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(Review Article)

Fused Deposition Modelling - An Extensive Review

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Abstract

3D printing is a revolutionary new age technology in the manufacturing sector. The parts which cannot be fabricated by conventional methods can easily be manufactured by 3D printing. This article incorporates the critical review of Fused Deposition Modelling (FDM), a well-established 3D printing technology. Various parts of FDM are exhaustively described. However, there are some issues in existing printer with regards to time consumption and quality of the printed object. The extruder is one of the preferred topics of research nowadays. There are many kinds of extruder available in the market, choosing the particular extruder and nozzle may enhance the properties of the printed object. Current scenario of 3D printing technology across the world has also been described.

Keywords: 3D printing, FDM, Extruder, Hot End, Filament

1. Introduction

3D Printing is Technology or art which makes 3-dimensional physical objects by a process called additive manufacturing process. It is also called Rapid Prototyping. In this technology an object is created by resting the material on the base plate of printer up-to desired part of the required size is created. A powder type material or melted material is used to make an object in this process. The way of creating text or pictures is called printing. 2D Printing should be possible by utilizing the ink and paper though in 3D printing different type filament materials are used for printing the various things which are more applicable for a human. This is the main innovation now a day's. An entire model is created at once by using of 3d printer. Parts made by another technique is to take additional time and cost for design makes several parts separately and afterward join every part via various joining method. The main principle of 3D printing is flexible output and changing code into the noticeable system. The 3D printer is the machine in which change the input computerized information of the CAD model into the physical part. 3D model is making by utilizing the various software of CAD. 3D printing is used for different businesses, for example, footwear, adornments, aerospace industries, medical industries, military, education, construction, automobile industries, etc. [1]

Various Additive manufacturing techniques are presently available. Some of the techniques are used soften or melts material to creates the layers for producing the object, e.g. FDM (Fused Deposition Modeling), SLM (Selective Laser Melting), SLS (Selective Laser Sintering), while some of the other techniques are used different cure fluid materials, e.g. LOM (Laminated Object Manufacturing) and stereo lithography. [2]

2. History

Charles Deckard Hull was the first founder of the 3D Printing system in the year of 1984. Charles gives a name to this innovation as stereo lithography and gets a patent for this innovation in the year of 1986. [20] This innovation had become famous in the 1990s. What's more, other techniques of this innovation was presented, such as FDM (Fused Deposition Modeling) and SLS (Selective Laser Sintering). In year of the 1993, MIT (Massachusetts Institute of Technology) is converted that name from stereo lithography to 3D Printing system. In the year of 1996, 3 main products of the 3D printer were presented by 3 various companies, like "Actua 2100" from the 3D system, "Z402" from Z Corporation and "Genisys" from Stratasys. [2]

3. Fused Deposition Modelling (FDM)

FDM technology is invented by Scott Crump. This is an additive manufacturing process which used for the production of applications and moulding prototype. FDM is working on the principle of additive manufacturing in which resting the filament layer by layer for making the objects. In this technique most of the plastic filament or metal wire utilized. This filament material is attached to the extrusion nozzle which is fitted with the extruder. [1] In the first step of FDM technique Nozzle will be heated for melting the filament material, this material is to warm up until the point when it is at a semi-liquid state (generally 1°C higher than the solidification temperature). At that point, the 3D printer utilizes computerized modeling data from a CAD file to make the 3D object layer by layer. These layers are made by using computer software which "slices" the CAD file into layers which are fractions of a millimeter.[3] The nozzle is moved both horizontal (x-axis) as well as vertical (y-axis) direction by use of controlling mechanism. This mechanism controlled by the utilization of reference of Computer Aided Manufacturing (CAM). For moving the extruder head Stepper motor or servo motor is used. When CAD design sends to the printer, the nozzle will be heated to melt the metal wire or plastic type filament. Then it will be move-in x and y-direction to make the object which is made layer by layer. The material after extrusion from the nozzle is hardened immediately. [1] This process repeats itself until the whole model is printed. There are many advantages of FDM technology; it is simple to control, use, and fix. In addition, the cost of the material and machine are relatively low. [3]

