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ADDITIVE MANUFACTURING OF SPARE PARTS IN MARITIME INDUSTRY – TECHNOLOGY TRANSFER IN MARINER EDUCATION

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ABSTRACT
Ships are carrying many spare parts, but not all needed at all times. Hence, supply chain is organized to deliver parts which are not aboard. Lately, additive manufacturing is considered to supply necessary part. Additive manufacturing is considered by many projects related to the maritime industry. Several companies are trying to integrate it into their processes. Several navies are interested in integration of the 3D printing technology. Hence, it can be predicted that this technology will play important role in future for spare parts management. This paper presents an attempt to integrate new technology into mariners' education. We present Master level student work in this research. Firstly, appropriate 3D printer is chosen. Then, it is built from parts. Next step was to test it. Finally, it is presented to the students as laboratory exercise. Students responded very well and showed enthusiasm and interest for this technology.
Keywords: 3D printing, mariner education, technology transfer

1. INTRODUCTION
Education is one of the slowest changing parts of human activities. Hence, introduction of some new technology into educational curriculum is delayed, and education is slowly advancing. Additive manufacturing (or 3D printing, popularly) is not novel in world of technology. This technology was proposed for the rapid prototyping [1, 2]. Practical use was considered in [3]. It is also used for hybrid manufacturing [4]. 3D technology has advanced so much, that open source, free, and/or cheap options are more often [5]. This paper shows example of introduction of this technology to the marine engineering and marine electrical engineering education. Why to introduce 3D printing into mariner's curriculum? The answer is simple. There are trends in maritime industry, such as in [6, 7, 8, 9, 10]. Port of Rotterdam plans a dock with 3D printing of spare parts [10]. Some maritime companies and navies experimentally introduced 3D printing of the spare parts aboard their ships. A case study on acceptance of 3D printing of the spare parts in the maritime industry is published in [11]. Obvious application is in the spare part management [8, 12]. The advantage is in the possibility to print anything which is needed, and not to carry it on the journey. Furthermore, there are a lot of occasions when spare parts are not available aboard at all, and must by supplied from the distance by the supply chain. Advantages are obvious. Some studies considered availability of ship's systems in the context of 3D printing of the spare parts [13]. It is shown, that ship systems are more available if the additive technology is available aboard ships.
Knowing above mentioned, it can be concluded that knowledge of 3D printing must be include into mariner's education. This paper shows successful attempt of introducing this technology to study curriculum of the Maritime Faculty in Split.

2. 3D PRINTER CHOICE AND CONSTRUCTION

The first question is where to include additive technology. The easiest way is to mention it in lectures (theory). On the other hand, the lectures are the passive way of learning, which means that students learn 10-20% of the presented topic [14]. The obvious alternative is to develop laboratory exercise. This work started as a part of the master thesis of the marine engineering student. Paper's first author supervised the work. The final product was the laboratory exercise at the 4th year of Marine electrical engineering and information technologies study of the course: New technologies in electrical engineering materials. Student, assistants and laboratory personal helped in the actual work.

The first step was to choose appropriate printer. The printer should be affordable, due to budget limitations. It should be easy to use, because students should operate it at the exercise. Since, there is no need to actually print metallic parts, only models of parts, a cheaper printer with PLA or ABS filament was available for choosing. We have chosen Wellman K8200 printer [15] due to fact that it satisfies requirements and it was available in town electronic equipment shop. It can print objects of 20 x 20 x 20 [mm], which is satisfactory for the educational purposes at this stage. Major characteristics are: satisfactory precision, single head for the filament, heated bad, support of the STL (Standard Tessellation Language) files, USB port.

Since the printer is delivered as the kit, it was predictable that it is easy to construct. It was not the fact. Since the beginning there was problem of finding appropriate tools. Figure 1 shows modification, which was enforced during construction. Namely, the hated bad was damaged in the first trial of the montage. Using Internet advices, we changed the original upper board of the heated bad with the glass.

