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Opportunities and Scope of Desktop 3D Printers in India

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Abstract. AM is an advanced manufacturing technology used for fabricating parts in layers, from a CAD file. Various methods and materials have been developed to cater to its expanding applications. AM has seen tremendous growth in the recent past. While growth in the technical aspect is essential for the development of new techniques, growth in the economic aspect provides the need of innovation. With its ever-increasing industrial and personal applications, the 3D printing technology has experienced advancements in both the aspects. Yet its full potential has not been harnessed in developing countries. In this work, it is proposed to optimize the existing desktop 3D printers for developing countries. A market survey was conducted to recognise the lagging areas and the design modifications were made accordingly to produce a compact, efficient and cost-effective personal 3D printer for the respective needs and applications in developing countries. The data collected was relevant to the Indian market. The construction, testing and analysis of the prototype, 3D printer 1.0 and 3D printer 2.0 resulted in reduced cost, high print speed and improved product quality of the produced personal 3D printers, to make it suitable for the Indian market.

Keywords* : *3D Printers, manufacturing, rapid prototyping.

I. INTRODUCTION

Additive Manufacturing (AM) technology comprises of a process which builds objects by adding material, layer over layer, to produce a 3D object. It is used for producing a variety of structures and complex geometries; and offers the advantage of preparation of complex objects with a shorter cycle time and lower cost, when compared with the conventional manufacturing processes. There are various AM methods which are employed for different materials and applications. These include Fused Deposition Modelling, Solid Base Curing or Solid Ground Curing, Stereolithography, Selective Laser Melting, Selective Laser Sintering, Directed Energy Deposition, Ballistic Particle Manufacturing, Powder Bed Fusion and Laminated Object Manufacturing [1].

With different precision and tolerance values, these methods are optimally employed for production of application specific products with different materials like polymers, metals ceramics and concrete [2]. Initially, 3D printing was used for prototyping by architects and designers but in the past few years 3D printing has widely been applied in many fields of engineering and industry such as aircraft, dental restorations, medical implants, automotive products, construction and prototyping [3]. With the reduced cost and size of 3D printers in the recent-past, the category of personal or desktop 3D printers was introduced. Personal or low-cost desktop 3D printers are those AM machines which have a unit cost of less than $5,000 [4]. Personal 3D printers are chiefly based on FDM, as complex geometrical parts can be produced safely in an office-friendly environment using thermoplastics [5]. Hence, the range of its applications were expanded to homes, schools, offices, libraries and laboratories.

When compared to industrial 3D printers, the market segment of personal 3D printers is recent, yet, it has achieved an average annual growth rate of about 170% from 2008 to 2013 [4]. Additionally, it has been forecasted by industry observers that the 3D printing market will generate revenues of USD 20 billion by 2020 [6]. This shows that the 3D printing technology has a potential of generating revenue, which opens the market with opportunities in the field of manufacturing, to develop small to medium scale production. With a tremendous growth in the market, increasing capital generation and a developing potential of manufacturing capabilities, the use of 3D printing could provide business opportunities for start-ups, improve educational environment, improve emergency response and support rural development to boost the economic growth of developing countries. Applications of 3D printing in developing countries include disaster relief, quick production of medical supplies, reduction of carbon footprint and, low-cost prosthetics and laboratory equipment [7] [8].

Yet, the use of 3D printing in developing countries is limited or otherwise scarce. According to World Intellectual Property Organisation, 3D printing technology vastly exist in Universities or in FabLabs. While 54% FabLabs are present in Europe and 19% in North America, the largest two continents only comprise of a collected 15% of FabLabs in the world, that is, 11% in Asia and 4% in Africa.

