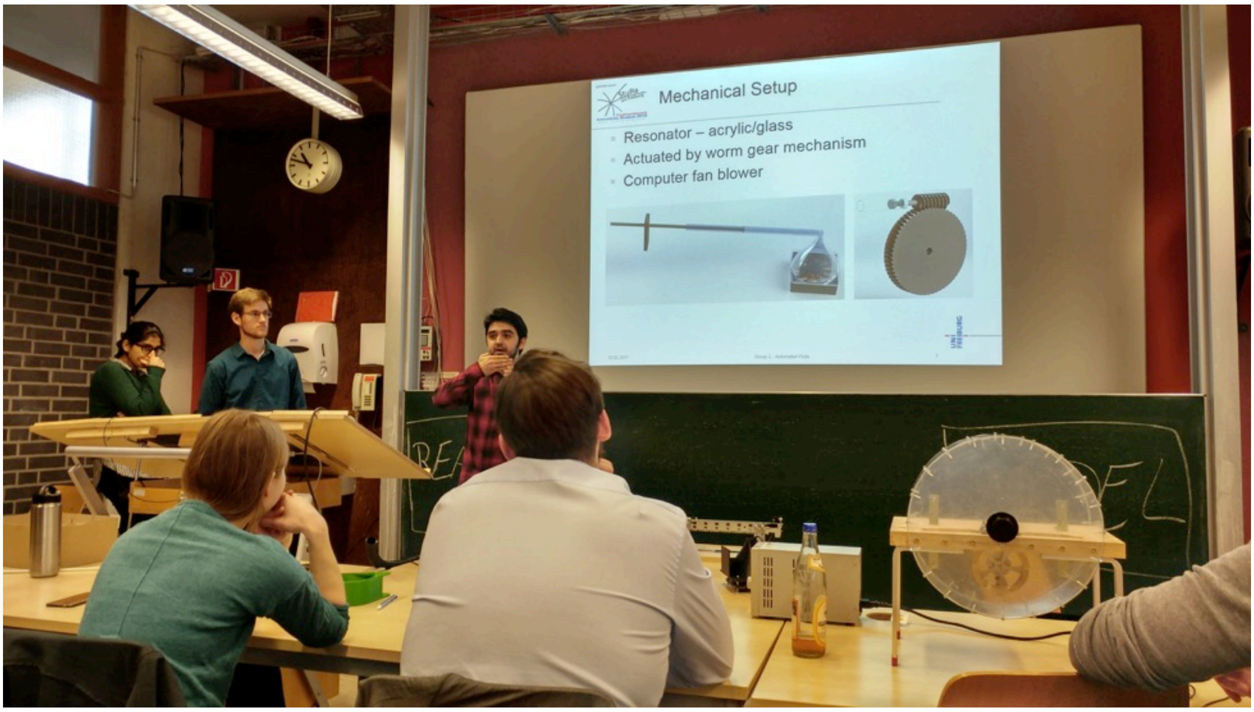
Constructed systems are ready for presentations, in which students would figure out the difference between model and reality



Demo of group 1: Self-stabilizing table (by Yuxiao Zheng, Tinwang Wong, Mohsin Shaheer Ali)