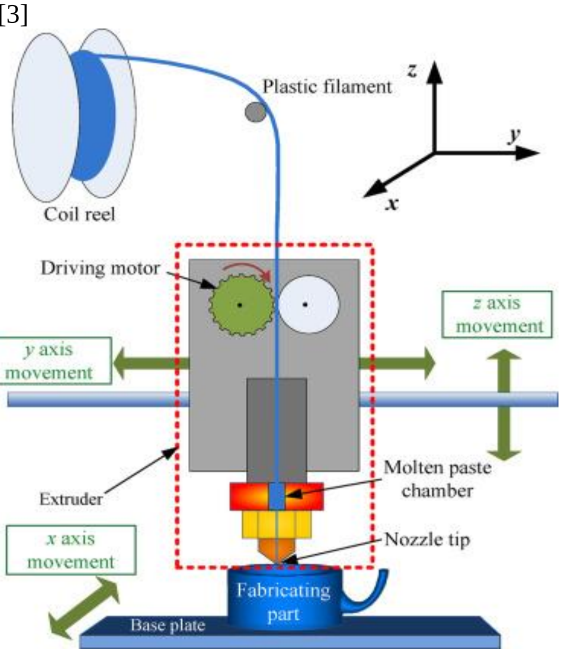

Figure 1. Fused Deposition Modeling (FDM) [11]

3.1 Technical Specifications for FDM:

- Standard lead time: Depend on size of the part, number of parts and degrees of finishing.
- Accuracy: ± 0.15% (together with lower limitation on ± 0.2 mm)
- The thickness of layer: 0.18 – 0.25 mm (varies according to depending on the material)
- Minimum thickness of wall: 1 mm
- Maximum dimensions of build: Unlimited Dimensions as parts may be composed of the number of sub-parts. The maximum build envelope is 914 x 610 x 914 mm
- Surface structure: A rough surface of unfinished parts but it is possible to all types of fine finishes. FDM parts can be colored/impregnated, smoothed, sandblasted, coated and painted. [4]

4. Main components used in FDM 3D printers

By knowing the main components of FDM 3D printers, how they function, and what they are fit for we can:

- Attain better quality, strength, and speed.
- Easily maintaining the 3D printer when required.
- Choose the correct machine according to requirements.
- Upgrade and modify components for particular applications. [5]

Main components are given in below:

1. Frame,
2. Extruder,
3. Nozzle,
4. Hot End,
5. Heated Bed,
6. Cooling Fan,
7. LCD Display,
8. Stepper Motor,
9. Controller Board,
10. Power Supply,
11. 3D Software, etc. [5-6]

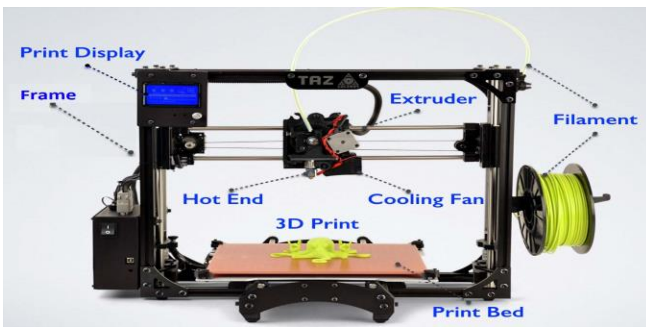

Figure 2. Main components used in FDM 3D printers [5]

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4.1 Frame: A frame is used to hold the machine together with components. Main intention and most significant design are that the frame must be strong. As the head of frame moves to and fro, the machine will shake, and if the frame is shaky, then accuracy suffers and it will in the long run break. If looks of the frame don't matter, then the really cheap and effective solution is to use a box as an alternate which belonged to something different. That would give a generally accurate (as in, corners are square, sides are parallel) frame to bolt with the other components. [6]

4.2 Extruder: The extruder is one of the main significant components in the 3D printer. It is responsible for transmitting and sending the right amount of filament material to the hot end where the filament is melted and extruded down in thin layers to create an object. It is momentous to note that the extruder isn't the same as the hot end. The extruder is generally referred to as the "cold end" because the filament material is "cold" when it transmits through the extruder to the hot end. [5]