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Additionally, it was described that innovation drives economic growth of a country as it results in further innovation, healthcare, capital and productivity. Although the discussions of innovation were generic, the need of innovation in terms of 3D printing in developing countries was identified as this report also included the history of patents in 3D printing. While China, Germany, Japan and USA account for approximately 80 percent of all 3D printing patents filed between 1970 and 2011, developing countries lagged in innovation and/or use of AM [6]. Thus, there was a need to identify and improve upon the lagging-areas to overcome the respective barriers to make-available this technology in developing countries for timely and well-paced advancements in innovation, productivity and economic growth. Such an attempt was made in this project. The aim of this project was to design, develop and construct a compact, efficient and cost-effective personal 3D printer for the respective needs and applications in developing countries and attempt to optimize personal 3D printers for developing countries based on market analysis. The market analysis was carried out in India, as India was identified as a developing country with minimal use of AM.

II. METHODOLOGY

The methodology of the work has been established in terms of the following segments.

2.1 Market Survey and Analysis.

A market survey is an analysis of the condition of the market for a product or service, which may include the availability, unit cost, customer preferences and competition. To begin with, a questionnaire was designed in which questions were a combination of open-ended and fixed-alternative questions. Applications of 3D printers at home and at various fields of work along with the expectations of the current customers were covered. The target consumers were adults and the questionnaire were filled by adults of 19 years to 66 years of age, whose professions included law, medical, engineering, teaching, designing, architecture and arts. From the market survey, it was recognised that although 79.6% of the people agreed to purchase personal 3D printers on the condition of effective cost and availability of application in their field of work, only 1.9% of the people had seen 3D printers in the market, while 34.2% of the people were not aware of the local availability for purchase of 3D printers in the market and 44.4% claimed that 3D printers were not available for purchase in their hometown. It was observed that 70.4% of the people agreed to purchase 3D printers for household applications on the condition of its cost-effectiveness.

From the data, it was conclusive that the technology of 3D printing remained unavailable in the Indian market due to ineffective cost, lack of awareness, large-sized machine, poor product quality and market unavailability, of which ineffective cost was the most prevalent with 72.2% opting for ‘low-cost’ as one their 3 primary expectations. It was also revealed that the most demanded property was high-speed followed by precision and durability.

In order to understand the condition of the existing market, it was essential to study and compare the specifications of the personal 3D printers available in the market, which are tabulated as follows.

Table 1. Comparison of Specifications of available frugal 3D Printers.

	Makerbricks I3C [11]	Reshape Ideas Anycubic Mega i3 [12]	Anet A8 DIY Kit [13]	3D Bazaar Creality Ender 3 [14]	3idea Easythreed Nano [15]
Maximum Retail Price (INR)	17,604	39,500	16,689	25,000	20,999
Sale Price (INR)	17,604	35,500	16,689	20,999	12,999
Assembly	Semi-Assembled	Assembled	Unassembled	Unassembled	Assembled
Machine Dimensions (mm)	N.A.	405x410x453	500*400*450	440x440x465	188x188x198
Print Dimensions (mm)	180X180X180	210x210x205	220x220x240	220x220x250	90x110x110
Extruder Temperature (Celsius)	__	260	__	__	180-210
Maximum Print Bed Temperature (Celsius)	__	110	__	110	__
Print Speed (mm/s)	N.A.	20-100	N.A.	N.A.	10-40
Nozzle/Filament Diameter (mm)	0.5/N.A.	0.4/1.75	0.4/1.75	0.2-0.4/1.75	0.4/1.75
Number of Extruders	1	1	1	1	1
Print Material	PLA, ABS	PLA, ABS, HIPS	ABS, PLA, Nylon PVA	ABS, PLA, Wood	PLA

'Table 1' shows that 3D printers were available in the market, for as cheap as INR 12,999, although, the cost was compensated on the print size and speed of the 3D printer, affecting its functionality, while the printer itself was portable. Other attempts of cost-reduction involved do-it-yourself (DIY) kits, essentially to reduce assembly cost. Additionally, all the low-cost printers had one extruder and the most common filament material was Poly Lactide (PLA) with a diameter of 1.75mm. The study of the existing 3D printers revealed that cost-reduction of 3D printers has been previously attempted. However, a reduced cost also created a constraint for the optimization of 3D printers from the engineering perspective. It was observed that four of the five 3D printers tabulated above had the same basic design. In accordance with Minetola et al., it was recognised that attempted cost-reduction of 3D printers resulted in problems like, poor aesthetics, dimensional accuracy, lack of strength of the printed objects et cetera [10]. It was identified that there is scope and need to optimize cost, machine to print volume ratio, product quality and speed in order to improve the overall product quality of personal 3D printers.

