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3D Printing the Woodburytype – Plastic Printing the Plate or Gel Printing the Image?

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Abstract

The Woodburytype process is one of the only printing processes capable of producing continuous tone. It is a 2.5D process that produces a textured relief print from a gelatin-based ink that contains no photo-active element and therefore does not degrade with time. Despite all these advantages, the process is time consuming and requires the use of precision equipment to build the printing plate. We explore initial insights into using additive manufacture technologies in producing both a printing plate and directly depositing the gelatine-based ink using a paste extruder setup.

Introduction

The Woodburytype is a 19th Century printing process - one of the few that is capable of producing continuous tone. This is due to the linking of the tone directly to the print height, producing a relief print that can vary smoothly and continuously [1, 2, 3, 4]. Currently, the most common method of fabrication from plate to print is to produce a printing plate in a CNC mill, using a direct tone to height map translation, common in additive/subtractive manufacture software. This process produces the relief plate and uses a dual pass of a large-radius drill-bit in order to quickly remove large unnecessary sections of material and a secondary pass of a smaller-radius drill-bit, in order to provide detailing. From this, the Woodburytype can be printed directly by filling the relief with a gelatinous ink and pressing against the substrate. The ink itself is usually comprised of a mixture of water, gelatin and a pigment. The dried print takes the shape of relief printing plate and effectively produces a low-relief casted version of it, due to the loss of water during the drying process. Fig. 1 shows an example of such a print, with a great tonal range of therefore detail in the image. It also displays one of the primary weaknesses of the Woodburytype process, in that without great control and precision of the pressure during the print, large regions of white are tough to print, as during the Negatives of the image can be produced by further taking a silicon mold of the milled plate – meaning multiple plates can be produced from a single plate. Overall, this process can provide an extremely detailed plate, however it requires processing on the course of days and requires expertise in high-quality subtractive manufacture processes.

Woodburytype can also be thought of as an example of a 2.5D printing process as the variation in the third (or z) dimension is present but restricted to a much narrower range than the other two dimensions [5]. As such, 3D printing methods such as fused filament fabrication provide an ideal method of selective deposition for such a process, as they provide extremely precise and reproducible movements, particularly in the x and y dimension. The restriction of the z-dimension is also helpful in attuning a 3D printing platform, as it places less reliance on the deposited material to be self-supporting over many layers and so we are not as restricted to standardized printing material or recipes. In addition to this, additive manufacture platforms are far more common in the lab and the home - so this may provide a route for the general audience to produce high-quality relief printing plates.

We explore the possibilities of '3D printing a Woodburytype' using additive manufacture platforms to print either the printing plate or the Woodburytype print itself. The former involves actual fabrication of these printing plates in PLA, while the latter involves ink characterization and design of a suitable paste extruder system. The resolution, process, requirements and overall printability of each approach is taken into account for comparison purposes; however, the quantization of the layer-by-layer additive manufacture process mean that they can never truly replicate the continuous tone of the original Woodburytype. We aim to achieve a Woodburytype with a 3D printed component that is indiscernible to the naked eye and decreases the production time of the Woodburytype process, from printing plate to print [1, 2, 3]. This process could then be further utilized as a method of producing bespoke 2.5D surfaces from gelatinous or viscous material.

***Figure 1.** An example of a Woodburytype, printed using a standard silicone mold of a CNC milled plate. This displays all the range, print height difference and weaknesses of a generic Woodburytype print.*

