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An Application of 3D Printing Technology for Rapid Prototyping of an IoT Enabled Sensor Enclosure

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ABSTRACT: IoT and embedded electronics is getting popular due to its versatile applications in various fields for domestic, commercial and industrial usage. However electronics or electrical systems that are primarily built using electronics, needs enclosures to protect it from the environment as well as for maintaining its privacy concerns. 3D printers are valuable to rapidly prototype/fabricate/build enclosures for custom applications. The steps, involved in rapid prototyping using 3D printers start from understanding the specification and measurement requirements e.g. colour, look, dimensions, and tolerances. Followed by designing the model using a specialized computer-aided designing (CAD) software application. After modelling and designing in CAD, the file is converted and saved with a different file extension called the Standard Tessellation Language (.stl). Design files with the .stl extension can be fed to the most widely used 3D printers on the market today. Finally, printer parameters must be optimally set to print insert jobs automatically with minimal human intervention. The purpose of this document is to demonstrate a project and document all steps related to rapid prototyping of packages/enclosures for custom IoT-enabled sensors. It also summarizes the experience and strengths and weaknesses of using this technology in general.

KEYWORDS: 3D printing, FDM, IoT, Sensors, agriculture, rapid prototyping, design thinking, product, design, engineering.

I. INTRODUCTION

The term IoT (Internet of Things) has recently become more relevant to the real world, mainly due to the improvement of mobile devices, integrated and ubiquitous communication devices, cloud computing services, and data analysis algorithms [1]. Through the IoT, communication extends to all things that surround us through the Internet. It is not only machine-to-machine communication, wireless sensor network, sensor network, 2G / 3G / 4G, GSM, GPRS, RFID, WIFI, GPS, microcontroller, microprocessor, etc. [2]. These are considered as the assistive technologies that make the IoT possible applications [3]. However, most systems based on the IoT consist of integrated hardware using electronic or electrical systems, and therefore require an enclosure to protect it from environmental influences and maintain its privacy concerns. This involves using various materials, such as metal plates or plastics, and turning them into products by applying different manufacturing processes (such as metal plate processing or plastic moulding). One of the main shortcomings of traditional manufacturing technology is its limitations, and a large amount of capital investment is required to establish the industry [4]. Unlike traditional subtractive manufacturing technology, additive manufacturing technology has unlimited possibilities. In additive manufacturing, you can start with a basic printer and then expand to more advanced industrial-grade 3D printers as needed. This is also supported by many researchers, because their reports can always find the idea of using 3D printing technology to develop habitats on other planets [5,6,7]. The first 3D printing process was based on stereolithography technology invented by Japanese researcher Dr. Hideo Kodama in the 1970s. Fused deposition modelling 3D printing technology was developed by Scott Crump in the 1980s, who later founded Stratasys Ltd., a leading 3D printer manufacturer [8].

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II. RELATED WORK

Now, one of the most widely used manufacturing techniques in plastic products is injection moulding. However, it requires a huge machine and it requires a high-quality, accurate moulds. Therefore, a large capital investment is required [9]. And the idea of using fused deposition modelling 3D printing technology to make commercial-grade products can help save the huge capital investment required for the injection moulding process. 3D printers are built using electromechanical hardware components. From a structural point of view, the basic 3D printer consists of a printing bed, extruder, filament, which are integrated together in a three-axis motion table, where everything is controlled by a specially designed controller, also known as the motherboard [10]. From an application perspective, 3D printing products involve following the procedures for designing 3D parts in any 3D modelling software (such as AutoCAD, Fusion 360, FreeCAD, etc.). Then convert the 3D parts into the standard tessellation language abbreviated as STL, and then provide it to the cutting software, which cuts the 3D parts into small units, and allows the cutting machine to output G code information acceptable to the 3D printer motherboard. All these steps have been outlined in a previously published article [10,11]. The objective of this article is to discuss a study conducted by the authors that used a low-cost 3D printer to quickly prototype an enclosure for a customized IoT enabled sensor system. This article also summarizes the experiences as well as the advantages and disadvantages of using this technology in general. This article is an attempt to help readers to find answers to some questions such as: Selection of 3D printers based on power and materials used to meet the specifications as well as the time, cost and quality analysis.

