HYDROGEL PRINTED BY 3D PRINTING TECHNOLOGY

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Abstract*—As a cutting-edge technology in the field of manufacturing of medical implants; three-dimensional (3D) printing technology and hydrogel emerge as a promising solution. This project presents the design and development of a hydrogel extrusion device intended to be used in medical field. A plastic cylinder loaded with hydrogel material is placed into the device. Feedstock is pressed through an extrusion nozzle by a piston driven by an electrically actuated drive-screw and nut mechanism. The device allows the build material to heat up to 80 ◦C. Forced air cooling is used to assist the cooling or hardening process of the freshly-printed material during fabrication. The feedstock container, nozzle, and material-loading process are all suitable for use in a sterile environment. The device is designed for seamless integration with existing 3D printing firmware and slicing software. After designing the device, a prototype was produced and installed on a 3D printer.(Abstract)*

***Index Terms*— Hydrogel, 3D Printing**.*(key words)*

I. Introduction

In recent decades, 3D printing technology, also known as build-up manufacturing, has been at the forefront of manufacturing research. It is possible to form materials quickly, similar to photocopying or printing. 3D printing technology has been widely used in clinical medicine, drug research, material science, and other related fields due to its unique advantages. In clinical medicine, regenerative medicine research is based on 3D printing technology, such as human ear, bone tissue, brain-like tissue, and so on. 3D printing technology is important in the research and development of drug dosage forms in the field of pharmaceutical research. Tablets, suppositories, capsules, and other dosage forms based on this technology are currently available.

Furthermore, it can be used to investigate compound preparations. Many new materials in the field of material science are being researched and developed using 3D printing technology, such as 3D printing film, 3D printing N-95 anti-virus mask, and so on. Wearing a 3D printing N-95 anti-virus mask to prevent novel corona viruses improves not only the wearer's comfort, but also the mask's integration with the face. Materials based on 3D printing technology can now compensate for the shortcomings of traditional manufacturing methods, it also has high efficiency, which can save a significant amount of time, and has become a commercial success. Hydrogel is a type of smart material that is very soft and moist. It is biocompatible and can recover when subjected to external forces. It also has a large specific surface area and is capable of responding to external stimuli. There are currently two types of hydrogel: physical hydrogel and chemical hydrogel. Physical forces, such as electrostatic interaction, chain winding, hydrogen bonding, and so on, are primarily responsible for the formation of physical hydrogels. In general, physical hydrogels are unstable. When heated, the physical forces within the hydrogel are destroyed, and the hydrogel transitions from solid to liquid. Chemical hydrogel is a three-dimensional network polymer formed by chemical bond cross-linking that is heat stable. Many types of intelligent hydrogel have become a research hotspot due to their ability to respond to external stimuli. The light-responsive hydrogel, temperature-responsive hydrogel, enzyme-responsive hydrogel, pH-responsive hydrogel, pressure responsive hydrogel, magnetic-responsive hydrogel and ion-responsive hydrogel are the most common types of hydrogel. There are some types of double responsiveness as well. Temperature and pH double responsive hydrogel, temperature and ion double responsive hydrogel, temperature and enzyme double responsive hydrogel, and pH and light double responsive hydrogel are the most common types of hydrogel. The intelligent hydrogel responds quickly to external stimuli, which causes the hydrogels swelling behavior to change and the contents to be released quickly. Because of this property, intelligent hydrogel is widely used in the pharmaceutical industry, development and research. The use of intelligent hydrogel as drug delivery systems can not only target drug delivery but also control drug administration. The majority of cancer drugs are ineffective due to a lack of targeting specificity and a rapid drug release rate. These issues may be addressed by the development of intelligent hydrogels. Intelligent hydrogels used as drug delivery systems include hydrogel microspheres, hydrogel micro beads, hydrogel films, and hydrogel nanoparticles. Particles, hydrogel micelles, hydrogel micro needles, and hydrogel patches are all examples of hydrogel. Because of its high sensitivity, good stability, and low response deformability nano hydrogel is used in drug delivery systems such as hydrogel microcapsules, nano hydrogel particles, magnetic nano hydrogel, and responsive nano hydrogel. Despite the fact that hydrogel is now widely used, the majority of traditional hydrogel and intelligent hydrogel are fragile and easily broken, special care should be taken when researching and using them. To address this issue, a hydrogel based on 3D printing technology was developed. Researchers are increasingly interested in 3D printing hydrogel due to its unique properties. Many researchers have now studied its physical and chemical properties, such as swelling behavior, electrical conductivity, mechanical strength, hardness, and so on. There are corresponding interactions in the interior of 3D printing hydrogel, including ion bond interaction, dynamic covalent bond interaction, supramolecular host-guest interaction, hydrogen bond interaction and hydrophobic interaction. It is the existence of these interactions that make 3D printing hydrogel have high strength and hardness, which make up for the fragility of most traditional hydrogel and intelligent hydrogel, and make it more and more widely used in the field of material science. Like intelligent hydrogel, there is also 3D printing stimulus-responsive hydrogel which can respond to external stimulations. It mainly includes 3D humidity-responsive hydrogel, 3D photo-responsive hydrogel, 3D temperature-responsive hydrogel, 3D magnetic-responsive hydrogel, 3D photo thermal double responsive hydrogel and 3D temperature, pressure, and pH triple-responsive hydrogel, which may be prepared into hydrogel particles for drug delivery. At the same time, with the development of 3D printing technology and the in-depth study of hydrogel, more and more materials act as printing “ink” to prepare 3D printing hydrogel. Moreover, there are many methods for its preparation. The traditional preparation methods of hydrogel mainly include physical cross-linking and chemical cross-linking. Compared with the traditional preparation methods, 3D printing technology has great advantages. Hydrogel prepared by traditional methods has a relatively simple shape and preparing hydrogel with the specific shape usually requires molds. 3D printing technology can generate 3D model patterns for printing in advance, and the obtained hydrogel shapes are diversified. For preparing hydrogel with more complex shapes and fine structures, 3D printing technology takes less time, which can be prototyped rapidly, and consumes less cost compared with traditional preparation methods generally. 3D printing technology can save the preparation materials of hydrogel and improve the utilization rate. In addition, the mechanical properties of hydrogel prepared by 3D printing technology are better than those prepared by traditional methods, and can meet the requirements. Although 3D printing hydrogel is widely used in the field of material science, it is mainly focused on regenerative medicine in the medical field.

