RAPID PROTOTYPING FOR ROBOTICS APPLICATIONS

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ABSTRACT: The paper aims to an overview of the rapid prototyping technologies available and to analyze the possibilities of use in robotics technologies. Rapid prototyping can be an economical solution for robotics applications where conventional technologies are either too complex or too expensive.

KEYWORDS: robotics, rapid prototyping.

1. OVERVIEW OF RAPID PROTOTYPING TECHNOLOGIES

Rapid prototyping are a series of techniques and technologies used to quickly fabricate a scale model of a part or assembly using three-dimensional computer aided design (CAD) data (1). Introduction of the rapid prototyping was made in 1987 with the introduction of stereo lithography. Today several techniques have been developed that are included in the rapid prototyping category. The most commonly used technologies are presented in table no.1.

***Table 1 Rapid prototyping technologies* (2)**

Prototyping technology	Base material
Selective laser sintering (SLS)	Thermoplastics, metals powders
Direct Metal Laser Sintering (DMLS)	Almost any alloy metal
Fused deposition modeling (FDM)	Thermoplastics, eutectic metals.
Stereo lithography (SLA)	photopolymer
Laminated object manufacturing (LOM)	Paper
Electron beam melting (EBM)	Titanium alloys
3D printing (3DP)	Various materials

At the base of the rapid prototyping technologies regardless of the technology is the 3D model of the part. The development of the CAD technology was the base for the development of the rapid prototyping technologies.

The commonly used data interface between Computer aided design software and the rapid prototyping machines is the STL file format. An STL file is triangular representation of a 3D object.

The rapid prototyping technologies are us in most areas of the industry, in general for making small scale prototypes of the products. In figure no. 1 is presented the use of the rapid prototyping technologies in the major sectors of the world economy.

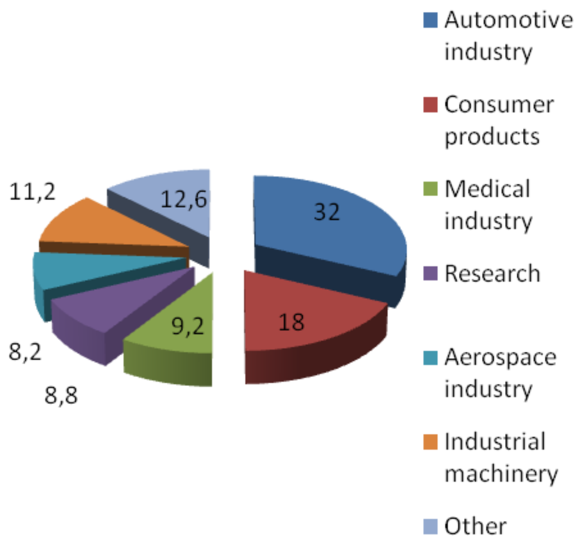

Figure 1 - Use of the rapid prototyping technologies in industry.

In figure. 2 is presented the use of rapid prototyping technologies in the world.

The benefits of rapid prototyping technologies should be compared with its limitations. At first the advantages of rapid prototyping technologies were not overwhelming; the scales are tipped over conventional processes (3).

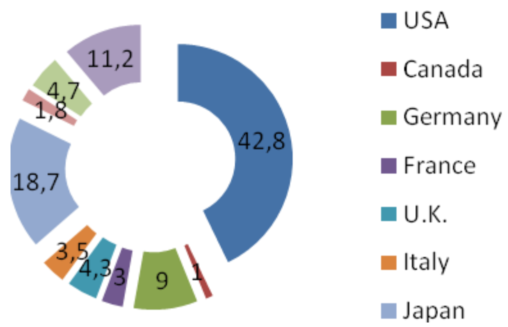

Figure 2 - Use of rapid prototyping technologies in the world

2. ADVANTAGES AND DISADVANTAGES OF USING RAPID PROTOTYPING TECHNOLOGIES.

As rapid prototyping technologies are developed and more and more technical problems are solved, more recently, the balance tends to tilt in favor of increasingly rapid prototyping technologies (3).