III. MATERIALS AND METHODS

III a1 MEETING WITH POTENTIAL CUSTOMER

The details of the potential first prototype of the pre-commercial grade product is summarized in table 1. This was when and where the lead author approached the founder of Smart Food Safe Solutions Inc. Canada, Mr. Prasant Prusty sir and gave him information on IoT enabled sensor development [3] and enclosure design with 3D printing and prototyping option. Also, all technical information was shared in regards to the potential prototyping of pre-commercial grade product and the cost associated with the rapid prototyping techniques and what advantages this technique gives over the traditional manufacturing techniques. Later the customer was convinced and he shared the details of the requirements of his potential product that could be tried manufacturing using 3D Printing Technology. Considering the requirements an initial sketch was drawn and then a details 3D Design/Model was created using Catia P3 V5-6 R2017; (a proprietary application software tool by by Dassault Système, to create 3D computer-aided designs). The details of the design is shown in figure 2. From design it was clear that product to be printed was a machine and it consisted of two parts. 1) Main body of enclosure, 2) Cover lid with text label (as a sticker). Considering the requirements and the designs the next step was to assess the cost associated with the rapid prototyping techniques and what advantages this technique gives us over the traditional manufacturing techniques. The details are specified in the next sections.

Table 1. Information of the first prototype commercial grade product to be created using 3D Printing.

Name of Invention	3d Printed Enclosure Design for IoT Enabled Sensor Based on RF & WiFi (Coordinator Node).
Idea Patent Applicants Name	PVPIT Budhgaon and Smart Food Safe Solutions Inc.
Company Name/Company Product and Services	Founder of Smart Food Solutions Inc. Canada.
Designed by and helping credits during managing the 3D printing	Mr. Sanket S. Patil, Mr. Rajiv S. Gangatirkar, and Mr. Neeraj A. Inamdar, UG Students -Dept. of Mechanical Engineering, P.V.P. Institute of Technology Budhgaon, Sangli, Maharashtra, India
Credits on Mentorship	Dr. Dinkar V. Ghewade, President Innovation Cell, Dr. Nandkishor M. Dhawale, Vice President Innovation Cell, P.V.P. Institute of Technology Budhgaon, Sangli, Maharashtra, India

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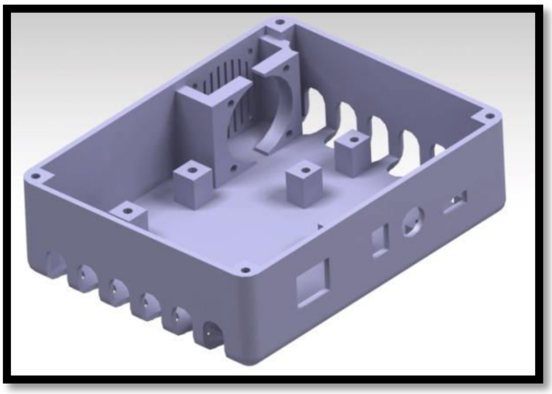

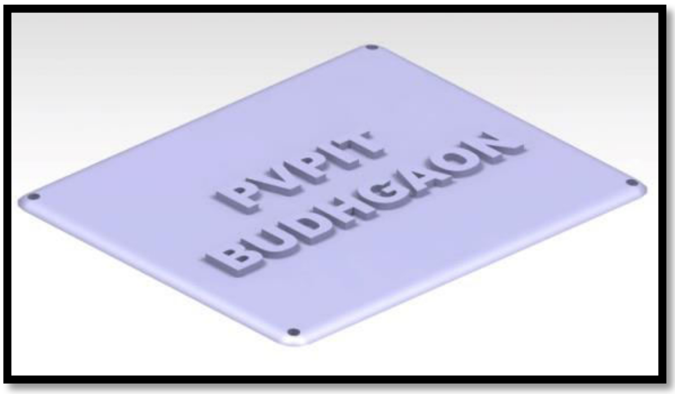

(a) (b)

Figure 1. The designed parts of the to be 3d Printed Enclosure Design for IoT Enabled Sensor Based on RF & WiFi (Coordinator Node), (a) Main body of enclosure; (b) Cover lid with text label.