Fig 1. Fabricated model of Cartesian 3D Printer

II. LITERATURE REVIEW

For the development of our project, we gathered information from the several journals to have a better knowledge and understanding regarding 3D printing and Hydrogel. From the journal "Hydrogel prepared by 3D printing technology and its application in medical field” by Cheng Liu, Peng Zhang and Na Xu it was noted that 3D printing hydrogel has excellent physical and chemical properties and applications in the medical field. As a new material, 3D printing hydrogel is more and more popular among re- searchers because of its unique properties. Its preparation methods and printing ink are constantly improving and mining. In the medical field, it is becoming more and more widely used. However, 3D printing hydrogel also has some disadvantages. Firstly, there is a lack of preparation materials. 3D printing hydrogel has certain requirements for hydrogel ink, so many natural or synthetic compounds used to prepare hydrogel cannot be used. Generally, a single hydrogel is difficult to be used as 3D printing ink directly, most of the composite hydrogels with modifiers are used. These modifiers can be nanoparticles, cellulose, inorganic ions and related polymers. The mechanical anchoring formed by the interpenetration of the composite hydrogels greatly improves the mechanical properties. In addition to forming the composite hydrogels, the hydrogel ink can also be co- printed with harder polymers during the printing process to improve the mechanical properties.

Secondly, the composition of the composite hydrogels is different, and the printing ink obtained is not uniform enough, which will reduce its printability. Therefore, we improve the uniformity of the ink by heating and stirring during preparation. Thirdly, in order to ensure the printing performance of hydrogel ink, the viscosity of printing ink is relatively high generally. But high-viscosity ink will damage the viability of cells, which will limit its medical applications. Usually, the concentration of polymer in the composite hydrogel is reduced or the temperature is changed to adjust the viscosity of the ink. We can also add ceramic, metal-based nano or microparticles as rheology modifiers to interrupt the cross linking of hydrogel, thus decreasing the printability of hydrogel ink. Then the low viscosity hydrogel ink is prepared on the premise of ensuring printability. Fourthly, the 3D printing hydrogel is obtained by the accumulation of many thin layers during the preparation process. If each thin layer is not cross-linked quickly, it cannot support the subsequent thin layers accumulation. Therefore, the cross-linking reaction of the hydrogel precursor should be faster. The cross-linking methods that can be used include ultraviolet cross-linking and ion cross-linking, which can improve the cross-linking efficiency. Finally, the relevant properties of the 3D printing hydrogel prepared by the existing preparation methods cannot meet the growing demands, and the preparation methods are relatively simple. We can try to combine the traditional preparation methods to make up for the shortcomings of the single method. It is also possible to improve traditional preparation methods or try to develop the new 3D printing system. Although 3D printing hydrogel is facing with some problems that need to be solved urgently, as a new design material, these problems will be solved gradually with the deepening of future researches. At present, the applications of 3D printing hydrogel in the medical field is increasing, it will be used more and more widely in this field in the future.