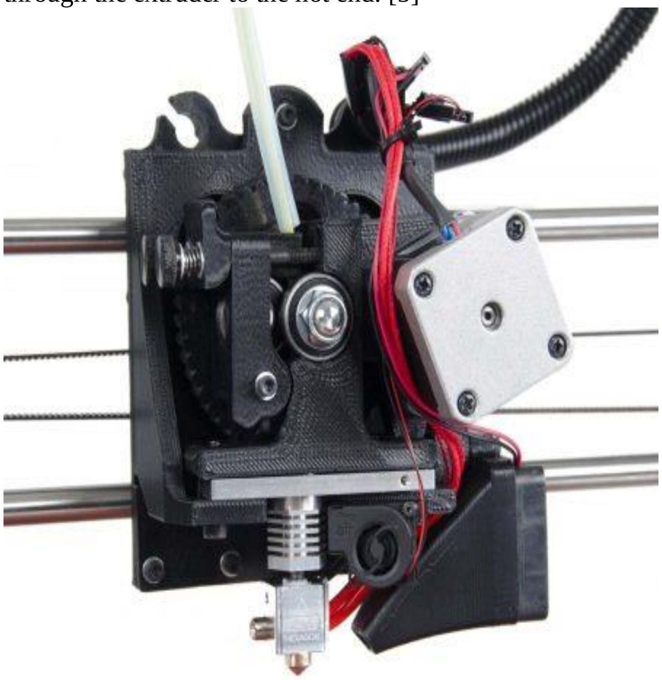

Figure 3(a). Extruder [5]

There are two basic types of extruder depending to the drive– Direct extruder and Bowden extruder. [7]

4.2.1 Direct Extruder: Direct extruders are simply extruders that are directly attached to the hot end. It's important to note that a direct extruder is not necessarily the same thing as a direct drive extruder. A direct drive extruder just means that the filament drive mechanism is directly mounted to the motor shaft. Both bowden and direct extruders can be direct drive. [8]

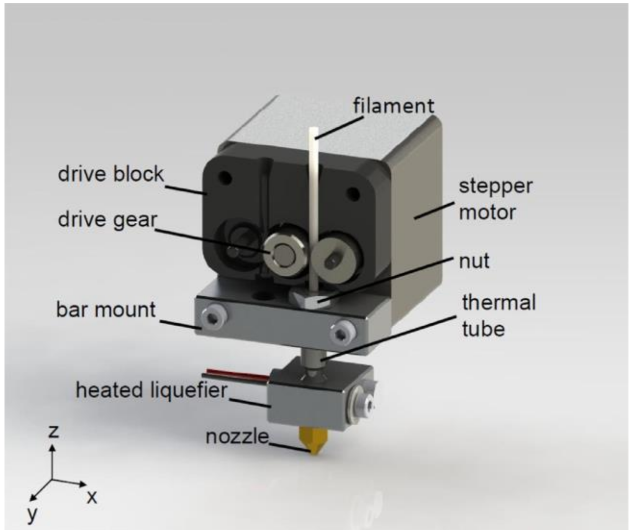

Figure 3(b). Direct extruder [12]

4.2.2 Bowden Extruder: A Bowden extruder is not directly attached to the hot end. Instead, a tube extends from the extruder body to the hot end. This is called a Bowden tube. The filament is constrained by the tube and travels through it to the hot end. [8]

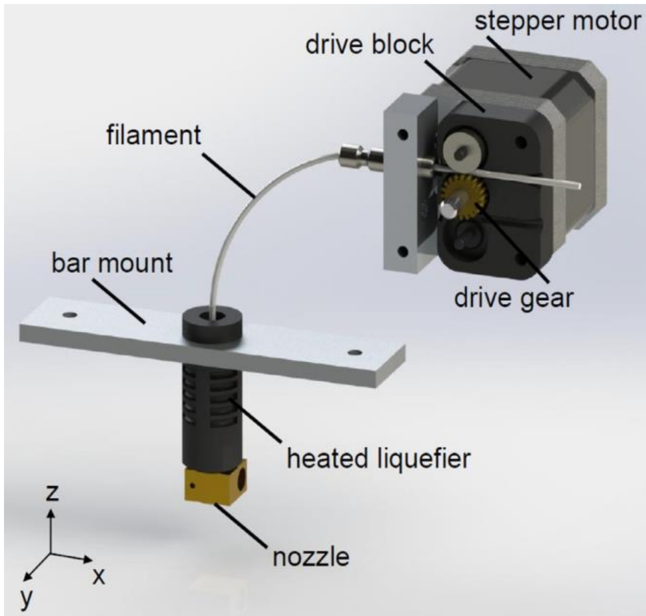

Figure 3(c). Bowden extruder [12]