III a2 COST CALCULATIONS FOR MASS PRODUCTION USING INJECTION MOULDING PROCESS

The cost considerations of the injection moulding process are the initial cost of making the mould, the cost of the material, the cost of machining, the cost of labour, etc. In addition, when we choose the injection moulding process, the minimum number of parts that we must carry has certain standards to order according to the processing and economic factors of in the injection moulding industry. According to the results of the survey, the minimum number of parts to be injected during the injection moulding process is 1000, so we calculate the unit cost according to the following formula.

Total Cost = Mould Making + Material + Labour + Machining Maintenance and other (EQ.1)

Table 2. Information summarizing the total cost of product using injection moulding.

Mould Making Cost (a)	**Material cost (b)**	**Labour cost (c)**	**Machining, Maintenance and other (d)**
1,50,000, (Local mould maker)	1000 units * 200 gram = 200000 grams = 200 kg. (Average cost of commonly used plastic moulding Materials like ABS, Polyethylene.) Overall Material cost 200* 80 =16,000	Rs. 600 per day. (Local market labour cost.)	Rs. 8000 per hour. Total hours = 6 Total cost = 6* 8000 = 48000 (Local industry information.)

So total cost per product using EQ.1 will be, 1,50,000 + 16,000 + 600 + 48000 = 2,14,600
Therefore, the unit cost per product shall be 2,14,600/1000 = Rs. 214.6

III a3 COST CALCULATIONS FOR BATCH PRODUCTION USING FDM 3D PRINTING

The cost considerations for mass production using FDM 3D printing process include product design cost, material cost, processing cost, labour cost, etc. Order. Therefore, we can manufacture products with minimal capital investment according to customer orders, which will be an advantage of the plastic moulding process. The formula used to calculate the costs associated with using FDM 3D printing is listed as EQ.2, as shown in
:

Total cost = Product Design + Material + Machining + Labour (EQ.2)

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Table 3. Information summarizing the total cost of product using 3D Printing.

Product design cost (a)	Material cost (b)	Machining, Maintenance and other (c)	Labour cost (d)
It took 1.5 hours for the student authors to design the product in Catia. Taking arbitrary average hourly rates charged by designers as RS. 700 per hour. Therefore, 700*1.5 = Rs. 1050. (The product design cost is one time cost.)	Thus, is easily calculated by the slicer tool. As per the tool the total material consumption per product was ~ 200 grams. Generally, 3d printer PLA filament cost is around Rs. 950 per 1000 gram. So, the material cost per product was supposed to be 200*0.95= Rs.190	Machining cost is considered keeping in mind electricity consumption expenses and maintenance cost. 360-watt machines consumption 1 kW in roughly 2.8 hours. As per slicer tool information. The time required for whole machine for printing = 8 hours. Therefore, total kW consumption = 4.11 electricity consumption expenses. 4.11* 8 = Rs. 33 Maintenance cost was considered to be RS. 10 per hour. 8*10 = Rs. 80.	As per the slicer tool the printing time was supposed to be 8 hrs. Considering an average hourly labour rate as 50 Rs there for the associated labour cost was to be 8 *50 = 400. (Labour cost is minimum as machines are automatic only requires human intervention during start of print and at end of print to remove part.)
So total cost per product using EQ.2 will be, 1050 + 190 + 113 + 400 = Rs. 1753 Per Product Prototype However, considering the designing cost as to be charged only once the unit product cost could be Rs. 703.			