From the journal "Application of 3D printing technology in bone tissue engineering" by Y.Feng, Abid Haleem, Rajiv Suman, we cited that in orthopaedics, bone defects create a high impact on the quality of life of the patient. It leads to a higher demand for bone substitutes for replacement of bone defect. Bone tissue engineering can help to replace a critical defect bone. 3D printing is a useful technology for the fabrication of scaffolds critical in bone tissue engineering. There are different binders which can create bone scaffolds with requisite mechanical strength. These binders are used to create excellent osteoconductive, bioactive scaffolds. Computed tomography (CT) and Magnetic resonance imaging (MRI) help to provide images of specific defects of an individual patient, and these images can further be used for 3D printing the detective object. A bone defect caused by specific disease is sorted out by transplantation in clinical practice. Now a day bone tissue engineering opens a new option for this treatment of bone defects with the manufacturing of porous bone scaffold using 3D printing technology. From the journal "3D printing of bone tissue engineering scaffolds" by Min Wang and Chong Wang, we noted that over the past twenty years, which are very short time for R & D in science and technology, 3D printing has advanced at a phenomenal pace due to its advantages in producing products with customized shape, tailored structure, adjustable composition, etc., and wide applications of the products by many industries, especially the biomedical industry. The initial exploration on 3D printed scaffolds soon yielded great excitement in bone tissue engineering fields. The limitations of conventional 3D printing on making advanced bone tissue engineering scaffolds have been continuously tackled by inventions and innovations in 3D printing, which have made it possible to develop complex bone tissue engineering scaffolds. However, some problems are still challenging, which are expected to be solved in future: as natural bone tissue has a multi-scale hierarchical structure, 3D printed scaffolds are expected to precisely mimic the structure of the native bone tissue. However, most extrusion-based 3D printed scaffolds have limited printing resolution and could only mimic the hierarchical structure at a relatively low level. Therefore, advanced micro-extrusion nozzle should be designed to enable the production of bone tissue engineering scaffolds with a significantly higher resolution (i.e., the printed struts have a significantly smaller diameter) while not causing nozzle clotting; defected bone tissue often contains both cortical bone and cancellous bone, showing a heterogeneous structure with gradient mechanical properties. However, integrated bone tissue engineering scaffolds with greatly varied mechanical properties are difficult to produce, and hence better 3D printing strategies should be adopted to enable the production of customized scaffolds with complex features; it is highly important to provide scaffolds with excellent vascularization to enable sufficient oxygen/nutrient transportation during bone regeneration, but few scaffolds are specifically designed to achieve bone regeneration with required vascularization. Thus, appropriate strategies including the controlled release of angiogenic agents and formation of vascular-like channel in scaffolds are needed to provide scaffolds with both improved bone regeneration capability and enhanced vascularization; compared to 3D printed scaffolds which could recruit host cells in vivo, loading cells into 3D printed scaffolds are considered to be more effective in treating bone defects, especially the defects with a critical size. However, post-seeding of cells on scaffolds often results in uneven cell distribution and limited cell density, whereas in situ incorporation of cells during 3D printing process would be desirable. Among current 3D printing techniques, apart from 3D bioprinting which produces cell-laden hydrogel structure, no existing 3D printing technique can enable cell incorporation during the printing process. Therefore, superior 3D printing techniques should be invented to achieve simultaneous scaffold fabrication and cell incorporation; scaffolds with excellent capability for anti-bacteria or anti-cancer are increasingly needed to treat infection/bone tumor resection-induced defects. One needs to carefully design 3D printed scaffolds in order to best regenerate bone tissues under the optimum conditions.

From the journal "Design and Characterization of a novel 3D printed pressure-controlled drug delivery system it demonstrated the possibility of using 3D printing via fused deposition modelling for the fabrication of pressure-controlled dosage forms. Customized G-code generation enabled the printing of objects with an adjustable wall thickness without the need of support structures. By small variations of the extrusion rate via the extrusion multiplier, capsules with different mechanical properties could be obtained. Since a high uniformity in filament diameter is needed for reproducible 3D printing, the extrusion process was another critical process step for the production of this pressure-controlled drug delivery system. In this study, Eudragit RS filament without any plasticizer was successfully manufactured by hot melt extrusion with the aid of a self-constructed piston extruder. The proof-of-concept was demonstrated by the application of a biorelevant stress test device that enabled dissolution testing under conditions realistic for the upper human GI tract. Physiological pressure events during gastric transit were shown to be able to initiate drug release from this novel drug delivery concept.

TABLE 1

AUTHOR	YEAR	JOURNAL	OBSERVATION
Cheng Liu Peng Zhang Na Xu	2021	Hydrogel prepared by 3D printing technology and its applications in the medical field	3D printing hydrogel uses the composite materials with modifiers as printing ink. 3D Printing Hydrogel have excellent physical and chemical properties.
Y.Feng Abid Haleem Rajiv Suman	2020	Application of 3D printing technology in bone tissue engineering	3D printing technology provides an excellent capability to manufacture customised implants for patients

Min Wang Chong Wang	2020	3D printing of bone engineering scaffolds	3D printing of bioceramic pastes followed by sintering improves bone formation surface mdifications of 3D printed scaffolds improves the cellular responses
J. Krause Werner Weltschies	2019	Design and characterization of a novel 3D printed pressure-controlled drug delivery system	Explored the feasibility of 3D printing via fused deposition modeling (FDM) in the manufacturing of a pressure-controlled drug delivery system.