4.3 Nozzle: The peak of Hot End is called Nozzle. Filament material turns out in the nozzle. According to requirement nozzle should be exchangeable. Size of the nozzle is really important. It generally varies within 0.25 mm to 0.80 mm. 0.5 mm nozzle is the most widely used. But according to desired output and required design, the best practice is that change sizes of the nozzle. [5]

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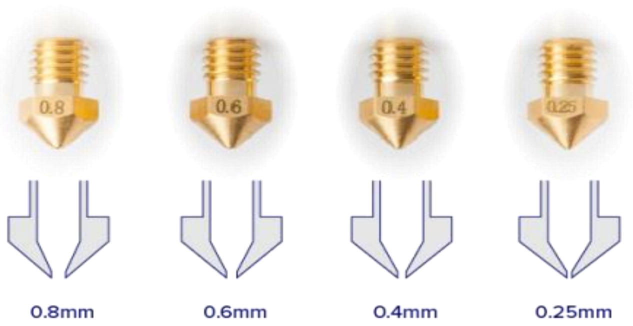

Figure 4. Nozzle [5]

4.4 Hot End: The Hot End is one of the main part in the extruder of a 3D printer. Hot End is the part where the plastic is melted and after that extruded in small tiny layers. Nowadays in the market there are a wide range of types of Hot Ends available as shown in figure 5. [5]

Figure 5. Hot End [5]

4.5 Heated Bed: A heated bed needed for high-level temperature extrusion filament materials. Heated Bed will keep heated up to the plastic during a printing procedure as well as detain it from distorting. Also, Heated Bed will guarantee the best adhesion among the layers of output material, which is the outcome in the best structural integrity of printed objects. Heated Bed was pivotal to the first layer to ensuring the best level of foundation. Generally temperature range is 40 °C to 110 °C. Heated bed isn't a touching field for us. [5]

4.6 Cooling Fan: A major role in the 3D printing process is played by Cooling Fan. It is the must has a feature. A cooling process is not required in every one of the 3D printing materials, but it is really advantageous for most 3D printers. Some 3D printers have only one cooling fan, where other 3D printers have up-to three cooling fans. A Cooling fan will be accurately modified overhanging characteristics, will brittle but rigid the sharp edges and will result in better bridging capabilities. [5]

4.7 LCD Display: The LCD Display controller enables to 3D printing without any requirement of a computer connection or by using the software host, for example, Cura. It required an SD card for reading the G-code commands. The display permits more effective space usage and frees up to the computer for other works. It is perfect for everyday printing and will be utilized in the majority of print objects. [5]

4.8 Stepper Motor: For 3D printer, Stepper motor is another essential component. Stepper motor is a DC motor that has multiple coils allowing them to move in small increments. These multiple coils are connected in the groups which are called phases. By energizing every phase in order, a motor will be rotated, in only 1 step at a time. By using a computer that movements will be control, it can be very precise. Stepper motor is the best utilized for low-speed torque, speed control, and positioning. [9]

According to the variety of 3D printer, Stepper motor is utilized for different applications e.g., a stepper motor is utilized for moving the extruder or build the stage in x, y, and z-direction. Even the extruder have a stepper motor for pulling the filament material. It is regularly utilized for printers and robotics. [13]

In various sizes, the stepper motor is arriving. NEMA 14, NEMA 17, NEMA 23 and NEMA 24 are the most famous sizes utilized in 3D printers. NEMA means National Electrical Manufacturers Association, It is a standardized measurement. It is referred to the frame size of a stepper motor. [13]

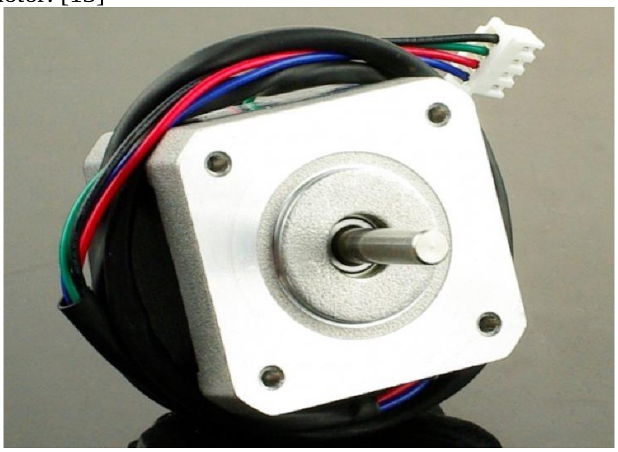

Figure 6. Stepper Motor [13]

4.9 Controller Board: Controller board are the brains of the 3D printer, powering everything from motors to hot End. The processing power of the controller board can play a large role in how detailed prints of a 3D model which come out as a final product.

