BOTBALL REVOLUTION - Print your own Parts

Mechanical Engineering

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***Abstract*—Nowadays, hardly any sector of technology can get along without a 3D printer. In this paper current possibilities of drawing models and printing parts are described. Furthermore, ideas for integration of 3D printing in the Botball are discussed and an example of a change of the Botball-set for future competitions is given. It also includes a review of building a 3D printer on one's own which could be a possibility for Botball.**

***Index Terms*—3D printing, Botball, PLA, CAD, Prusa Mendel**

I. Introduction

Botball is a very future-oriented competition [1]. On the one hand, programming and robotic skills will be beneficial in the future and on the other hand, the planning and documenting part of a project is vital. But in 2017 there should not be any field of technology without this one special device: a 3D printer.
Every year there are major and minor changes in the Botball-set. The parts are evolving and the set is getting better and better. Now the next step into the future could be a 3D printer for every team.

II. State of the Art

In the following section current possibilities of drawing models and printing parts are described.

A. History of 3D printing

In 1984 3D printing was invented by Charles Hull. The first technology was stereolithography. Since the 1990s the 3D printing technology has also been used for the medical research. Media visibility has been gained since the 2000s, in 2008 it got even more attention by the media when the first 3D printed prosthetic limb was used. In 2009 the patent for FDM (= Fused Deposition Modeling) expired and the prices plummeted. So the public got access to this technology. Since 2010 the new inventions have piled up: a 3D printed car, a 3D printer in space or even 3D printed food. [2]

B. CAD construction methods

In the next paragraphs, three of the most common CAD construction methods are presented [3].

1) Bottom Up: In this construction method every element is drawn separately and after that assembled. If a component shall be changed, it has to be opened again separately but the changes are visible in the whole document. The major disadvantage is that the parts are not connected so if one part is changed, everything has to be changed by hand. This method is used if the components have defined dimensions and do have not to be changed very often.

2) Top Down: In this construction method a "master-draft" is created. References are dependent on one part of the overall sketch. If this component is changed, for example a drive shaft, all others will change automatically, e.g. the bearings.
This method is typically used if there are huge assemblies which depend on only one part.

3) Middle Out: This construction method is a combination of the two variations described above and the most common one. The first step is to draw the main elements in a separate draft. After that, the parts are put together.

C. CAD programs

In the next sections two professional CAD programs which are free for students will be described. Inventor is also free for pupils, their teachers or mentors [4]. Creo Parametric is also free for pupils of primary and secondary school [5].

1) Creo Parametric: This program is for an easy beginning with CAD drafts. Parametric construction, FEM (=Finite Element Method), Animation and Rendering are supported. A quite small library of standard parts is also included. There is only one big disadvantage: the poor file management system.

2) Inventor: This program also supports all functions of Creo Parametric (like parametric construction, FEM, etc.). Additionally, tools for easier usage like gear or frame generators are included. Inventor is definitely the better choice. There are lots of advantages: a really good file management system, a big library of standard parts and a clear user interface including the construction of complex component groups.

D. 3D-printing technologies

The best known printing technologies are "Stereolithography" for commercial use and "Material Extrusion" for home use. In the following section these two are compared [6].

1) Stereolithography: The short form for this technology is SLA. A laser melts layer by layer to form the object and then it is cured by light to strengthen the material again. This is a really precise but expensive process.

2) Material Extrusion: In this technique the material is heated up and then extruded vertically and horizontally on the plate. By cooling down, the material hardens by itself. So the model is created layer by layer.

E. 3D Printers

The printers available on the market are very different. In the following section there is a comparison of some of them, a cheap, a medium-priced and an expensive one. There are even more expensive 3D printers for business, but in this paper only printers for the mass are discussed.

1) The cheap one: XYZ da Vinci Junior 1.0
This 3D printer cannot compete with top-of-the-range models, but could be taken into consideration for home use. The target groups are especially schools, which want to enjoy easy 3D printing. A disadvantage could be that the print area is only 15x15x15cm and only PLA can be used. The price is about 460€ and that is seen in the printing quality and the provided supplies [7].