III. 3D PRINTING METHODS

3D printing methods include :

- Extrusion
- Light and photo polymerization
- Direct ink writing (DIW)

3D PRINTING BASED ON EXTRUSION

The extrusion-based 3D printing technology uses a lifting worktable, a nozzle, a heating chamber, and a wire outlet structure. It is based on the melt deposition process. In the heating chamber, the combined hydrogel ink is heated until it melts into the structure. The lifting worktable can move in the Y and Z axes, and the nozzle, which can move along the X axis, can extrude hydrogel ink when pressure is applied. By managing the nozzle's and the lifting work-movement table's directions, the fine hydrogel structure for 3D printing is created. The hydrogel ink cannot be successfully extruded while manufacturing hydrogel for 3D printing unless the following conditions are met. These prerequisites include: (1) the hydrogel ink will experience less resistance while printing; (2) the hydrogel ink's shape can remain unchanged after extrusion; (3) the hydrogel ink printing line should have good structural integrity to enable 3D printing hydrogel to have a good adhesive self-supporting structure between each layer; and (4) the hydrogel ink should be biocompatible. When 3D printing hydrogel as tissue scaffolds, the hydrogel ink should make sure that the environment in the printed scaffold is favourable for cell survival and proliferation. It is discovered that the mechanical properties of hydrogel based on extrusion 3D printing technique have improved relative to conventional hydrogel, including hardness, flexibility, compression resistance, and so on. In addition to the traditional extrusion technology, they offered a number of unique strategies based on extrusion 3D printing technology, including the use of static mixers, micro-extrusion, and extrusion-based gradients. The hydrogel ink is typically forced outward using pressure in the extrusion process. 3D models are produced using CAD, and the required printing parameters are selected.

After a short period of mixing, it is cross-linked in the static mixer during the next extrusion, and the cross-linked hydrogel was extruded from the print head of the 3D printer. The printed hydrogel was not only intact in structure, but also stable in performance. Especially, this method was very suitable for hydrogel solution with low viscosity, which not only avoided the high shear stress during extrusion, but also avoided the washing step caused by cells embedding hydrogel ink after printing.

Micro-extrusion 3D printing technology is based on traditional extrusion technology. The drive unit carries printing ink, which is controlled by the built-in computer software. Then the ink is extruded and printed on the solidified freezing platform to form the 3D hydrogel structure. The final product is obtained after 4 or 5 freeze-thaw cycle. The effects of GO and hydroxyapatite (HA) content on the rheological property and printability of polyvinyl alcohol were researched, and the best dosage was chosen to increase the solution's printability. This technique produced hydrogel with good biomechanical and biological friction characteristics. It also made a good contribution to the creation of gradient structures that are biomimetic. The principal application of the extrusion-based gradient 3D printing method is the 3D printing of composite materials. Two syringes are filled with hydrogel ink, and pistons are placed on top of them. The printer's speed is then managed by two separate, concurrent programmes, and the two linear actuators' speeds are altered to deliver mechanical pressure to the piston. To create the 3D structure, the hydrogel ink is extruded from the syringes. The hydrogel ink in the two syringes discharges at various rates. One's outflow speed can be adjusted from 0% to 100%, while another can be set from 100% to 0%. This method was used to create a composite hydrogel that was covalently bonded by alginate and polyacrylamide ions. This printing process was particularly helpful in the creation of bionic scaffold structures, much like micro-extrusion 3D printing.

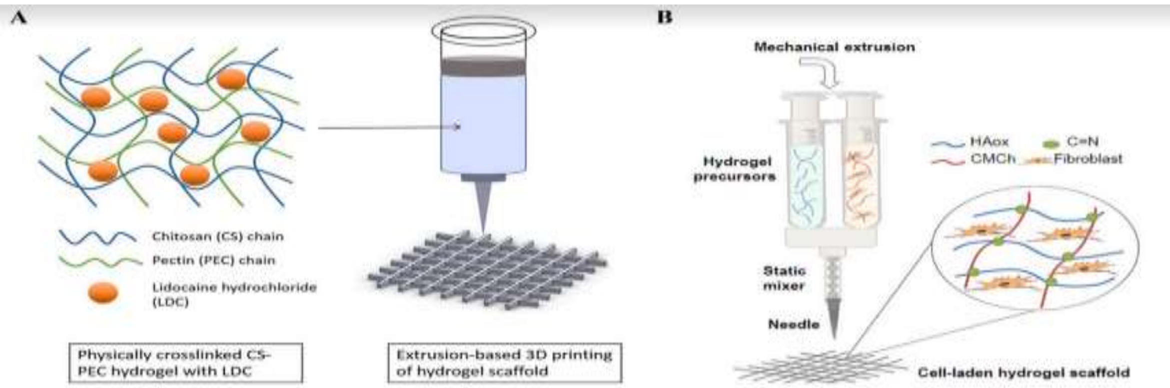

Fig 2. 3D printing hydrogel scaffolds prepared by extrusion technology.

(A) CS-PEC cross linked hydrogel was prepared by extrusion 3D printing technology to form a scaffold and the drug lidocaine hydrochloride was loaded at the same time.

(B) On the basis of extrusion technology, the hydrogel was printed in 3D by a double syringe system to form microneedle.

