Building of robotic systems in an educational setting

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***Abstract*— The process of designing and manufacturing robotic systems is complicated if looked at in the big picture. However once broken down into the smaller sub-assemblies that a simple three axis robot arm requires the entire process is straightforward. In this Paper we go through the entire process of designing a robotic arm, selecting our components, manufacturing techniques and software solutions. The entire process is simple enough to successfully convey to students in any STEM program and incorporates all areas making it ideal for interested students and educators. State of the art: we were able to find one paper covering a very similar process in a far more complex manner however that paper did not involve the steps for electronics and software and focused more on the cad side of things[1]**

***Index terms*—robotics, additive manufacturing, Internet of Things, electronics, STEM, education**

Contents

I. Introduction

Manufacturing Robots is a complicated process. From design to manufacturing there are a lot of parts to it. By breaking it down the process can either be simplified or split up between multiple students. The most important step to ensure success is to be very precise as for a robot precision is key. The design and manufacturing process can be split down into four subprocesses. Calculations, CAD, manufacturing, and programming. This enables students to expand into all these subtopics, enabling many future opportunities for them. In many ways this is the perfect STEM project for exactly that reason.

A. Paper overview

In this paper we go through the process of designing and manufacturing a robotic arm in an educational setting. Leading through the entire process from start to finish. For many Schools acquiring a robotic arm for students is simply not an option, whether that is due to space or financial constraints.

By having the entire process split up over different subjects students can always work with the help of the most experienced and qualified teachers for the step of the process they are in. From start to finish students take three semesters to finish their very own and unique robotic arm.

Students acquire skills in the areas of CAD, additive and subtractive manufacturing, programming, and mechanical systems. Creating a robotic arm from scratch is no easy feat so it is of course an enormous success moment in a student's education when a project they were working on for three whole semesters finally comes to life just as it should.

Overall, we believe that with the correct helping in their education. Students can achieve wonderful things that incorporate the principles outlined in this paper. Even if that is not a robotic arm. The Process for our group included a class of eighteen students but can be scaled to any class size. Over the course of three semesters five teachers were involved in the project

II. Calculations

The design process starts out with calculations and selection of parts that need to be externally sourced. The aim we had when designing our robot arms is to keep the parts that need to be purchased to a minimum. Therefore, we looked at what we had available, which lead to 3D-printing and plasma cutting to be the main methods of manufacturing for the robot which we will discuss in more detail in the section Manufacturing of this paper. In the Calculations we estimated loads on the robot and calculated the cheapest and most readily available bearings we could get away with using whilst still achieving our goal.

Another consideration we calculated in this step was the torque required to move the arm efficiently. in this step we also chose the cheapest stepper motors that were suitable for the task and the appropriate stepper drivers to control the selected motors. this meant choosing different drivers for different motors depending on the current required.

Furthermore, this is also the step where parts like gears will be calculated. Since our base design relies on a planetary gearbox to increase the motor torque to move the first arm more easily, we calculated the gear sizes and ratios. This step also included adding tolerances for 3D-Printing the parts.

All the Calculations for the robot were done in collaboration with the Teacher in the same Semester as the design of the Robot. The software we used for the calculations is PTC Mathcad Prime

III. Design

In the design or CAD part of the process all the calculations and acquisitions must be taken into regard. It is also essential to only use parts that are guaranteed to be available during the manufacturing of the robot. The entire process for the design is based on a principle of building from the ground up. We start the design from a Base made of a steel table that we cut and bend to shape later on. Then we add the gearbox we discussed earlier. we then move up to transferring the torque from the gearbox to the first link. It is advisable to keep the designs identical up to this point. This would mean just following either the teacher doing it or by tasks set by the teacher.

When it comes to the two arms and additional axis of the robot the creativity of the students is now essential. For our robots we all had to design the two arms and the Z-Axis by ourselves and therefore the results are quite different between the students[1]. Of course, the teachers will be there every step of the way so no major mistakes should arise in this step.

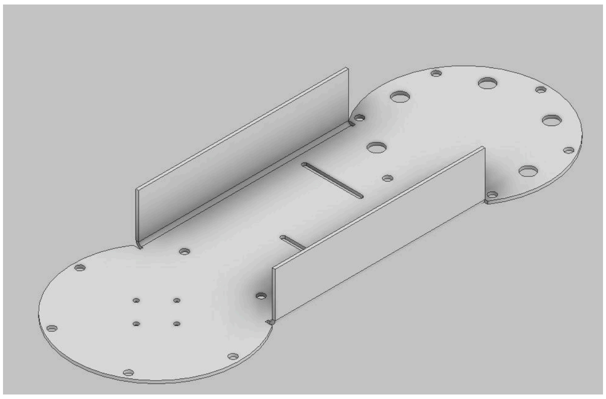

Figure 1: The arm of a student designed for plasma cutting.