Figure 1. XYZ da Vinci Junior 1.0

2) The medium-priced one: Conrad Renkforce RF1000
This 3D printer has a larger print area (25x20x23cm). Furthermore, there is a heating plate which allows better results of the printed models. This model allows printing with a great range of different materials (PLA, ABS, Polyamid (PA) / Nylon, Laywood, Bendlay, HIPS, NinjaFlex, smartABS, PVA, Laybrick, PP, PS). For this features, a price from about 1300€ has to be paid [8].

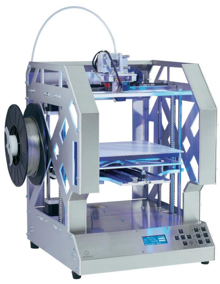

Figure 2. Conrad Renkforce RF1000

3) The expensive one: Ultimaker 3 Extended
This 3D printer is the most expensive one of this comparison with a price of about 3700€ . It has some special functions for example a dual extrusion, so there can be printed with two colors or also supporting material. The Ultimaker is optimized for the following materials: Nylonm, PLA, ABS, CPE, PVA. Soon it will be also possible to use CPE+, PC and TPU 95A. The print area is quite as big as the one of the Conrad Renkforce RF1000, but with 30cm really high [9].

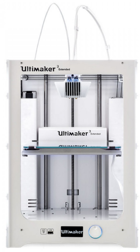

Figure 3. Ultimaker 3 Extended

F. Filament

There are lots of different filaments, but only the most common are described now. Flexible, glowing oder compostable materials which are also available nowadays will not be mentioned, because they are not as relevant for Botball as PLA and ABS [10].

1) PLA: PLA is the short form Polylactic Acid. It is reliable, offers great surface quality and is made from organic sources. It serves a wide range of applications, especially for new unexperienced users.

2) ABS: ABS stands for Acrylonitrile Butadiene Styrene. This materials is really stable and tough, it can resist temperatures up to 85 degrees Celsius.

3) Material for Botball: The teams have to decide if they want an adaptable or really durable filament. It should give the possibility to try both, so that the participants have to chance to discover the different properties.

G. The Botball-set 2017

The set is consisting of metal and LEGO parts, sensors, two ”Wallaby”-controllers and the ”iCreate”, a vacuum cleaning robot. Since 2016 there have been included new parts. Some examples are the omniwheels and a base for an omniwheel-robot. Though the changes every year, there are many improvements left [11].

III. CONCEPT

Using 3D printers for producing parts for Botball would definitely be an upgrade. Justifiably, it is not possible for students to buy an expensive 3D-Printer in addition to the Botball-set. In the next sections, the possibilities of printing parts are discussed. However, the chances should stay at the same level for every team, so there is also a paragraph that tries to deal with this issue.

A. Producing 3D models

1) Fab Lab Membership: Fabrication laboratories (=Fab Labs) are small-scaled workshops where lots of computer controlled tools (e.g.lasercutter, CNC mills, 3D printer) for creating models are, which are accessible for people who were registered before [12]. There are Fab Labs all over the world (more than 300 in over 50 countries) - in Austria there is one well-known in Vienna and Salzburg, called Happylab. High-tech machines are available for everyone who got instructions by one of the Happylab team members and is paying a monthly fee. There are different pricing models, starting with 9€ per month. The material has to be bought separately, but there is the possibility to buy it in the "Happylab Fabstore" [13].

2) Online shops for 3D printing: There are also online shops where models can be ordered. They are produced and sent to the defined address. One example is "i.materialise". Files can be uploaded and the estimated price is relatively high [14], according to the website. The shipping costs are about 10€ [15].

3) Extension of the Botball-set: It would also be possible to enhance the Botball-set. There is an extremely high amount of DIY (= Do it yourself) building kits, but buying such a kit doesn't mean it automatically is worth the money. Some of them are sold at totally overcharged prices. After doing a lot of research on the market the perfect and cheap example is found: the Prusa Mendel.