3D PRINTING BASED ON LIGHT AND PHOTOPOLYMERIZATION

Although extrusion-based 3D printing is extensively utilized, it has a very major flaw: the hydrogel created using this technique has poor resolution. Therefore, this approach is ineffective when printing the high-resolution hydrogel. Some materials can be produced using extrusion-based 3D printing technology while yet maintaining the straightforward geometry of a 2D extrusion. Currently, light and photo-polymerization are employed to create high-resolution 3D printing hydrogel in a highly automated and assembly-free manner. In the meantime, there is some flexibility in the way the printing process is designed. The main principle is that the photo initiator in the system is excited to produce free radicals or cations under the condition of light source and electron radiation, which causes the compounds in the printing material to polymerize and then cross-link to form a curing film**.** The curing film starts off as a 2D curing single layer. The platform then descends by a distance equal to the thickness of the single layer intended. The surface of the 2D curing single layer is once again covered in hydrogel ink.

DIW TECHNOLOGY

In addition to the printing technology already stated, 3D hydrogel can also be created using DIW technology. This method is really used to handle the hydrogel precursor solutions of several natural polymers (like gelatin and chitosan) and synthetic polymers (like acrylamide). A three-axis translation platform, a compressed air supply unit, a cylindrical nozzle, and an optical microscope for real-time monitoring make up the majority of the DIW equipment. The fundamental idea is rather straightforward. The 3D printer's nozzles release elastic printing ink with a certain viscosity to create fibres, which are then printed to the portable XY axis platform through the nozzle. The nozzle may move in a variety of X, Y, and Z axis orientations, and the fibres can be deposited into a variety of 3D structures. Following are some benefits of employing DIW technology to print 3D structures: In 3D printers, the nozzles don't need to be changed regularly, which significantly speeds up printing. DIW technology also allows for the printing of non-linear patterns by altering the printing parameters. Finally, there are numerous printing modes.

The hydrogel ink created by CS and PVP has excellent rheological and thixotropy characteristics, making it ideal for creating intricate 3D hydrogel structures. After mixing, the freezing-thawing cycle was performed. In order to create a double-network cross-linked hydrogel, it was then immersed in Na3Cit solution. Hydrogel for 3D printing offered exceptional mechanical qualities. Hydrogel for 3D printing has been generated in a wide variety of shapes through secondary moulding, including whale and butterfly shapes. It is currently a possible application material for tissue engineering and intelligent machines.

IV. BASIC COMPONENTS OF A 3D PRINTER

For the development of a 3D printer, we should first of all identify is basic components necessary for its efficient working.

The basic components of a 3D printer are listed below:

DEMONSTRATION OF A 3D PRINTER

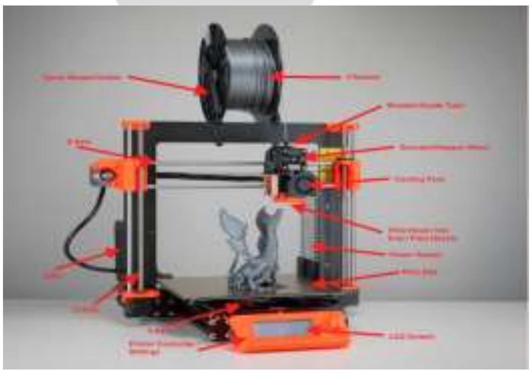

Fig 3. Demonstration of a 3D printer

EXTRUDER

Extruders are a crucial component in 3D printers. In simple terms, the extruder is the tool that holds the filament in place and controls the amount that is fed into a Hot-end.

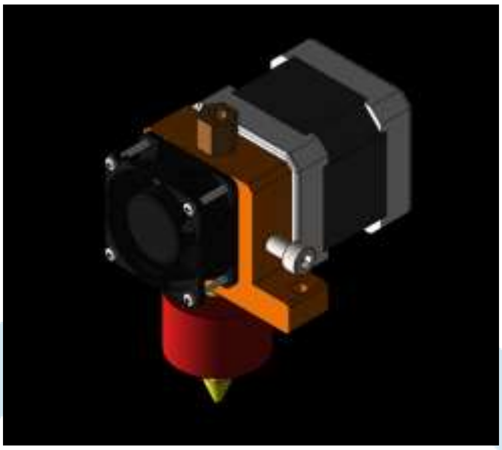

Fig 4. Extruder

PRINT BED

A print bed is the part that the 3d printed object rests on during the printing process. As each layer is extruded, the print bed moves down to allow for the next layering step,

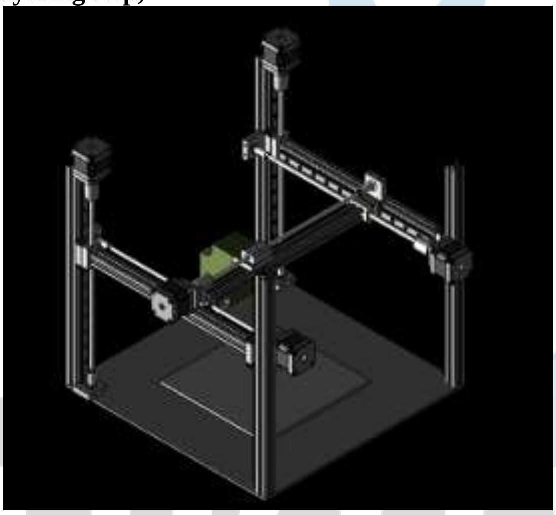

Fig 5. Print Bed

HOT END

A hot end is where the filament is melted then extruded through a nozzle. Hot ends come in many forms but the standard ones consist of a feed tube, a heat sink, thermal barrier tube with a heat-break, heat-block and the nozzle in that order.