2.2 Design Procedure.

The prepared 3D printers were of cartesian type, i.e. comprising of individual mechanisms in the x, y and z directions, run by one stepper-motor each. The extrusion mechanism comprised of a feed motor, heater and a nozzle, and the part was printed on a heated base. Arduino was used to control the flow of current in the respective components, operating on a DC input using an AC to DC converter. Other components included limit switches, belts, guide rods, etc. The postprocessor used was Cura Engine and the printing technology used was FDM [16]. Reduction of cost was inspired by the RepRap project wherein the attempt was to produce a 3D printer that could produce 3D printers and by the work of Minetola et al. who used self-replicated parts to enhance the design and performance of four Prusa i3 machines [10]. Additionally, the procured components were standard components available in the Indian market, to ensure minimum cost. The design process is as follows:

2.2.1. Prototype. Making the prototype was the first attempt at the construction of the 3D printer. It was essential to clearly identify the scope of optimisation, which in-turn was used to appropriately plan and prepare the design, list of material, time required and monetary investment. The design used for the prototype was the design identified as the most common in the market.

The prepared prototype comprised of aluminium extrusions to support the respective axis, while the respective components were mounted on carriages and guided on aluminium guide rods. The mechanism of the x axis controlled the build plate, the mechanism of the y axis controlled the extruder head and that of the z direction raised the y axis assembly in order to give the product its height. The extrusion head was an assembly of a feed-motor, a heater and a nozzle. The glass build plate had a hot plate attached to it, responsible for heating the build plate.

On testing of the prototype, it was observed that the effect of heating in the build plate was in the middle of the plate which resulted in a low print volume. It also resulted in warping i.e. the ends of long products being bent as the extruded material did not adhere to the build plate. Moreover, the glass build plate was subjected to a regular heating cycle which melted the build plate at its middle, resulting an uneven print surface. Furthermore, bed-levelling error was identified as a recurring problem as it was observed that the products were slanted in z direction. It was also recognised that the functioning of the prototype at low speed of 100mm/s was appreciable yet, the same at high speed of 500mm/s had significant errors like under-extrusion and blobs on printed surface, while other problems faced included layer shifting and overheating. The reason identified for this was excessive moving weight as the extruder head held the motor which controlled the flow of the printing material.

2.2.2. 3D Printer 1.0. In accordance with the observations, changes were made in design. Although the axis system was the same as the prototype, the structural volume was reduced by reducing the number of mechanical components. A t-slot aluminium base was used; its size was reduced according to the range of the motion of x axis. The build plate material was also changed to aluminium, to which the hot plate was directly attached. The build plate was rested on another aluminium plate over sprung screws, which enabled user-controlled bed levelling and uniform heating throughout the plate. Uniform heating of the large build plate solved the problem of reduced work volume and warping. Additionally, the feed-motor was removed from the y axis carriage to reduce the moving weight, which stabilized the extruder head at high speed, to improve high speed performance. Thus, the structural volume reduced, work volume increased, the cost reduced while maintaining the accuracy and precision at moderate speeds of 250mm/s; bed-levelling and heating errors were corrected. The performance of the printer at high speed had improved yet, at high speeds of 1000mm/s, the layers of the printed product were wavy rather than flat in the x direction due to vibrations in the x axis. It was essential to improve upon the high-speed functioning as it was revealed in the market survey that high speed was the most demanded property in 3D printers. Additionally, 3D printer 1.0 comprised of complicated and unnecessary connections at the z and x axis. Hence, further scope of improvement in its performance and design was identified.