B. Keeping chances equal

Chances should be the same for every team in Botball. It would not be acceptable that one team has the possibility for printing the whole robot. So there must be a definition of the amount of grams, meters or printing time. In the following paragraphs the pros and cons of measuring by grams/meters or time are discussed.

1) Grams/Meters: Material costs can be negligible. It could happen that gears need as much material even if they are complexer than for example a solid plate.

2) Printing Time: There are also complex components which have very long printing times, though they are not really big. So the teams would have either few complex parts or lots of easy components.

C. Findings

The best option is a voluntary extend of the Botball-set for building a 3D-printer and a defined amount of grams. This is the fairest possibility, which is also testable by weighting the parts. Building a 3D printer is a worthwhile experience to make. The "hands-on" principle had got lost over the last year, so now it could be reactivated. A goal of the Botball-competition is to evolve the skills of the teams. The printer can be used for a long time, even for printing models for a diploma thesis that every student of a vocational school has to do or the so called "VWA" which is a pre-scientific work every pupil of a school of general education has to do. So the teenagers can profit from the benefits of the 3D printer for a really long time. Apart from this, Botball should also make a lot of fun being together in a whole community. Building a 3D printer and especially using it causes a lot of fun!

IV. IMPLEMENTATION

To test this concept so the "Prusa Mendel" was built. Now there is given an overview on building and testing the printer. Also the problems that occurred are reviewed.

A. Choosing a model

There is a great variety of "DIY-building-sets" available on the market. Prepared assembly kits can be bought at about 200€, but these models are often pretty instable and have only small printing areas. If the parts are bought separately in different online shops, much bigger and higher qualified printers can be realized at the same pricing level. As mentioned before in this paper the Prusa Mendel will be described.

B. Getting the parts

To save money most parts (like motors, gears, bearings) were ordered from "AliExpress". This a really cheap mail order company which is originally located in China. The parts are low priced, but sometimes also with low quality. A disadvantage is, that their delivery times are extremely long, e.g. gears arrived after 3 months! The mounts and special parts were 3D printed, which means they could be printed by oneself, but the parts could also be bought for 30€. The total costs for the hardware were about 200€. This sum should be definitely affordable for the Botball-teams as a one time purchase.

C. Assembling the hardware

For building the 3D printer the manual according the website "rerap.org" was used. This is a popular 3D printing community and collection of manuals, tips and reviews. There are provided videos for every step to do. There is only a short overview given, the detailed manual is available at: http://reprap.org/wiki/Prusa_Mendel_Build_Manual. The first step is to build the basic framework, which consists of two triangles building the sides. Then the basic bearing and motor mounts were added to the frame. Next step was adjusting the motors on the carriages of the axes. Finally the print bed was assembled.

D. Adjusting

The first step is to build the basic framework, which consists of two triangles building the sides. Then the basic bearing and motor mounts were added to the frame. Next step was adjusting the motors on the carriages of the axes. Finally the print bed was assembled. Three constants (x_steps_per_mm, z_steps_per_mm, e_steps_per_mm) have to be calculated and defined. There are given formulas for this values and could look like this [16]:

$$\#define\ x\_steps\_per\_mm = \frac{Steps * Microstepping^{-1}}{BeltPitch * PulleyTeeth}$$

E. Software

For printing, the 3D printer needs a special type of file, called GCODE. This is a numeric code programming language that tells an electronic machine how to make something. Parameters like velocity, duration and direction. This GCODE is created of ".stl"-files by certain programs which split the models into separate layers called "layering" and calculate the material that is needed. Two examples are described in the next sections [17].