Geometric form – essentially rapid prototyping technologies allow unlimited production of objects of their geometric shape. It's main advantage over subtractive technologies (turning, milling) and the main reason why there is additive technologies. However, this freedom of the geometric shape brings some disadvantages for the rapid prototyping technologies.. Production speed is much lower than conventional production. By some estimates the current mass production methods are between 100-100 time faster than rapid manufacturing technologies. Also the surface roughness and geometrical tolerance is much less precise than conventional technologies. Finally, although the maximum size of objects produced by additive technologies are growing day by day, is below the maximum dimensions of parts produced by conventional processes.

Additive technologies offer the possibility to use multiple materials and the possibility of local control of macro and micro structure of the piece. This means that the functioning of the manufactured piece can be optimized in ways impossible with conventional technology. Materials can be selected for their mechanical, thermal, optical, characteristics. These materials can be deposited in layers according to their properties in such a way as to optimize or change the track properties, material properties beyond it.

CAD technologies lead directly all additive processes, making it theoretically possible complete elimination of cutting. In practice often cutting process are necessary because of limitations in the material or in the rapid prototyping technology.

Technology differs in that speed manufacturing of relatively small prototype with small cross sections is large, however during the manufacturing of prototypes about the same size, but with large cross sections increase significantly.

3. PRINCIPLES OF STEREO LITHOGRAPHY (SLA)

Stereo lithography is the first of rapid prototyping processes commercial available on the market and is most common in the world also over all other processes. The process was developed by the company in Valencia California 3DSystems U.S. company founded in 1986 (3).

Stereolithography (STL) contains a group of technological procedures of depositing layers of thermoplastic material in such way that the finished piece has a homogenous structure with good physical and mechanical properties. In stereo lithography the object in build layer by layer by an laser using an UV curable thermoplastics resin in a recipient which haze the possibility of realizing an movement on one axis corresponding with the layer build-up of the work piece.

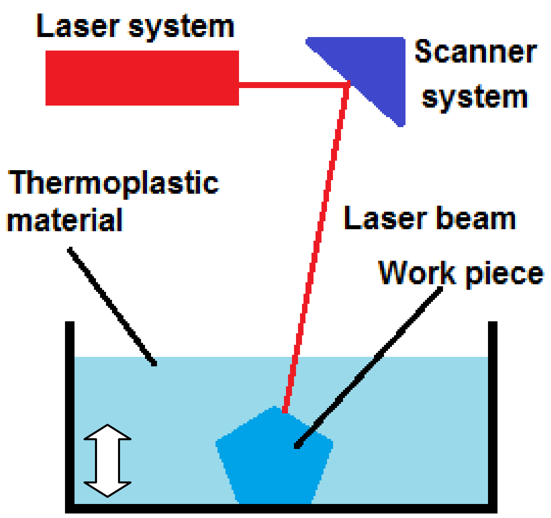

Figure 3 - Principle of SLA

4. PRINCIPLES OF SELECTIVE LASER SINTERING (SLS)

Selective laser sintering (SLS) developed after 1992 is based on experience gained in design and manufacturing equipment for stereo lithography (STL) and the expansion of technological research on certain groups of materials with mechanical and technological properties closer to the functional needs of engineering (ceramics, paper and paperboard coated, composite materials, etc.) (3).

It has been shown that a thin layer of certain mixtures of powders under the action of the laser beam can reach the local melting temperature which marks the transition layer of dust in the liquid phase. Based on the physical properties of powders used immediately after termination of laser an action takes place almost instantly, local solidification is achieved, the solidification is produced after directions of macromolecular chains and surrounded by a volume of particulate radiation unexposed said.

5. PRINCIPLES OF FUSED DEPOSITION MODELING (FDM)

Fused deposition modeling technology is currently second in the rapid prototyping technology to spread globally after stereo lithography, but knows a great development, in 2004 becoming the best-selling rapid prototyping technology in the world (3).