The Control board is made up of two components: a microcontroller and a circuit board. These components can be either combined into one board or be separate units attached to each other. Both work simultaneously to control and distribute power to all other components. It is referred to as the brains and the central nervous system of the printer. Without it, nothing else would work. [9]

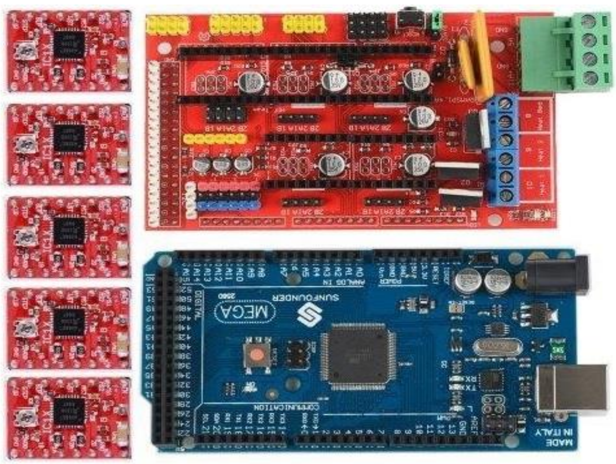

Figure 6. RAMPS 1.4 Controller Board [9]

5. Materials used in 3D printing

Following materials are used in 3D printing:

I. Plastics
   1. Acrylonitrile Butadiene Styrene (ABS),
   2. Poly Lactic Acid (PLA),
   3. Nylon or Polyamide,
   4. High Impact Polystyrene (HIPS), etc.

II. Metal
   1. Stainless Steel,
   2. Aluminium,
   3. Gold,
   4. Silver,
   5. Titanium etc.

III. Ceramics

IV. Bio Materials

V. Food. [10]

5.1 ABS material: Full form of ABS material is Acrylonitrile Butadiene Styrene. Since the beginning of 3D printing, ABS is one of the most broadly utilized material. This material is extruded easily, light in weight, slightly flexible and extremely durable. This properties of ABS is created perfection in 3D printing. ABS needs minimum power or force for extruding an object than while utilizing the PLA material that is one another famous filament material for 3D printing. Easier extrusion for small objects is created by this facts. It needs maximum temperature, which is a disadvantage of ABS material. [2]

5.2 PLA material: Full form of PLA material is Poly Lactic Acid. PLA is other well spread type material in between 3D printing enthusiasts. PLA is the biodegradable thermoplastic material which is derived from the renewable resource. Thus it is more eco-friendly between others plastic material. PLA material is biocompatibility with a body of the human. This characteristic of the PLA material is awesome. According to Structure, PLA material is harder from the ABS material. PLA material melts around 180 °C to 220 °C which is minimum from ABS material. [2]

5.3 Nylon (Polyamide): Polyamide or Nylon is generally utilized in form of the filament by using with FDM technique or in form of powder by using with sintering process. Nylon is durable, flexible and strong. It is normally white in colour, however, it tends to be coloured for either pre or post-3D printing. Though it is more expensive than ABS or PLA type material since it is used for particular material characteristics such as a resistance of specific chemicals. [10]

5.4 Bio-Materials: They are naturally otherwise synthetic material which is utilized for making the bones or tissue, prostheses, and artificial organs. For various medical applications, bio-materials are used in 3D printing nowadays.

In nowadays, a few investigations are examining at live tissues inclusive of the objective of creating applications for printing the human organs for external tissues and transplant for human body parts where replacement is required. One another 3D printing region utilizing biomaterials focus on making foods. [10]

6. Possibilities of modification in the extruder

While studying the FDM we find there is some area in the extruder to research which can make the process faster and accurate. The modification can be done in the extruder are as follow:

- The speed of printing can be improved by using a dual extruder. Using dual extruder the surface finish of printed parts can also be increased by this method. It can be achieved by using different diameter nozzle of a dual extruder. In one extruder there is bigger diameter nozzle and in the second extruder there is a smaller diameter nozzle. Bigger diameter nozzle is used for print the area of the part which not need good surface finish like. It is used for deposit material inside the outer surface of the part. Also, it is bigger in diameter so it consumes less time to print. The second nozzle of smaller diameter is used for fine printing, means to print the surface of the part which requires good surface finish like the outer surface of a part. It improves the surface texture, accuracy, reduces the staircase effect and improves the look of the part.
- Sometimes thermocouple does not sense temperature of filament properly which cause the jamming of a nozzle or overheating of the filament.