Fig 6. Hot End

STEPPER MOTOR

These are responsible for the mechanical movement of the device and are controlled by Stepper driver. These motors connect with X, Y as well as Z axis. These motors help in driving the print head, print bed, along with the lead screws. Because the rotations are made in steps, they are called Stepper motor.

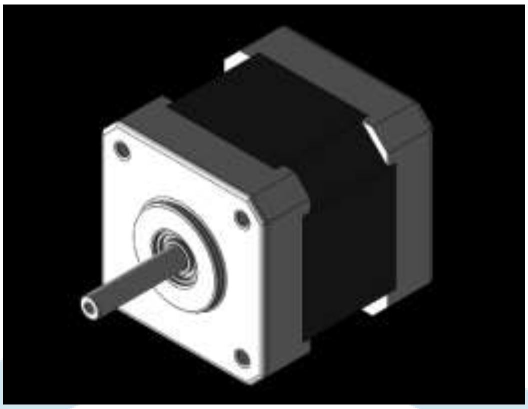

Fig 7. Stepper Motor

SMOOTH ROD

A smooth rod is a metal rod usually used on the axis for components such as the X-carriage or print bed of a RepRap to slide on. The most commonly used diameter is 8 mm, but 10 mm and 12 mm are seen in more rigid designs as well.

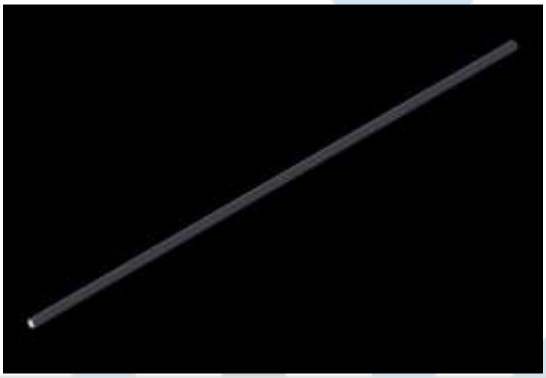

Fig 8. Smooth Rod

V. TOWARDS AN IMPROVED 3D PRINTER EXTRUDER DESIGN

DESIGN CONSIDERATIONS

In order to develop a device that can replace the thermoplastic material extruder on a typical desktop material extrusion 3D printer, there are several design aspects that must be taken into consideration. The first aspect relates to the electromechanical components of a thermoplastic filament extruder. Most desktop material extrusion printers use stepper motors to grab and push feedstock into a heated nozzle. The nozzle is heated using a ceramic heating cartridge, and the temperature is controlled using a thermistor, thermocouple or a temperature sensor. This means that the printer has the required electronics to control all these components, which include the stepper motor drivers, Analog-to-Digital Converters (ADCs) for temperature control, voltage regulators, and relays for switching the heating elements on and off.

Another aspect is the size of the 3D printer. The dimensions of the extruder carriage, and the mass allowed on the axis that holds the extruder, constrain the maximum dimensions of the paste extruder. Another important fact is that the biggest 3D printer manufacturers develop their own proprietary software, which does not allow for the set-up of the parameters needed for a different type of extruder than the one specific to the machine. Therefore, the only possibility to circumvent this problem is to use open-source firmware and software. The material extrusion desktop 3D printer on which the paste extruder was added-on is a Cartesian-style printer, equipped with a dual extruder (Fig 9). The printer has a closed build chamber and a build platform that can heat up to 110 _C. As for electronics, the printer comprises all the components that the paste extruder requires in order to function.

These include two low-current stepper motor drivers, and two ADCs, which allow temperature control using thermistors. The 3D printer runs on open-source firmware Sailfish 3.4 (www.sailfishfirmware.com), during tests. Certain applications for paste-like materials, especially in the medical and food industries, require the use of sterile instruments. In order to fulfil this demand, the paste extruder design uses standard single-use 60 mL syringe tubes to hold the feedstock, and can be easily adapted to accommodate different tube sizes. Material extrusion AM is an “additive manufacturing process in which material is selectively dispensed through a nozzle or orifice". For increased adaptability and ease of use, a Luer lock system and blunt tip needles were used for the nozzle. Several dimensional variants are available for the blunt tip needle diameter (Fig 10).