Fused deposition modeling technology is very "office - friendly" technology, meaning that is suitable for use in offices, not necessarily in production halls. This is due to relatively small space it takes, does not produce toxic fumes or loud noises, and does not require a controlled atmosphere for prototype manufacture.

Technology differs in that speed manufacturing of relatively small prototype with small cross sections is large, however during the manufacturing of prototypes about the same size, but with large cross sections the speed decreases significantly.

Like most rapid prototyping technologies fused deposition modeling technology builds prototypes based on additive technologies, building them layer by layer on a support piece, starting from the bottom up.

A filament (thin wire of plastic or metal) is carried out from a coil is transmitted by feeders and flexible tubing to an extrusion head which will melt the filament at its exit from it. The extrusion head can start or stop instantly the molten filament output from it. It is mobile both vertical and horizontal electric motor is moved by a precise technology controlled by the computer numerical control of fused deposition modeling machine. Extrusion head movement is coordinated with the prototype CAD file.

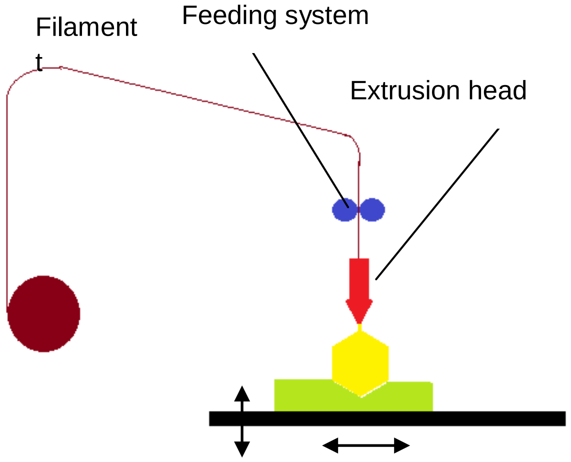

Figure 4 - Fused deposition modeling.

6. PRINCIPLE OF LAMINATED OBJECT MANUFACTURING (LOM)

Laminated object manufacturing (LOM) is a process of manufacturing that uses a carbon-dioxide laser to create successive layers of a three-dimensional object from layers of paper with a polyethylene coating. The first step is to create a base on which the paper can attach itself to (4).

***Table 2- Characteristics of the paper used for LOM** (3).*

Indicator	Value
Density	1,449 g/cm^3
Thermal diffusion plane (at 19 ° C)	0,00107 cm2/s
Tensile breaking strength	66 MPa
Elongation at break	2%
Compressive strength in the plan	26 MPa
Transverse compressive strength	3,9 MPa
Compressive deformation at breaking the plan	1 %
Breaking strain compression, cross	12,9%

Pieces obtained of paper are less expensive with mechanical and physical appearance similar to pieces made from wood. In table 2 are presented some characteristics of the paper used for LOM techniques.

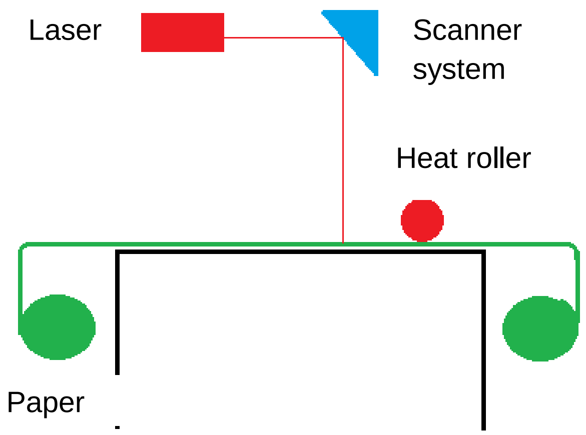

Figure 5- Laminated object manufacturing.

7. PROPOSALS FOR RAPID PROTOTYPING IN ROBOTICS APPLICATIONS.

In ISO 8373, the International Organization for Standardization defines a robot as "an automatically controlled, reprogrammable, multipurpose manipulator with three or more axes." (5). Although in the ISO 8373 the robot is defined as having three or more axes, the developments in robotics include autonomous robots.