As shown in Tables 2 and 3 and in Figure 3, it is clear that the cost of 3D printing for each product is almost 3.5 times the cost of each product related to the injection moulding process. However, customers learned of its benefits by continuing to use 3D printing. One of the main reasons is that your products can enter the market very early. At the same time, it avoided a large capital investment and helped you reduce the burden of product sales during the injection moulding process. After simply putting these thoughts in front of Mr. Prasant Prusty, he was impressed and sent an amber signal to move on. However, this also brings another challenge to the production of cubes with good compressive strength. This was achieved by redesigning the product and 3D printing while maintaining a high fill percentage, so the product passed the test and helped confirm the transaction.

III b More Challenges

Once the customer is satisfied. Afterwards, he briefly presented the general idea and general aesthetics of the Enclosure Design for IoT Enabled Sensor Based on RF & WiFi (Coordinator Node) and insisted on whether it can be manufactured at the lowest cost through 3D printing technology. The client already has experience with his products, and all the necessary knowledge is obtained from him through a small meeting to discuss the characteristics of the product, the parameters, the aesthetics of the product and the general shapes and dimensions of the product. Taking into account all the points discussed at meeting a design was created using Catia and sent to the customer for review. The customer was impressed by the design and aesthetics of the product and, based on his experience in machine building in recent years, made some suggestions for improvement. After re-adjusting the design requirements, the first prototype was printed using the FDM 3D printing process and tested under real conditions. Then it was now time to select the printer, printing parameters, hardware changes, etc. For usability reasons, a choice was made between the Geeetech A10 3D printer and the Creality ender 3D printer.

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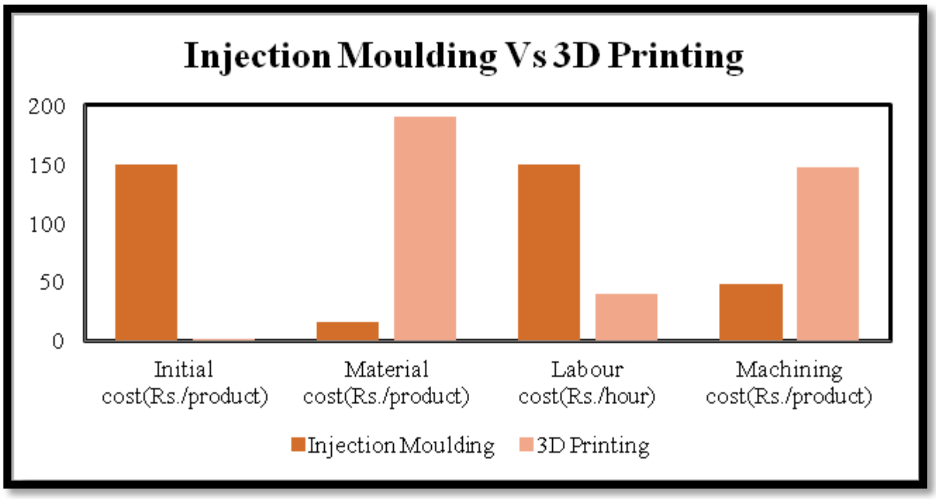

Figure 2. Comparison of cost involved in injection Moulding and 3D printing.

III b1 COMPARISON BETWEEN PRINTERS

Table 4. Comparison between low cost readily available 3D Printers

Aspects Category	Aspects	Creality's Ender 3	Geeetech A10
Mechanical	Drive system	Stepper motor, Belt driven	Stepper motor, Belt driven
	Build volume.	230*230*250	230*230*260
	Extruder system	Bowdon system	Bowdon system
	Material compatibility.	PLA, ABS, PETG	PLA, ABS, TPU, PETG,
	Dimensional accuracy	0.1 mm	0.1 mm
	Motherboard	V3.1.7 32 bits motherboard	V4.2.7 32 bits motherboard
	End stops	Limit switch	Limit switch
	Temperature control	Thermistor based PID control	Thermistor based PID control
Electronics	Power supply	24 volt, 10 ampere Standard PSU.	24 volt, 15 ampere Standard PSU.
	Power rating	260 w	360 w
	Motors's	NEMA 17 stepper motors	NEMA 17 stepper motors
General	Max. Temperature Nozzle, Heat bed	250, 110	260, 110
	Automatic Bed Levelling	No	No
	Input type	LCD with Knob	LCD with Knob