Some students preferred one manufacturing option over another and the processes of manufacturing and designing wildly varied in this step, so it is essential to give the students some freedom to get the best results out of each one of them.

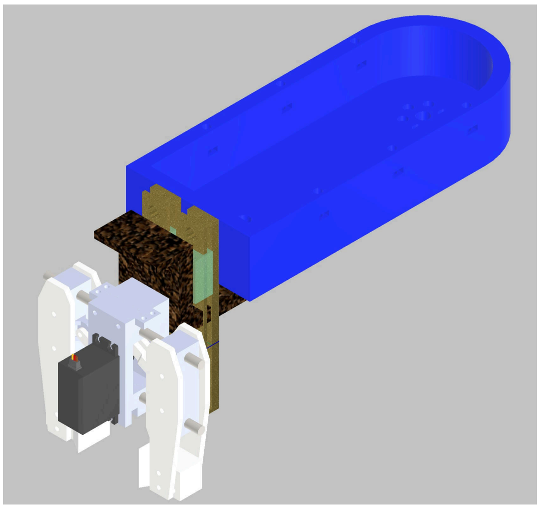

Figure 2: The arm of a student designed for additive manufacturing.

In the design Process Students used the CAD software they were familiar with from the previous two years which in our case is Autodesk Inventor. The design together with the calculations was done over the course of one semester with two hours per week put into it.

IV. Manufacturing

This step is very dependent on the equipment available in the workshop. For our school, our main two methods were cutting and bending sheet metal or additive manufacturing using a 3D-Printer. The Machines used here are for one our Hesse Maschinenbau PlasmaCut 2010, multiple Prusa3D Prusa Mini 3D Printers, a pair of Creality Ender 3 S1 Pro 3D printers for bigger parts as well as the school's brand new Bambu Lab P1S 3D Printer. The students had four hours each week for the manufacturing over an entire semester.

Figure 3: A Robot during the manufacturing process. This one relying on additive manufacturing.

In this step students will have to implement the design they made from the previous step. This step is easy up to the point where designs differ as students can cooperate on the base parts since they should be identical up to this point.

Figure 4: The Plasma cutter in action cutting out the parts.

After the base process it will be more complicated, and it is essential that the students have freedom to do their own pace in the workshop and work on their robot to implement their unique design for the arms and z-axis. During the process it is inevitable that students run into issues, so they need to have the time and resources to redo their designs to adjust for the lessons learned from the issue. Every design will have its benefits and drawbacks[1]. No student will have a wrong design as long as they are functional[2].

V. Programming

In addition to the three steps mentioned before it is obviously to give the robot some functionality. This is accomplished in the last part of the project by programming the robot using in our case a commodity ESP32-S2 microcontroller on a dev board. This controller is ideal given its powerful Processor Core and WIFI functionality. [2] It is a particularly good choice for Internet of things Projects as Espressif provides excellent developer tools for the ESP32[3] which are more consumer focused[4] then the tools for most similar Microcontroller modules from STMicroelectronics[3] or Microchip[4].

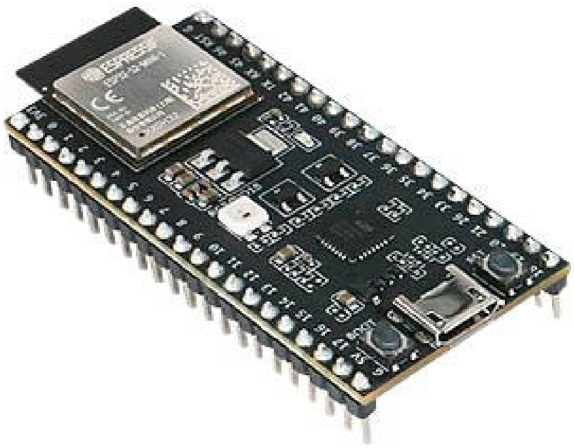

Figure 5: the ESP32-S2 dev board that is used.

In addition to the microcontroller, we need a power supply and stepper motor drivers. The motor drivers will enable us to use the motors at a higher voltage and with remarkably high precision. These parts are in our case incorporated into a spec electronics enclosure.