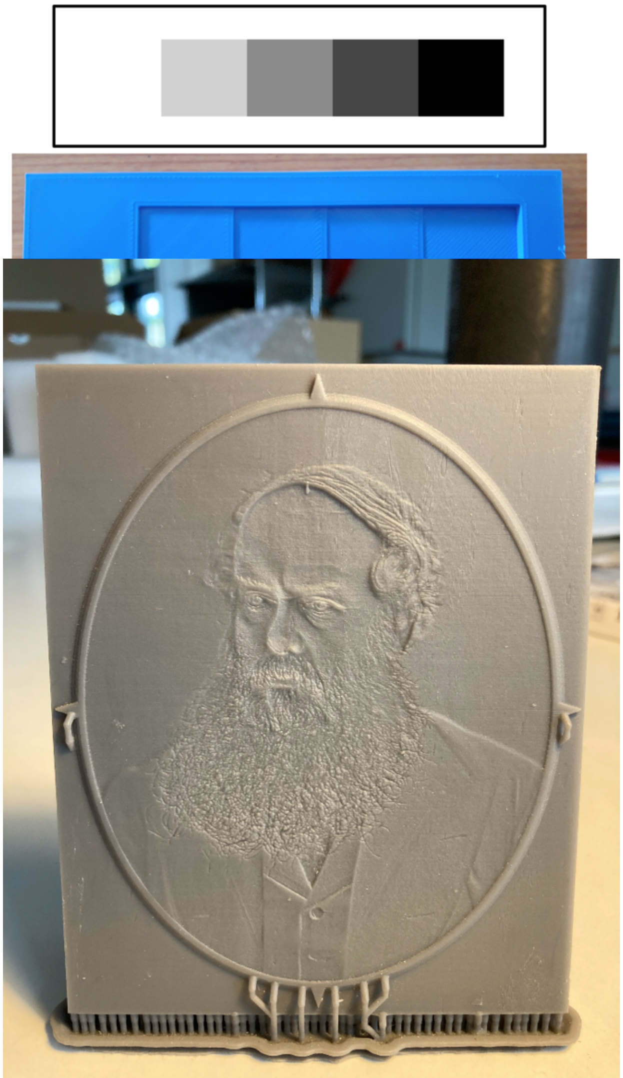

Figure 2. (Above) A simple step-wedge example of the conversion between a 2D image and a 3D printed model, printed on a Creality Ender 3. These five uniformly spaced steps of 2 cm x 2 cm provide the simplest example of the Woodburytype process, whereby the darkest regions of the print use the deepest relief sections. (Below) A more complex printing plate, made using an SLA printer. Although the detail is much finer, printing lines are still visible in the final print.

Printing the Plate

The similarities between Woodburytype and casting processes suggest that printing the plate itself may be suitable for quickly producing bespoke Woodburytype printing plates. Disposable mold shapes are a common use of 3D printing technology, whereby the 3D printer forms the shape of the desired object, a mold is made from that shape and then the print discarded or burnt out, in order to make space for whatever material is required.

A standard fused filament fabrication printer, the Creality Ender 3, is used to produce a series of plates, ranging from simple step-wedges to more complex images. These use the built-in 'image to height-map' function within Ultimaker Cura and therefore allow for the quick production of 3D models from

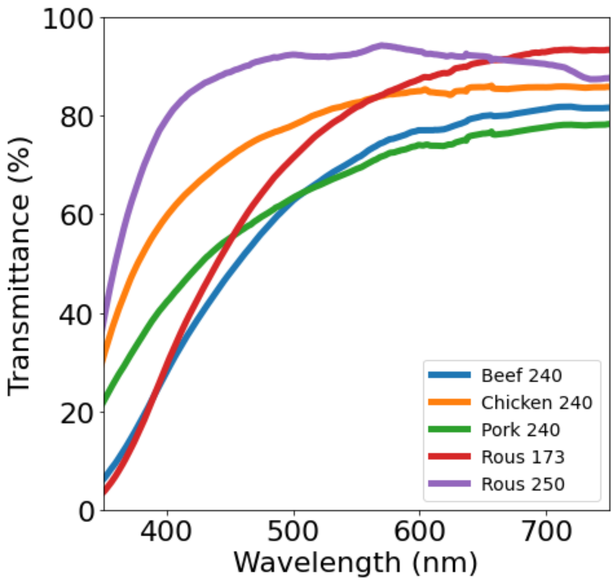

***Figure 3.** Transmittance data for a variety of gelatin samples, with varying Bloom and source. These will all have slightly differing viscosity responses that will make them tougher or easier to print.*

2D images. Woodburytype printing plates typically range in relief from 0 – 1 mm [1, 2, 3] (producing final printed reliefs in the range 0 – 170 μm) – as such we this as the bounds for our image height map and choose a simple linear scaling.

The model is simply sliced as normal – the layer thickness of which is dependent entirely on the software and 3D printer combination. We use a standard layer thickness of 0.2 mm in order to print these, to minimise time cost, however this can be reduced to 0.15 mm with further tuning of the printing process. Fig. 2 shows an example of such a process, in which a step-wedge mould is produced from a simple image of adjacent squares of increasing darkness. The tones of each section are spaced such that when a linear interpretation is applied to the image, the spaces between all the steps are equal and range in height from 0 – 1 mm. This was all achieved in less than 2 hours, including design of the image. The texture of the 3D printed structure, however, particularly on the flat surfaces reflects in the Woodburytype prints, where artefacts of the surfaces are left in the gelatine relief, producing a rough surface. This can be seen in Fig. 2, where the cross-hatching pattern is used to quickly fill in regions of flat printing plate. This affects both the tonal range and the overall clarity of the print, increasing the variation in the measured CIE L*a*b* values across each flat step, and therefore negatively affects the overall image appearance.

This could possibly be averted by processing the printed plate via sanding or post-processing prior to printing, in order to smooth out any surface variations, however this may cause a further loss in detail. Additionally, shown in Fig. 2, is a more detailed plate printed with a stereolithography printer. The image reproduced with this type of printer is able to be far more detailed than that of the fused filament fabrication printer and this approach is commonly used in the production of lithophanes. We choose a slanted angle during the print process, in order to preserve as much of this detail as possible, however print lines are still visibly obvious when a Woodburytype print is made from such a plate.