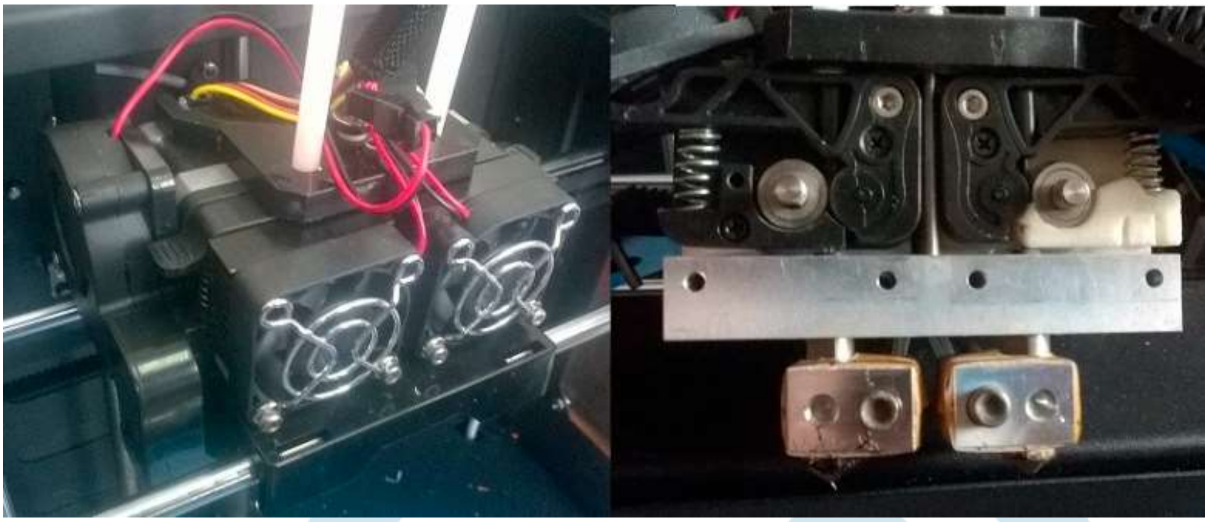

Fig 9. QidiTech Avatar IV dual extrusion system

Fig 10. Various nozzle dimensions, from 0.15 mm to 1.54 mm

The feedstock is pushed through the nozzle using a piston actuated by a drive-screw and nut mechanism. The stepper motor is fixed in position, and no linear guides are needed, as the nut was pre-tensioned against the drive screw (Fig 11), and the inner rubber seal prevents the drive screw from spinning. The pitch of the drive screw is 1.25 mm.

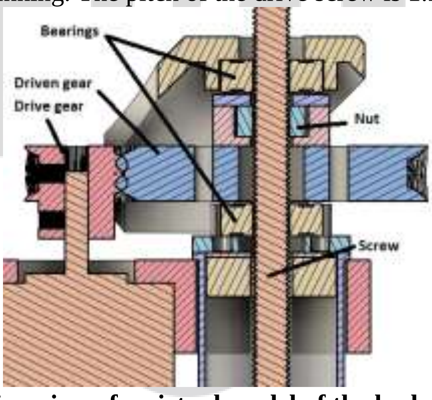

Fig 11. Section view of a virtual model of the hydrogel extruder

The hydrogel extruder was designed to make use of one of the stepper motors that comes with the thermoplastic material extruders, in order to not modify the 3D printer too much. The stepper motor is a NEMA17-sized motor, which is typically used in desktop 3D printer extruders. The stepper motor is used in 200 micro steps per turn setting. The shaft of stepper motor is connected to the drive screw through a set of double helical gears with a torque multiplier of 3.3 (Fig 12).

Fig 12. Herringbone gears transmission

DEVELOPED CARTESIAN 3D PRINTER

The cartesian type 3D printer is successfully developed in collaboration with iNSTA 3D technologies and is shown in the figure below.

Fig 13. Cartesian 3D Printer

HYDROGEL EXTRUDED USING CARTESIAN 3D PRINTER

The figure below shows some part fabricated out of hydrogel using two different nozzles and layer heights.

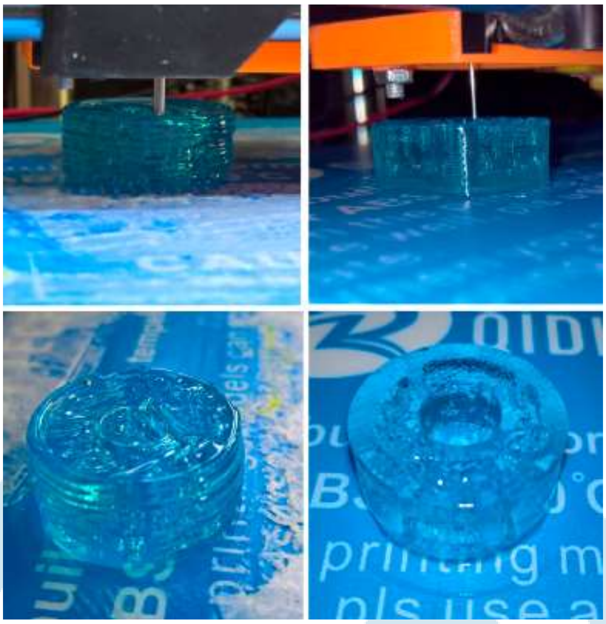

Fig 14. Part fabricated out of hydrogel using two different nozzles and layer heights (Left) 1.2 mm nozzle with 0.8 mm layer height (Right) 0.4 mm nozzle with 0.25 mm layer height.