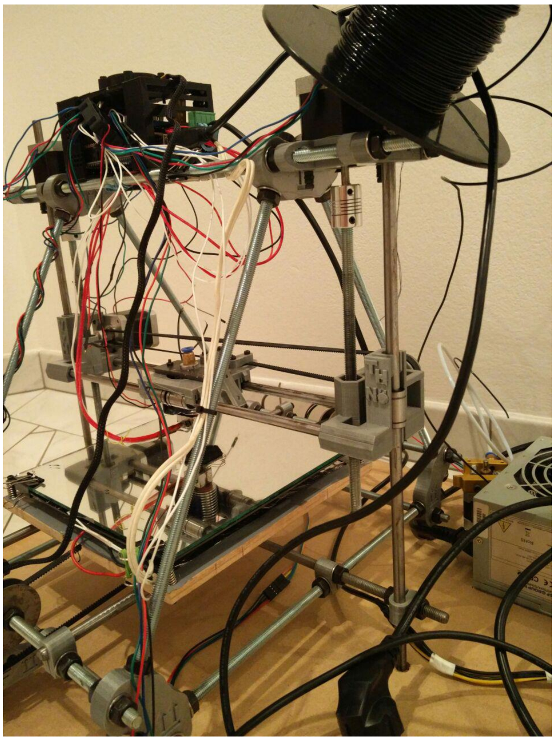

Figure 4. Prusa Mendel

1) Slic3er: : This software is free-ware, open source and really fast in calculating. In comparison to the ”Cura” software, the calculations are not so efficient. The printing times are extremely long and the printing quality is not as good as from the second software [18].

2) Cura: : This software is also open source, but the community is much bigger. The software is made for the ”Ultimaker” but it can be used for most of 3D printers. Different modi and also dual extrusion can be chosen [19].

F. Problems

Major difficulties were that some parts of the template were too big or too small. Sometimes parts had to be optimized. Also a short circuit of the Arduino-board caused a delay, because a new one had to be ordered. At another time, the printhead got clogged and it was difficult to clean it again. A lot of improvisation and creativity is needed for building a 3D printer.

G. Comparison to a bought 3D-Printer

A bought 3D printer looks more professional, but has not the ”Do-it-yourself”-flair. The precision of the ”Prusa Mendel” is good enough - except if you want a high end solution which is not affordable for most students. There are some tricky problems which have to be solved, but in the big community of Botball are the teams helping each other. There are specialists of every field and so they could give advise and solve problems in building the 3D printers together.

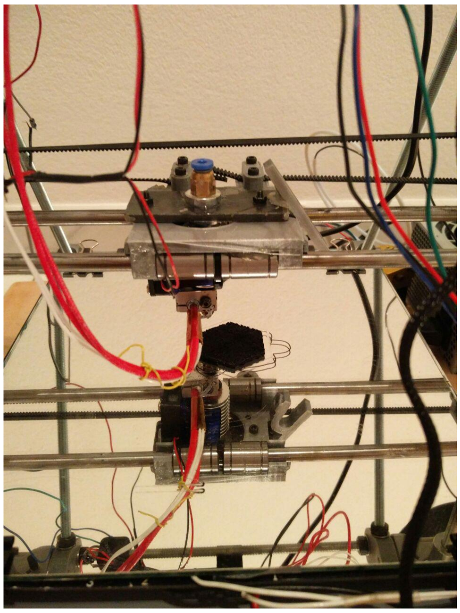

Figure 5. Model while printing

V. Conclusion

More freedom! More individuality! More fun!
Printing own parts should definitely be considered by KIPR for the next year’s competition. It would be an innovative and huge improvement and progress for Botball. With the definition of a specified amount of grams of filament and the same model of 3D-Printer, chances for winning are staying the same - like in the main concept of Botball. Then there can be seen differences between the skills of the Botball-teams. Some teams could also be overwhelmed by using this new technique, so the workshop at the beginning of the ”Botball-season” should take three instead of two days. On one day should be a crash course in CAD-drawing and building the 3D-printer. Also good documentations should be available - like the programming and the special functions are described in the homebase. Using the ”Prusa Mendel” would be a good decision, because there are lots of documentations and manuals already present and the cost-benefit ratio is really persuasive. The teams can better realize their own creative ideas. There would be no limits for creativity and variety any longer.

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