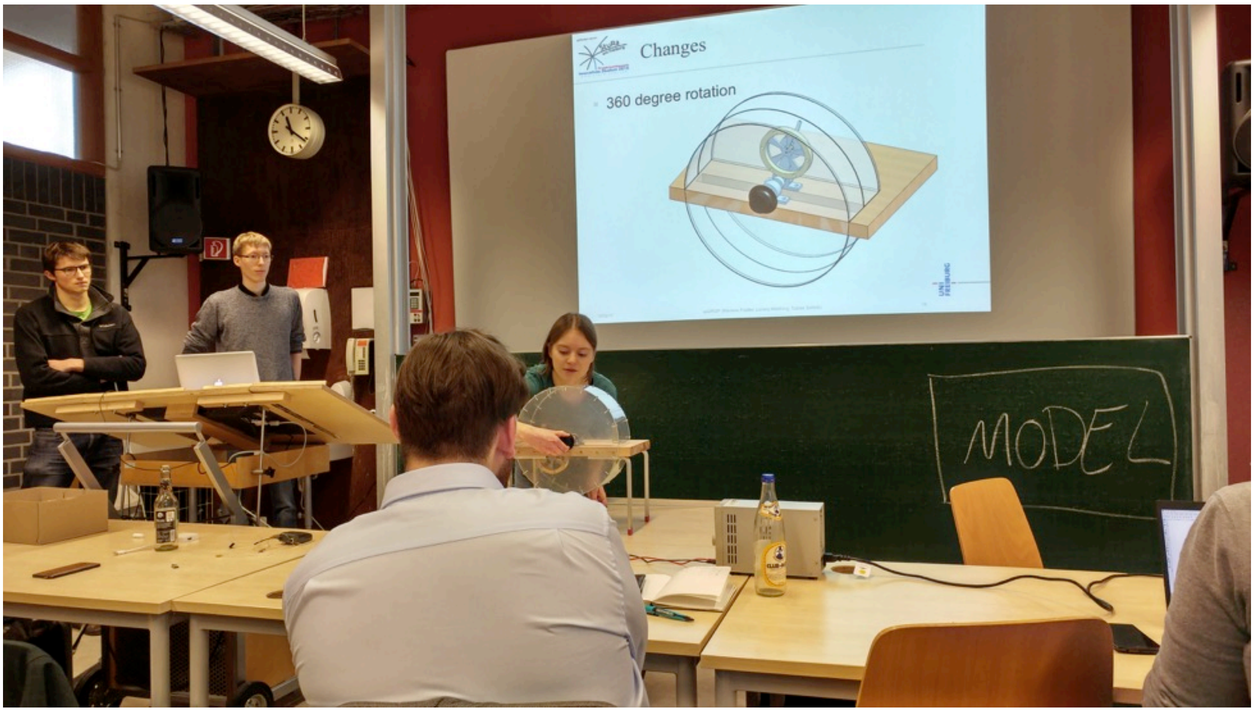
Group 1: Using experiment data to tune the PID controller



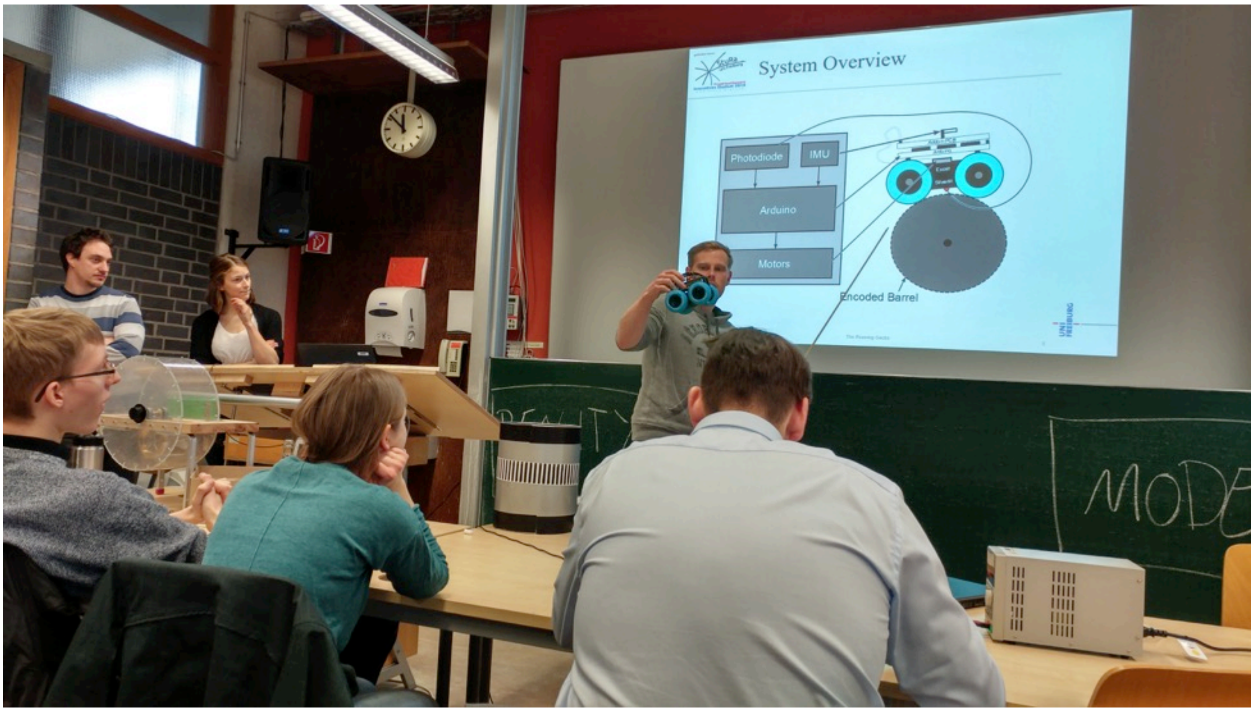
Group 2: Automated flute (by Armin Jamali, Saniea Akhtar, Connor May)