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This inaccurately sensing of temperature by the thermocouple is may be removed by proper positioning of the thermocouple in extruder body or use of indirect contact type temperature sensor instead of direct contact type temperature sensor like radiation pyrometer.

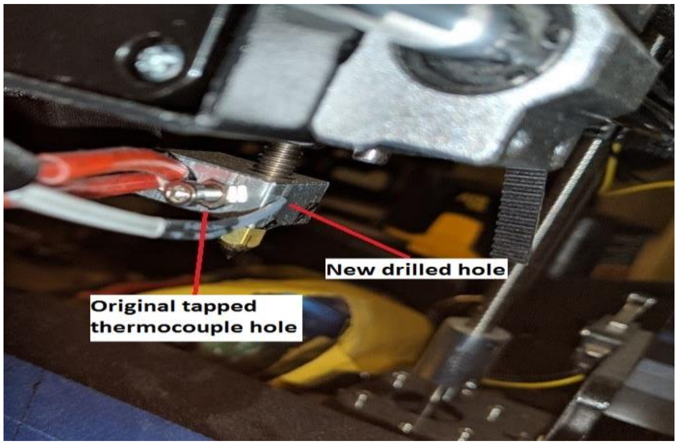

Figure 7. Extruder Heat Block Modification [14]

- Plastic waste is one of the big problems in the world. This creates a lot of land pollution. So there are some possibilities that we can use this plastic in 3D printing. To use this plastic we have to know about its type mean it has to thermosetting and it's melting temperature. By using granular extruder it may be used to convert this waste plastic into semi-liquid form. In this extruder, there is a granular section at its upper portion which has a cone shape. In which one screw convert the plastic material into granular form. After that, the process of converting these granules into semi-liquid is same as the conventional FDM extruder. By using this method it may happen that it reuses the plastic waste.

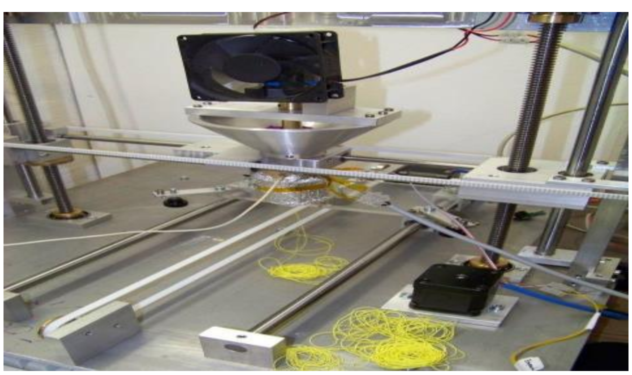

Figure 8. Granulate Extruder [15]

- Another modification that can be done is separate the nozzle and hot end. Which reduce the weight of the extruder head and increase the speed of the printing due to less weight.
- Recently most of the printers can print only one material like plastics or metal. In this area, we can change by combining this two printing process in which single 3d printer is able to print both plastics as well as metals. This can be achieved by using FDM extruder for printing of plastics and MIG welding gun for printing of metals. MIG welding gun is like extruder which has the arrangement of feeding the wire in it. When welding material is extruded from MIG welding gun is deposited on the platform as one layer. By adding such a layer on other layer parts can be print. This metal printing needs more surface finishing after or during printing.

7. Market Trends

7.1 Do it faster with 3D Printing: One challenge for the 3D printing industry is to speed up printing processes. So far Continuous Liquid Interface Production (CLIP) developed by Carbon is one of the fastest 3D printing technologies on the market. It works differently from other printing technologies and can be described as a photochemical process involving a liquid interface of uncured resin and a passing light source. It does not only work faster but also prints without interruption or visible layers. [16]

7.2 Do it Bigger with 3D Printing: In some industries like the wind energy, aerospace or automotive sector the production of big and technically complex components takes a long time, needs huge and special tools and is consequently very expensive. Hybrid 3D printing can help to make these processes faster, cheaper and the components lighter. Therefore 3D printers have to be big enough to produce these huge components or the relevant tools. Currently, the biggest 3D print in the world is a tool for attaching wing components to Boeing. So this field has even more potential and large-scale hybrid 3D printers are on the rise. [16]