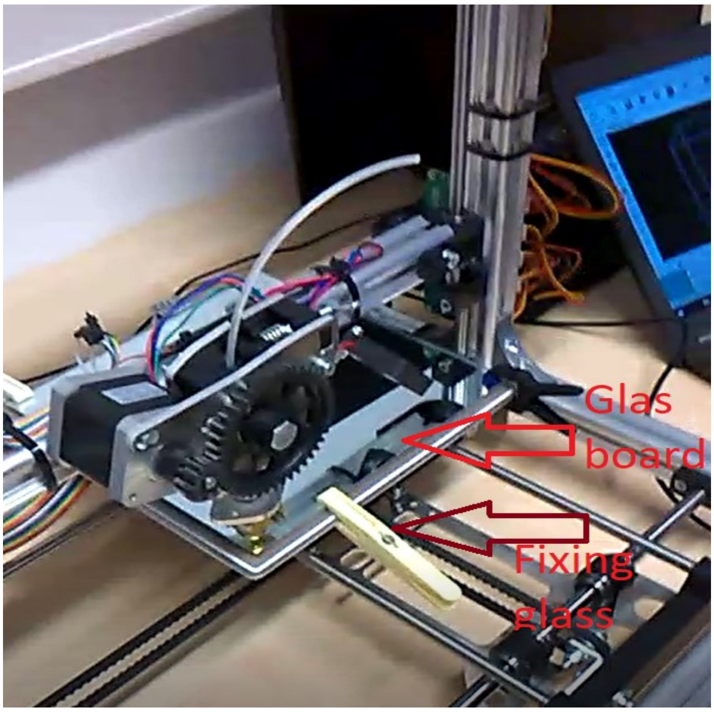

Figure 1. Modifications in the construction of the 3D printer: glass board instead the original, and clothespin used to fix the new board.

Student and laboratory personnel joined forces to finish construction and calibrate electrical part (motors). Construction and calibration of the printer took two weeks. Figure 2 shows the calibration procedure of the z-axe. This procedure should be performed before every printing.

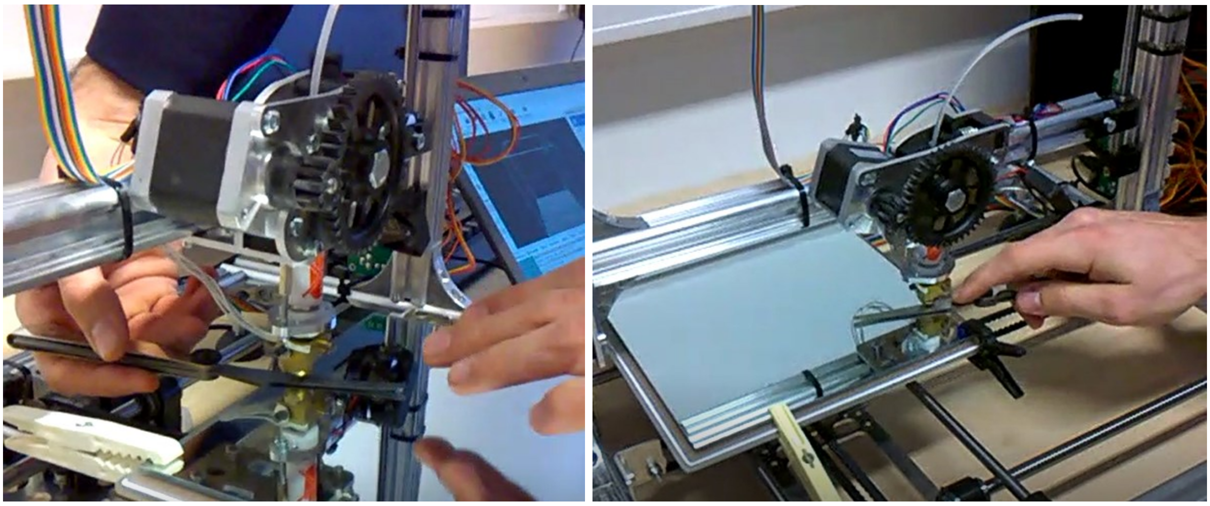

Figure 2: Calibration of the printer – the first step in printing spare parts.

3. RESULTS

This work was used as a part of the master thesis. Furthermore, the laboratory exercise is developed and a “Standard printing procedure” (SPP) is developed. The developed SPP is actual instruction to the students how to proceed in execution of their laboratory assignment. Students showed great enthusiasm for this assignment, and called it the best experience at the study.

Figure 3 shows the printed model of the piston and the piston rod of the motor 6DGRA18/22. The CAD is performed in Autodesk Inventor Professional 2015.

Figure 3. Model of engine parts printed for exercise.

The developed exercise consists of CAD modelling of the chosen part, printer calibration and actual printing of the modelled part.

4. CONCLUSIONS

This work shows that students are ready to learn novel technologies, which will be even more important in future due to constant development of novel technologies.

It is the attention to obtain 3D printer for metals, since actual parts aboard are made from metals, but this simple 3D printer with PLA is sufficient to learn about this technology, and to introduce it to the marine engineers' education. Further work is to test the quality of the printed spare parts, to compare mechanical characteristics of the printed and the original parts.

We also experimented with infill densities, which is matter for further considerations, and could lead to the interesting conclusions about sufficient mass of the material (optimization of material costs).

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