VI. 3D PRINTING PARAMETER SETTINGS FOR HYDROGEL EXTRUDER

As previously mentioned, the Cartesian 3D printer uses a version of Sailfish open-source firmware. The firmware defines and enables the set-up of several important parameters of the AM process. For the thermoplastic filament extruder, the volume of extruded material is set up by specifying the diameter of the filament df, the diameter of the nozzle dn, an over/under extrusion parameter e, and a constant that reflects the specifications of the driving mechanism, m. Thus, the volume of extruded filament Ve is:

$$Ve = \frac{df^2}{4} \cdot \pi \cdot e \cdot m \tag{1}$$

and the length of the extruded filament Le is:

$$Le = \frac{df^2}{dn^2} \cdot e \cdot m \tag{2}$$

These formulas were used to determine the parameters needed for the extrusion process while using the paste extruder prototype. The filament diameter is replaced by the inner diameter of the tube that holds the feedstock. The driving mechanism is also modified. The m variable for the thermoplastic material extruder is:

$$mt = 2\pi \cdot b \cdot s \tag{3}$$

where s is the number of motor steps, and b is the radius of the toothed wheel that grabs and drives the filament.
This formula changes for the paste extruder, where m becomes:

$$mp = \frac{z_1}{z_2} \cdot p \tag{4}$$

where z1, z2 are the number of teeth in the double helical gears, and p is the pitch of the drive screw. While these settings can be changed directly in the printer's firmware, the same result can also be achieved by using a slicing software program that allows the user to access and modify these parameters. The slicer program used to set the process parameters and split the test models into layers is Makerware from Makerbot. The source code of this software program was initially developed by Makerbot for use on its own products, and eventually made available to the public. The program uses text files that contain references to various parameters, and allow an end-user to easily load and unload fabrication process settings without modifying the printer firmware. Several test parts with basic geometry have been modeled, sliced, and 3D printed using various materials. The settings used for testing the hydrogel extruder prototype can be seen in Table 2.

TABLE 2

Setting	Value
Nozzle diameter	0.4 to 1.5 mm

Layer height	0.15 to 1 mm
Road width	0.4 to 1 mm
Number of contours	2
Temperature infill Print speed	35 ^{O}C 100% 30 to 50 mm/s

VII. CONCLUSION

As a new material, 3D printing hydrogel is more and more popular among researchers because of its unique properties. Its preparation methods and printing ink are constantly improving and mining. In the medical field, it is becoming more and more widely used. However, 3D printing hydrogel also has some disadvantages. Firstly, there is a lack of preparation materials. 3D printing hydrogel has certain requirements for hydrogel ink; so many natural or synthetic compounds used to prepare hydrogel cannot be used. Generally, a single hydrogel is difficult to be used as 3D printing ink directly; most of the composite hydrogels with modifiers are used. These modifiers can be nanoparticles, cellulose, inorganic ions and related polymers. The mechanical anchoring formed by the interpenetration of the composite hydrogels greatly improves the mechanical properties. In addition to forming the composite hydrogels, the hydrogel ink can also be co-printed with harder polymers during the printing process to improve the mechanical properties. Secondly, the composition of the composite hydrogels is different, and the printing ink obtained is not uniform enough, which will reduce its printability. Therefore, we can improve the uniformity of the ink by heating and stirring during preparation. Thirdly, in order to ensure the printing performance of hydrogel ink, the viscosity of printing ink is relatively high generally. But high viscosity ink will damage the viability of cells, which will limit its medical applications. Usually, the concentration of polymer in the composite hydrogel is reduced or the temperature is changed to adjust the viscosity of the ink. We can also add ceramic, metal based nano or micro particles as rheology modifiers to interrupt the cross-linking of hydrogel, thus decreasing the printability of hydrogel ink. Then the low viscosity hydrogel ink is prepared on the premise of ensuring printability.

Fourthly, the 3D printing hydrogel is obtained by the accumulation of many thin layers during the preparation process. If each thin layer is not cross-linked quickly, it cannot support the subsequent thin layers accumulation. Therefore, the cross-linking reaction of the hydrogel precursor should be faster. The cross-linking methods that can be used include ultraviolet cross-linking and ion cross-linking, which can improve the cross-linking efficiency. Finally, the relevant properties of the 3D printing hydrogel prepared by the existing preparation methods cannot meet the growing demands, and the preparation methods are relatively simple. We can try to combine the traditional preparation methods to make up for the shortcomings of the single method. It is also possible to improve traditional preparation methods or try to develop the new 3D printing system. Although 3D printing hydrogel is facing with some problems that need to be solved urgently, as a new design material, these problems will be solved gradually with the deepening of future researches. At present, the applications of 3D printing hydrogel in the medical field are increasing; it will be used more and more widely in this field in the future.

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