In recent years development in the area of robotics and artificial intelligence are focused on swarm intelligence. Practically this is a system on interconnected robots whit a degree of artificial intelligence that collectively in cooperation perform a task my interacting whit each other.

By cooperation is understood, in a widest sense the realization of a coordinated action of several participants (cooperators) engaged in a given task (6).

Generally when research is done in the area of swarm intelligence the physical support (the robots) are of small dimensions and do not require considerable strengthens of stiffens of the mechanical structure. What they do require is the low cost of the units, the easiness of manufacture, the possibility of manufacturing the parts in large numbers, and the lack of specialized tools. For this type of components rapid manufacturing is a solution. The components used in studies related to swarm intelligence can bee easily manufactured by rapid prototyping technologies and can provide the required mechanical characteristics.

The paper will analyze by means of FEM analysis the characteristics of a chassis made out of PBT (Polybutylene terephthalate) for a mobile robot for swarm intelligence studies. FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement (7). Finite Element Analysis (FEA) was developed in 1943 by R. Courant, who utilized the Ritz method of numerical analysis and minimization of variational calculus to obtain approximate solutions to vibration systems (7). The evolution of FEA analysis performance and availability is related to the development of the computer industry. If in the 70 the FEA analysis was available to some companies in aeronautics, military and nuclear industries, now the FEA systems are widely spread and used.

In table 3 are presented the main characteristics of the material.

Table 3- Characteristics of PTB

Name:	PBT General Purpose
Model type:	Linear Elastic Isotropic
Tensile strength:	5.65e+007 N/m^2
Elastic modulus:	1.93e+009 N/m^2
Poisson's ratio:	0.3902
Mass density:	1300 kg/m^3
Shear modulus:	6.902e+008 N/m^2

In figure 6 is presented the 3D drawing of the piece.

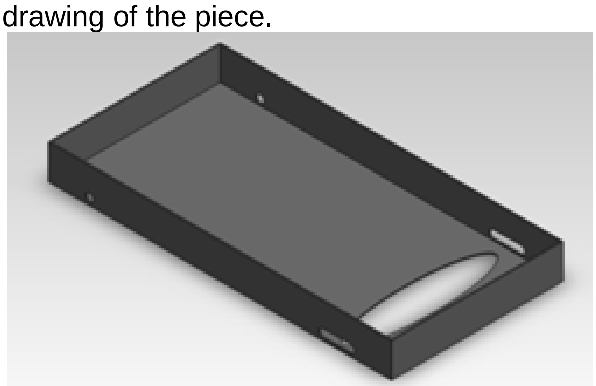

Figure 6- 3D drawing of the chassis.

The chaises have a weight of 0.482 kilograms and a volume of 0.000371m^3.

In figure 7 are presented the fixture points of the model (4 areas).

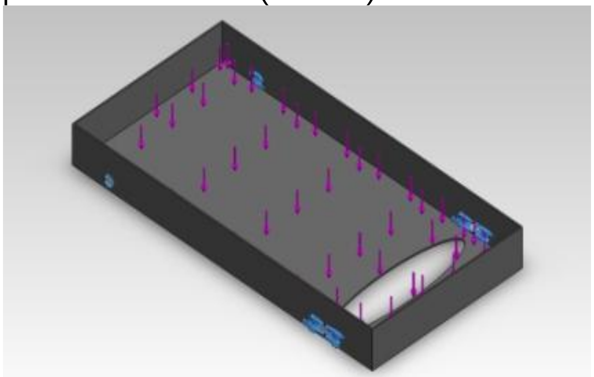

Figure 7- the fixture points of the 3D model.

The applied force (shown in figure 8) is 24.51 N and corresponds to a total load of the chaises of 2.5K, which takes in account the mechanical system of the robot, the power drive, the electronic board and the battery pack.