Printing the Woodburytype

Printing the Woodburytype material directly involves the assembly of a general-purpose gel/paste extruder onto a standard fused filament fabrication setup. This typically replaces the plastic extruder with a pressurized syringe, either driven by the original motor via a tightening belt or an external air pressure supply. The former is simpler in setup and cheaper in price, whilst the latter provides more precision in the pressure felt by the ink. We choose the former in an attempt to make this setup more generally accessible and reduce the overall costs.

Printing using such a setup has three vectors of tuning to improve printability; the extruder, the G-Code and the material. Assuming that the extruder and G-Code are somewhat fixed, only requiring an overall slowing of the printing speed, we instead seek to produce an initial ink most suitable for printing, from optical and rheological characterization data. This approach could be seen as far more complex than printing the plate, however due to the advent of fields such as bioprinting [6] and food printing [7], all of which rely on patterning viscous material – fundamental research into selective deposition of such materials could provide insights for a broad selection of research areas.

The Woodburytype ink formulation is constrained such that it requires a gelling component, to bind the pigment and form the shape of the relief plate. It should be as transparent as possible, to reduce optical interactions with the pigment, and should flow at a reasonable temperature. This gelling component is core to the production of the Woodburytype print and therefore must be chosen carefully. Gelatin is the primary choice, due to the low-temperatures required to induce flow, and the overall abundance and cost-effectiveness. However, other non-gelatin candidates could include agar and cellulose-based chemicals including methyl cellulose and hydroxypropyl methyl cellulose. We focus primarily on gelatin, as there is also a large variation in samples when allowing for gelatin of varying Bloom (gelling strengths) and sources. As such, we seek to determine whether these varying viscosity profiles can have an adverse effect on the optical properties, the overall most important component of the print.

Optical Properties

Gelatin has been highly favored within the photographic community for centuries due to the relative high-transparency it has and was commonly used as a vessel to hold far more photosensitive components, such as silver halides [8]. Even today it is used as a cheap holder of more optically interesting elements [9]. Again, we require high optical transparency as to provide a clear response from the pigment – this allows for tighter control over the optical and tonal range of the images.

Fig. 2 shows a variety of transmittance data from gelatin samples of varying sources and gelling strengths. The samples were all in aqueous solution at 17.5wt% and heated to 40c to ensured they were in the liquid phase. This heating also increased the rate at which bubbles left the solution, that would cause anomalies in the transmittance data. This data was produced using an Agilent 8453 UV-Vis Spectroscopy system.

The beef, chicken and pork samples (all at 240 Bloom) were procured from MM ingredients and used as received. The other samples were procured from Rousselot, at Blooms of 173 and 250, and are notable for their use in other ink formulations [1]. Despite colorimetric differences that are visible to the naked eye, the overall shape of the transmittance data is similar across all samples – being highly transparent for the majority of the visible spectrum, with some progressive loss toward the blue end of the spectrum.

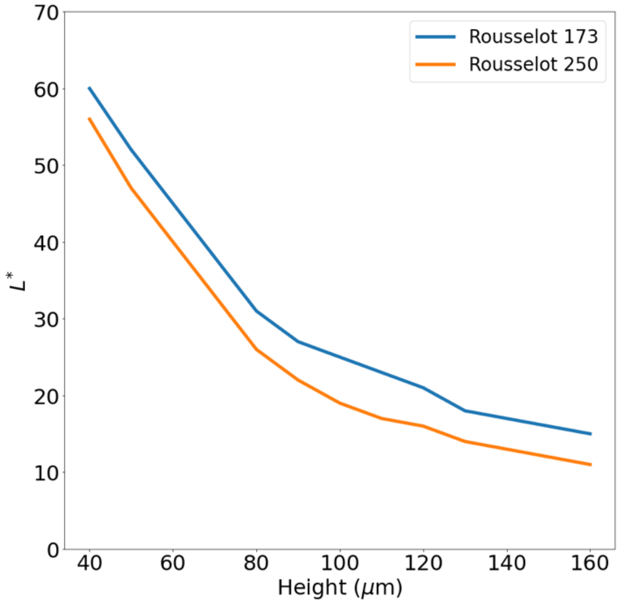

Figure 4. *CIE L*a*b* brightness values L* for a series of ten-step Woodburytype prints that utilize similar pigment concentrations of carbon black, but differing gelatin types. The overall character of the two prints is extremely similar with a systematic offset.*