7.3 Do it Fully Functional with 3D Printing: 3D printing is more than just printing an object. It is also able to fabricate fully functional objects in one step, including complex electronics. But at the moment, only a few printers on the market can integrate functional elements by themselves. The Voxel8 system, for instance, is capable of printing plastic with conductive traces on it. [16]

7.4 Bring Printed Structures to Life with 3D Printing: In the medical region, 3D printing could mean a breakthrough for transplantations. Be that as it may, this is additional theory than functional reality since printing living tissue structures is absolutely hard. A year ago, regenerative medication scientists at Wake Forest Baptist Medical Center in Winston-Salem, North Carolina, have created a big leap forward in this division after just about ten years of research.

They printed bone, ear, and muscle structures, which developed into practical tissue and built up a system of blood vessels when implanted. Nevertheless, there will be much more research necessary when it comes to more complex and bigger organs. [16]

7.5 Make Dwellings out of Plastic with 3D Printing: Building houses by 3D printers is hardly a new idea, but there is no freeform 3D-printed house built so far. This will change in 2017. A team of architects of Chicago's WATG's Urban Architecture Studio has announced an 800-square-foot single-family house completely made by 3D printing technology. The house will not just be fully functional with a kitchen, a bathroom, a living area, and a bedroom. It will also contain eco-friendly features such as, for example, instant and passive heating and cooling strategies. [16]

7.6 DIY trend in 3d printing: Lately, 3D printing started entering the apparel industry and although there is still a lot of work to be done, someday it might be possible to print a customized, perfectly fitting piece of clothing easily at home. [17]

8. 3D Printing Market Overview

8.1 Overview of Segment (fragment): The worldwide 3D printing market has been fragmented according to geography, application, and component. Geographically, a market has been resolved in-to LAMEA, Asia-Pacific, Europe and North America. As per application, the 3D printing market is classified into education & research, defence, healthcare, automotive, industrial, aerospace, consumer products, etc. Consumer products is the most elevated income creating portion and it is expected for highest producing fragment also amid forecasted period. According to a component, a market is divided in-to services, material, and technology. [18]

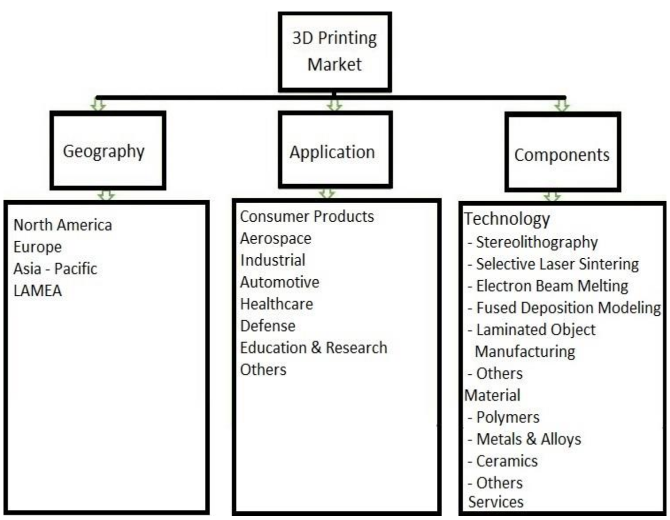

Figure 9. Segment Overview [18]

8.2 Scenario of Asia Pacific 3D Printing Market: Asia Pacific area is relied upon to be the quickest creating market for 3D printing. This advancement in 3D printing market is probably going to happen because of the developing uses of added substance manufacturing in, defence, aerospace, healthcare, automotive and consumer industry. Rather than using conventional manufacturing techniques, additive manufacturing is utilized in a car, buyer and human services items, for example, cell phones, toys, prosthetic inserts, medicinal gadgets, motor parts, and others. [18]

The automobile industry was the biggest income creating section in the Asia-Pacific market in 2014 with the most noteworthy income. Buyer items industry would be the biggest income creating portion by 2020. Main considerations contributing to this development are the expanding interest of products of consumer and automobile in Asia-Pacific market. The defence industry is relied upon to develop with higher CAGR from 2015 to 2020. [18]