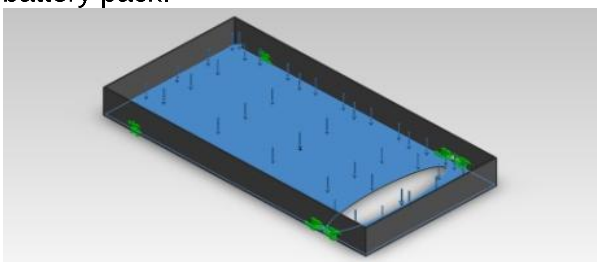

Figure 8- Direction of the applied force.

Table 4- Resultant forces

Components	X	Y	Z	Resultant
Reaction force(N)	1.2666e-007	24.5094	1.8537e-005	24.5094

Table 5- Characteristics of the used mesh

Mesh type	Solid Mesh
Mesher Used:	Curvature based
Jacobian points	4 Points
Maximum element size	6.12901 mm
Minimum element size	2.04298 mm
Mesh Quality	High
Total Nodes	73204
Total Elements	36166
Maximum Aspect Ratio	8.7219
% of elements with Aspect Ratio < 3	61.2
% of elements with Aspect Ratio> 10	0
% of distorted elements(Jacobian)	0

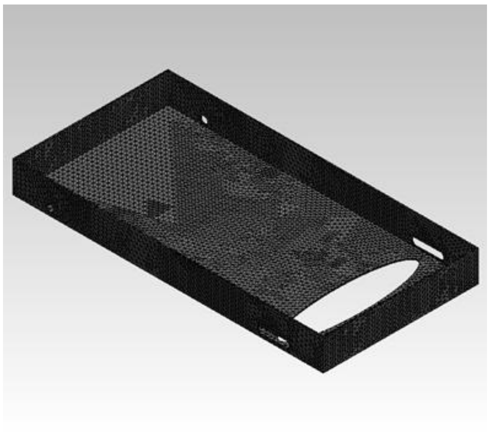

Figure 9 – Realization of the mash structure

8. STUDY RESULTS

Table 5- Results of the stress analysis.

Stress	
Type	VON: von Mises Stress
Min.	0.00175269 N/mm^2 (MPa) Node: 71221
Max.	2.86059 N/mm^2 (MPa) Node: 47742

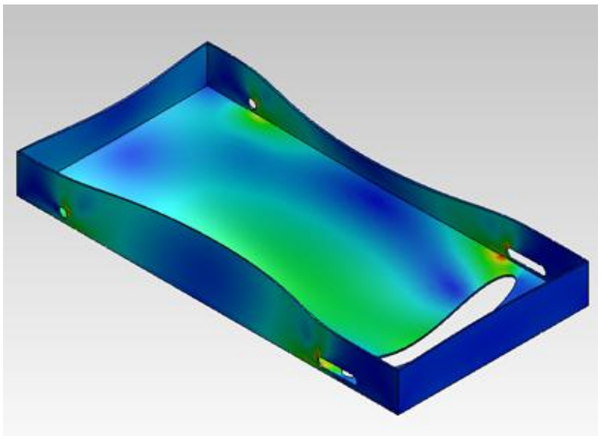

Figure 8- Stress repartition in the analyzed part.

Table 6- Results of the displacement.

Displacement	
Type	URES: Resultant Displacement
Min.	0 mm Node: 1
Max.	3.49447 mm Node: 51357

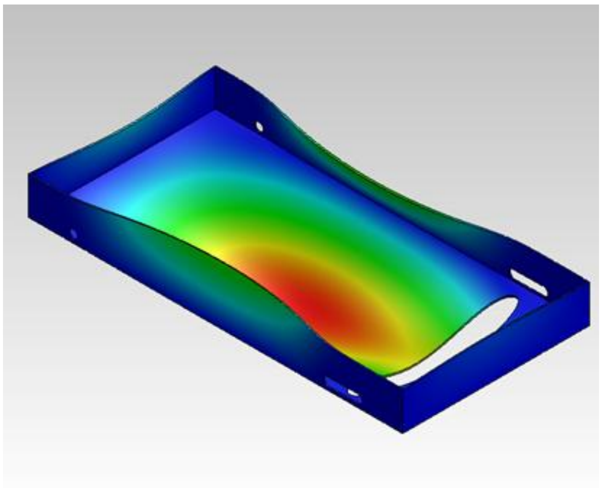

Figure 9- Displacements in the analyzed part.