[1] Students should be aware of the drawbacks of their designs and be able to explain why they chose a specific compromise

[2] The Requirements for functional may differ for students but a baseline should be set here

[3] https://www.espressif.com/en/products/sdks/esp-idf

[4] https://www.arduino.cc/en/software

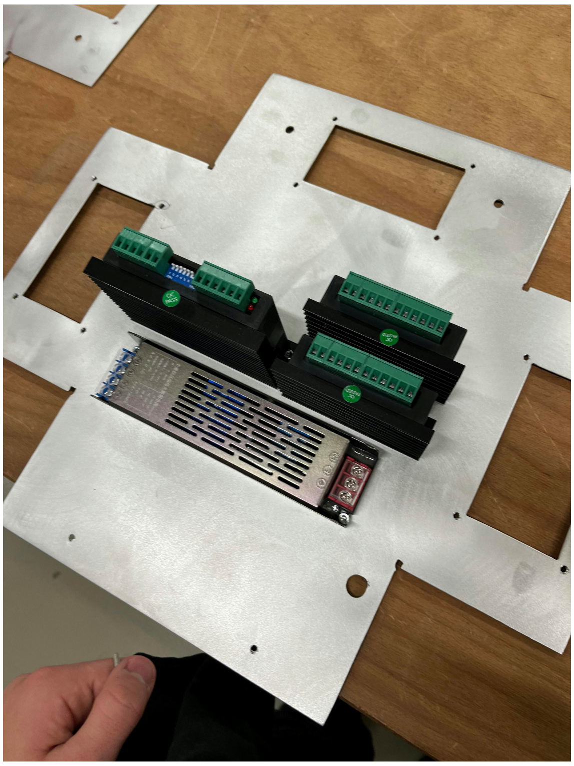

Figure 6: The electronics enclosure in manufacturing

From then on, the students are programming basic functionality into their robots like moving links and gripping items with their robots and moving them around successfully.

The full Process for the students in this module involved the wiring of the electronics enclosure to get to the desired functionality as well as the programming. For Programming the students were able to choose to implement their functionality using C++ via the Arduino framework or to use MicroPython which the ESP32 supports. This Module is done over six weeks of rotation workshop lessons in one semester.

VI. Results

Over 80% of students who have designed and built a robot from this project have said in a survey that they feel more comfortable interacting with robots after having designed their own robot links and developing a deeper understanding for the technology used.

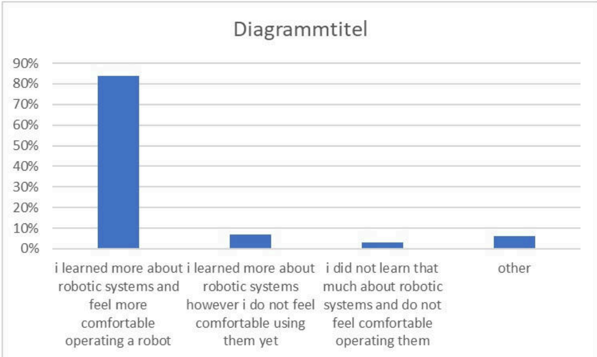

Figure 7: The survey results.

In addition to that the students have their robot arm to take home once they finished it making a great piece for decoration or can even be used at home for some fun tasks that the students think of.

The students also feel like they massively improved their skills in CAD and their understanding for the different manufacturing processes.

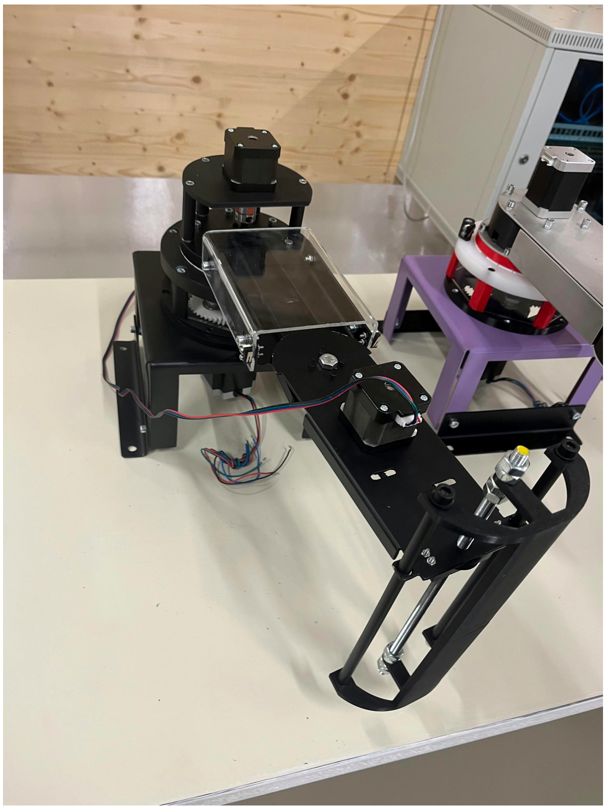

Figure 8: A student's finished robot.

References

[1] K. Kim, "How to Teach 3D CAD to Product Design Students Providing Integrated Design Experience," May 2014.

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[3] STMicroelectronics, "STM32WB5MMGH6TR Datasheet." 2020.

[4] Microchip Technology Inc., "PIC32CM5164LS00100 Datasheet." 2022.