2.2.3 3D Printer 2.0. On testing of 3D printer 1.0, it was observed that the z axis was the slowest and y axis was the most stable, while the most unstable was the x axis at high speeds which created visible lines across the 3D printed product. So, the solution was to design a printing head for 3D printer 2.0. The printing head incorporated a different axis system in which the base plate was held by the z axis while the x axis was incorporated in the printing head. Hence so the most unstable component at high speed was held by the axis, which is needed to function at a low speed, while the axis operating at high speed, that is x and y were operating on the most reliable and stable components in the printing head. This design was prepared for high-speed functioning as the apparatus of the x and y axis was reliable and the stability of the base had increased as it was incorporated onto the slowest axis. This design was simple and comprised of more self-replicated 3D printed parts, which included bearing holders, guide rod holders, belt holders, pulleys, motor holders and extruder head support, while the only procured parts were the extrusions, guide rods, and belts. Introduction of more self-replicated 3D printed parts provided freedom of design, simplicity of connections and reduction of the number of components used, thus optimizing the design and reduce the cost. Additionally, the printing head had the advantage that it could be scaled to be very small or very large without any change in the components. It could even be mounted on a wall.

III. RESULTS AND DISCUSSIONS

The final specifications of the prototype, 3D printer 1.0 and 3D printer 2.0 are as in the following table:

Table 2. Comparison of varying specifications of the prepared 3D printers.

	Prototype	3D Printer 1.0	3D Printer 2.0
Print Volume (X Y Z, mm)	150x90x130	200x190x265	350x350x300
Build Plate Dimension (in mm)	400x320	250x250	365x365
Machine Dimensions (mm^3)	762x1220x470	300x350x530	370x370x330
Print Speed (mm/s)	20-100	20-250	20-550
Weight (Kg)	___	10	7
Amount Used (INR)	32,500	15,503	11,835

'Table 2' shows that the maximum print volume of the 3D printers increased, while the machine volume was reduced to maintain portability. Also, the improvement of print speeds can be noted to be 100mm/s in the prototype, 250mm/s in 3D printer 1.0 and 550mm/s in 3D printer 2.0. On comparison of the 3 machines, it was found noteworthy that all the designs had the same filament diameter of 1.75mm, nozzle diameter of 0.4-0.5mm, material compatibility with PLA and ABS, USB and memory card connectivity, single-extruder type, base plate temperature 90-120 degree Celsius and the extruder temperature of 180-210 degree Celsius, which implied that the use of the same components but in a different mechanical design could improve the quality of the machine as problems like low speed, low product quality and high cost were improved upon without additional cost or material input. This could be an indication of cost reduction being a mechanical aspect, as the cost was reduced by incorporation of change in mechanical design to reduce the number of mechanical components procured or to increase the number of 3D printed components, while the software and the electronics used were the same in all the machines. Also, it must be stated that the summarised total cost is a result of the procurement of the available standard components and further cost reduction is possible with the option of procurement in bulk. Additionally, the change in design also resulted in an increase in stability, which enabled a higher print speed of the prepared printers, compared with the prototype. Furthermore, the concept of space optimization was incorporated in every design, as the ratio of the print volume to machine volume increased from 0.004 in the prototype to 0.181 in 3D printer 1.0 and to 0.813 in 3D printer 2.0, which ensured portability of the machine without compensating on the print volume.

A comparison of prepared 3D printers with the existing machines in the market shows significant improvement in performance, in terms of the print speed and print to machine volume ratio; and cost reduction. This shows that the need of optimization of the existing machines in terms of the design, functionality, and the quality of the product was rightly identified and optimized.

It was also observed that the discussion in WIPR, that innovation results in economic development as it leads to further innovation, can be observed on comparison of the produced machines. While the volume ratio, speed, durability and stability of the prototype were low, its monetary investment was maximum among the 3 machines. Further work using this innovation (the prototype) permitted the team to work on a changed design yet reduce the cost of the machine and improve its respective specifications. This was possible due to the existence of the prototype as the problems identified in the prototype could be implemented and the cost could be cut in terms of self-replicated 3D printed parts. Finally, the cost of the third machine was minimum, yet it had the best specification chart when compared with the previous machines. Thus, essentially innovation lead to further innovation, which improved the sophistication of the system and reduced the investment required for development, hence resulting in economic growth.

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