Table 7- Results of the stress analysis.

Strain	
Type	ESTRN: Equivalent Strain
Min.	1.71815e-006 Element: 34632
Max.	0.00097728 Element: 177

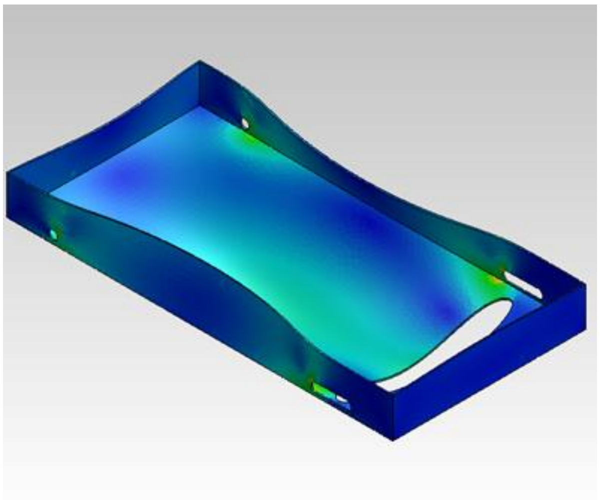

Figure 10- Strain in the analyzed part.

9. CONCLUSION

The component analyzed in this paper can me manufactured using rapid prototyping technologies and as resulted from the finite element analysis the part is suitable to be used for the design purpose despite the significant displacement of 3.49mm. This problem can be solved by thickening the area form a thickness of 2 mm to a thickness of 3.5 mm and upwards.

Do to the nature of rapid prototyping this can easily me achieved by modifying the 3D drawing and "printing" a new component.

A major advantage of the piece realized with rapid prototyping technologies is the reduced weight of the component which translates in to a higher battery autonomy and low production cost by eliminating the need for powerful motors. The component manufactured from PBT weights 0.482 kg. If the component would to be realized from AW 1060 aluminum alloy the piece would have 1.001kg (an added weight of 0.519 kg). If the piece would to be manufactured from 1023 carbon steel, the weight would be 2.915 kg (an added weight of 2.433 kg). In both chases the mechanical proprieties would be significantly better but the manufacturing time and costs would also be significantly higher.

Bibliography

[1] **eFunda, Inc**. eFunda, Inc. [Online] eFunda, Inc. [Cited: August 09, 2011.] http://www.efunda.com/processes/rapid_prototyping/intro.cfm.

[2] **2.http://en.wikipedia.org/wiki/Rapid_prototyping**. [Online] [Cited: August 09, 2011.] http://en.wikipedia.org/wiki/Rapid_prototyping.

[3] **Ioan, Mihailă.** *Tehnologii neconvenţionale.* II. Oradea : Editura Universității din Oradea, 2003. p. 260. 173-8195-25-x.

[4] **Center, Rapid Prototyping**. machines_lom.php. *www.rpc.msoe.edu.* [Online] Rapid Prototyping Center, 2007. [Cited: August 10 2011.] http://www.rpc.msoe.edu/machines_lom.php.

[5] **Kurfess., Thomas R**. *Robotics and automation handbook.* s.l. : CRC Press LLC, 2005. Vol. I, ISBN 0-8493-1804-1.

[6] **M.D. Zivanovic, M.K. Vukobratovic**. *Multi-Arm Cooperating.* s.l. : Springer, 2006. 978-1-4020-4268-3.

[7] **Widas, Peter.** http://www.sv.vt.edu/classes/MSE2094_NoteBook/97ClassProj/num/widas/history.html. *http://www.sv.vt.edu/classes/MSE2094_NoteBook/97ClassProj/num/widas/history.html.* [Online] 1997. [Cited: August 11, 2011.]