Figure 3 illustrates the two low-cost 3D printer options available. It can be seen from Table 4 that there is not much difference between the printers, so both printers are suitable for printing this product. The only difference between printers is power consumption. The rated power of Geeetech A10 is 360 W, and the rated power of ender 3 is 260 W, so Geeetech A10 will consume more power.

III b2 MATERIAL SELECTION

According to customer requirements for cost reduction. The design is based on minimum material requirements. This means keeping enough material in the specific dimensions of the part to withstand the load applied to it. The printed PLA material has a strength of approximately 42 N/mm^2 (may vary depending on temperature and printing parameters), which is sufficient to withstand pressure when normal human operations are considered. Compared with other materials, PLA materials are also easy to print. In addition, when we consider the use of the product, it will be used indoors, so it does not involve any major degradation problems. One of the other strong competitors in the

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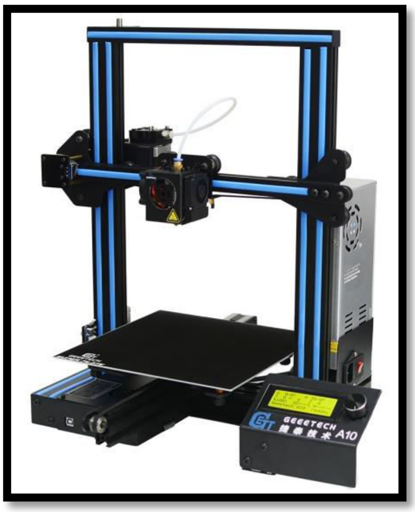
selection of materials is ABS material, but compared to PLA, it is a bit expensive and difficult to print. Therefore, the production of some products was selected based on mechanical principles and compatibility with PLA 3D printing materials.

(a)



(b)

Figure 3. Images of the low cost readily available 3D Printers, (a) Creality Ender 3; (b) Geeetech A10.

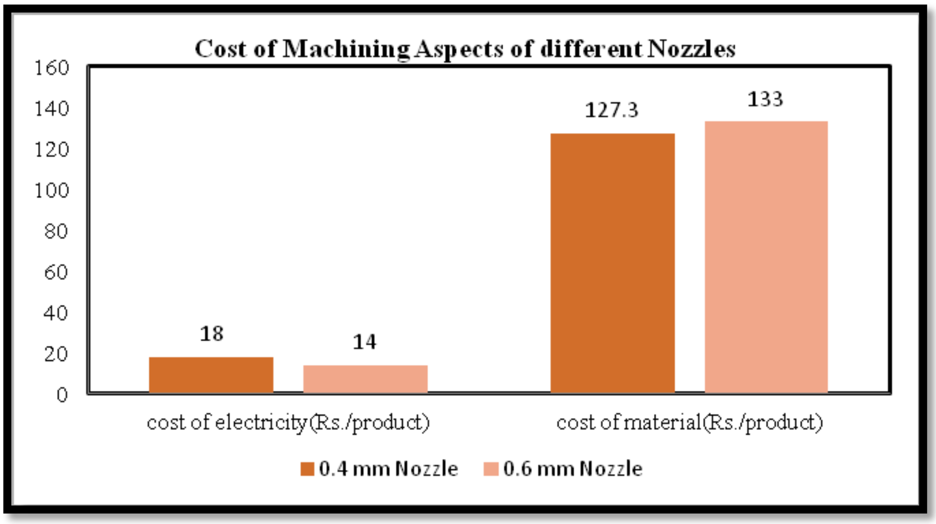


Figure 4. Comparison of various machining aspects of different nozzles in terms of cost.