Demo of group 2

Group 3: Flywheel inverted pendulum (by Lorenz Miething, Tobias Schöls, Marlene Fiedler)



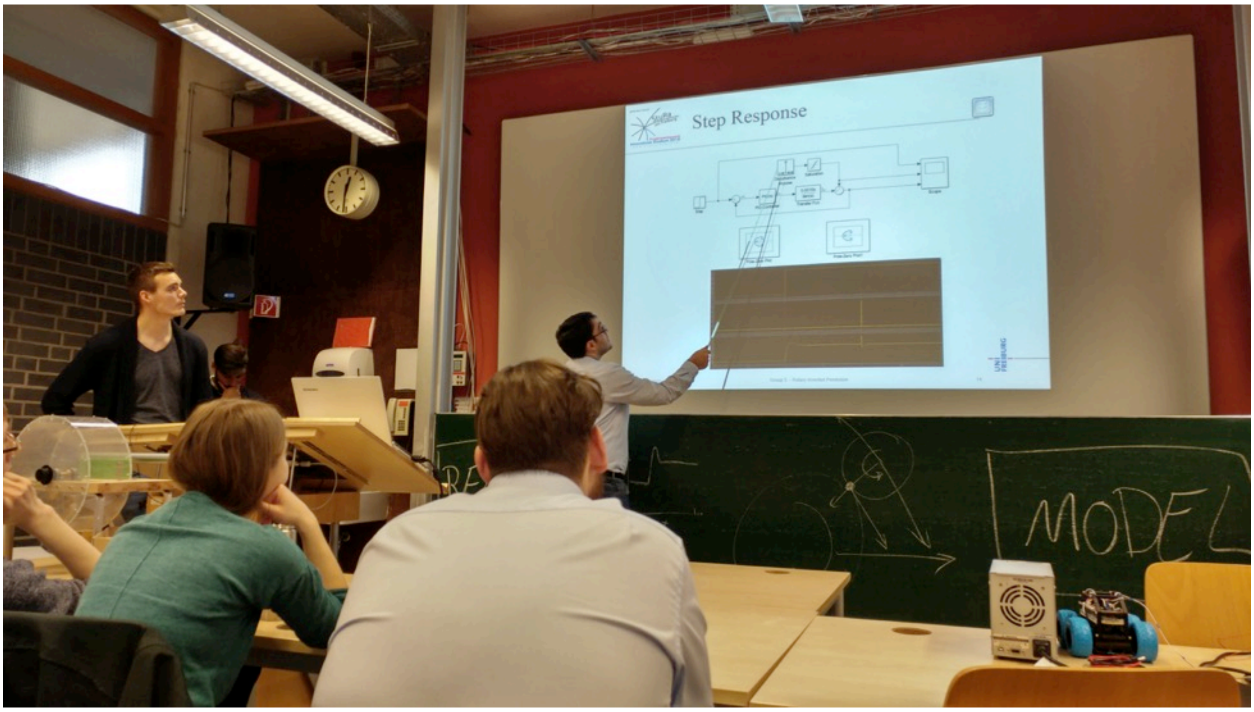
Demo of group 3



Group 4: Self-balancing car (by Mara Vaihinger, Julian Reimer, Yanning Häring)

Demo of group 4

Group 5: Furuta pendulum (by Lukas Klein, Ali Sadr, Muhammad Harris Khan)



Group 5: Analysis of the system using Simulink model