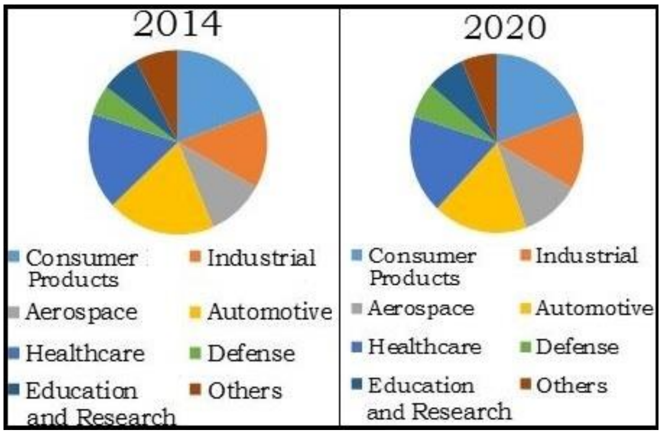

Figure 10. Analysis of Market Share in 3D Printing [18]

8.3 Analysis of Regional Share: North America was the greatest salary making locale in the industrial items showcase in 2014. Europe would be the greatest salary making territory by 2020. This region is relied upon to hold its initiative by 2020. The LAMEA region is depended upon to develop with most elevated CAGR from 2015 to 2020. The factor adding to the quick improvement of the LAMEA 3D printing piece of the overall industry is the extension and improvement of a modern part in this region. [18]

- Investors will welcome the strong 21 percent development as the AM business surpasses $7.3 billion. The report aggregates details on what number of 3D printers are really sold each year. According to the new report, an expected 1,768 metal AM frameworks were sold in 2017, compared to 983 frameworks in 2016, a surge of almost 80 percent. [19]

- The development isn't in machines alone, however, more organizations are making the machines also. The firm found that 135 organizations around the globe delivered and sold mechanical AM frameworks in 2017, up from 97 organizations in 2016. New framework makers are entering the AM market at a confounding pace while discharging machines with open material stages, quicker print speeds, and lower evaluating. [19]

- More than 278,000 desktop 3D printers (under $5,000) were sold worldwide last year (2015). The 2018 report has the evaluated number of desktop systems sold at almost twice the 2015 information (reported in the 2016 report). In a little more than two years, an amazing 528,952 desktop 3D printers (or systems) are accepted to have been sold. [19]

- The desktop 3D printer classification notices items and packs from a portion of the best-known producers, including Aleph Objects, MakerBot, Ultimaker, and numerous others. Incomes from the desktop segment were well finished $500 million in 2017. [19]

- In 2017, the AM business, comprising of all AM products and services around the world, grew 21% to $7.336 billion. The development in 2017 compares to 17.4% development in 2016 when the business came to $6.063 billion and 25.9% development in2015. The aggregate business estimate of $7.336 billion prohibits inward ventures from the manufacturer's likes of Airbus, Adidas, Ford, Toyota, Stryker, and many different organizations, both large and small. An astonishing number of the $1-5 billion organizations – a considerable lot of which are new to the vast majority of us – are putting resources into AM R&D (research and development). [19]

9. Conclusions

3D printing is currently emerging technology in the field of manufacturing. It is used in so many industries like a consumer product, aerospace, industrial, automotive, healthcare, defense, education & research, food etc. In the recent world, AM is becoming more and more popular due to its functionality and easiness of production. In FDM, extruder acts like the heart of the machine, hence, more focus should be given to developing the error-free system. More advanced research is required to overcome some drawbacks of this technology to procure more improved results in 3D printing.

Nomenclature

2D printing- Two Dimensional Printing
3D printing- Three Dimensional Printing
AM- Additive Manufacturing
FDM- Fused Deposition Modeling
CAD- Computer Aided Design
MIT- Massachusetts Institute of Technology
SLM- Selective Laser Melting
SLS- Selective Laser Sintering
LOM - Laminated Object Manufacturing
LCD- Liquid Crystal Display
SD- Secure Digital
NEMA- National Electrical Manufacturers Association
ABS- Acrylonitrile Butadiene Styrene
PLA- Poly Lactic Acid
HIPS- High Impact Polystyrene
CLIP- Continuous Liquid Interface Production
WATG- Wimberley Allison Tong & Goo
MIG- Metal Inert Gas
CLIP- Continuous Liquid Interface Production
CAGR- Compound annual growth rate
R&D- Research and Development
DIY- Do It Yourself

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