III b3 SELECTION OF MACHINING PARAMETERS

The selection of processing parameters is entirely based on learning and experience from printing and prototyping earlier. For this product, a 0.6mm nozzle was selected for the fastest printing without affecting the strength and surface finish characteristics. Figure 4 below summarizes the comparison of time and material consumption for 0.4 mm nozzles and 0.6 mm nozzles while maintaining other printing parameters of the same. It can be seen from Figure 3 that the 0.6mm nozzle increases material consumption by 5 grams, but time consumption is reduced by 1.5 hours. In terms of cost, the 0.6mm nozzle increases the cost of the material by Rs. 6. And reduce the cost of electricity (based on time consumption) to Rs. 4. Also, if we consider the production quantity (in the future), the 0.6mm nozzle works fine so they opt for the 0.6mm nozzle for printing.

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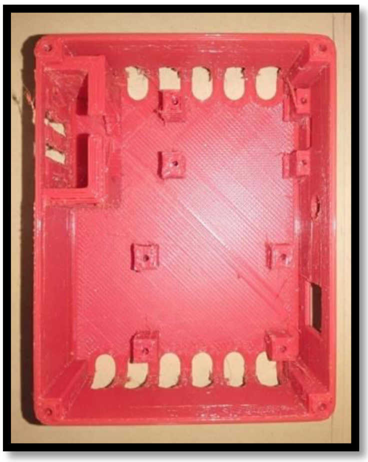

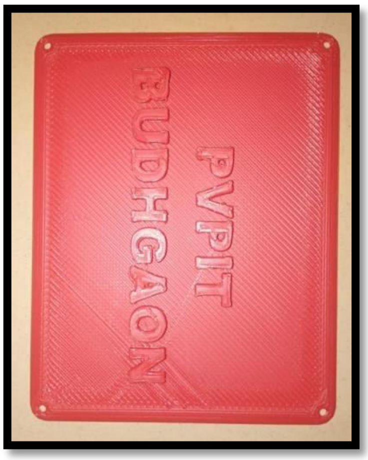

(a) (b)

(c) (d)

Figure 4. Comparison of real product assembled after 3 printing all its parts, (a) The main body of the enclosure; (b) the cover lid with text label (sticker); (c) the partially assembled IoT product [3]; (d) the partially assembled IoT product without customised enclosure [3].

IV. RESULTS AND DISCUSSIONS

Figure 5 shows an example of a real product. It was formed by assembling all printed parts using the procedure described in the previous section. Various IoT sensor package designs are available on the market, but these are industrial grade and require a little more capital investment and some skill to operate. In contrast, the enclosures described in this article are designed and prototyped primarily with home needs in mind. The housing was kept as small as possible to meet all functional requirements. After a bit of marketing, customers started increasing their case orders. As a result, we were able to print and assemble the enclosure on an order basis. At the request of our customers, we were able to print and ship about 20 cases to various parts of India. By carrying out this project from the development stage to the production stage, we gained a lot of experience, especially marketing knowledge.

V. CONCLUSION

New technologies appear every day, making existing technologies obsolete. Traditional manufacturing technology is efficient and effective for a specific manufacturing department. However, additive manufacturing technology can be easily adapted to the requirements of the product without major changes to its structure. Additive manufacturing technology is becoming more and more common and people see it as a hobby or a small business. When considering design and prototyping of IoT based hardware, it is important to protect the electronic components as well as to add aesthetics to the prototype (product). Therefore, using modelling and FDM techniques such as 3D printing techniques,

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you can quickly design and print the case according to the selected assembly or placement of all components. In this article, we were able to show you a simple approach to implementing an IoT project in an inexpensive way. It was also possible to document a complete and structured set of instructions to rapidly prototype the enclosure. It was also possible to find the answers to some questions such as: Selection of 3D printers based on power and materials used to meet the specifications as well as the time and cost analysis. Finally, the long print times compared to the low cost of capital of 3D printers generally determine the benefits of choosing this technology for mass production. However, this technology is ideal for rapid prototyping of custom packages and is described in this article.

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