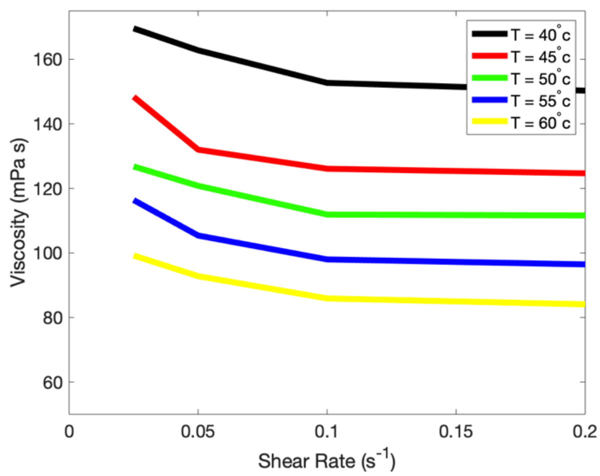

Figure 5. *Viscosity profile of 250 Bloom gelatin, varying with temperature induced upon it.*

Fig. 4 instead displays CIE L*a*b* data for two ten-step Woodburytype prints that simply use differing gelatin types in the ink formulation. The pigment is a highly absorbing carbon black and so should therefore drive the optical appearance over the 'transparent' gelatin content. We find that in general the two prints are extremely similar in optical appearance, with a systemic offset that suggests that the 173 Bloom gelatin is simply overall darker than the 250 Bloom. The difference between the two is such that both prints should be perceptually different from one another [10], however this does not affect the overall tonal range (maximal difference in L*) in any way and so either would be a reasonable choice for Woodburytype printing.

We use this data as justification that the variation between general samples is not enough to preclude any particular type

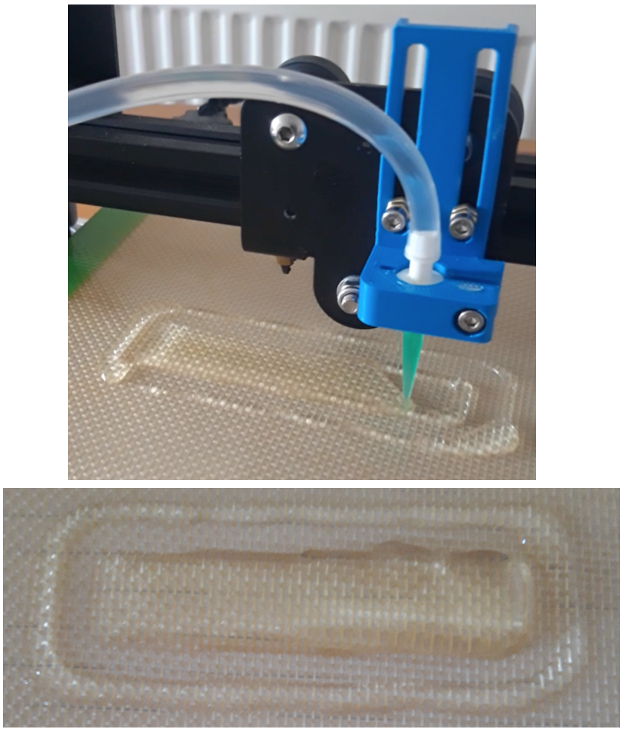

Figure 6. *Example of the direct gelatine printing of the step-wedge image from Fig. 2. Above shows how the material is fed to the nozzle and subsequently the substrate. The ink contains no pigment so that the overall structure is more obvious. Below is the final set film, showing how the step-wedge becomes a smooth incline and the standard defects in this process, including the loss of resolution and uneven edges. However, the information of a increasingly thicker film is*

and, therefore, we choose the source and Bloom based purely on the rheological and printability properties.

Rheological Properties

The required rheological properties for a Woodburytype print are not completely quantified. In the original printing process, the viscous gelling component is required purely to hold the shape of the relief plate and very little actual 'flow' is required beyond initially filling the plate. This change is driven primarily by the temperature imposed upon it rather than any choice of particular gelling component – we typically use 250 Bloom [1] due to the quick gelling time it provides.

Here however, in a process where the viscous ink is to be held in a syringe and selectively deposited to provide a 2.5D print, the overall flow properties become far more important. A full discussion of the range of acceptable properties required for printability via any one gel/paste extruder system is far beyond the scope of this study and, as such, we instead provide an insight into the characterization of one particular ink recipe and the corresponding print resolution provided by it.

As such, we initially choose one particular gelatin formulation and instead focus on how variation in the temperature can be used to vary the overall viscosity of the formulation. A 17.5wt% gelatin ink was produced using 250 Bloom gelatin and tested in a rotational viscometer at various temperatures. The standard working temperature of the Woodburytype inks is around 40 - 50c, as in Fig. 5, that displays a range of higher temperatures that could be used to induce a higher flow rate. Matching these flow rates directly with the rate at which the G-Code is undertaken and the setting of the gelatine is vital, however overestimating to a higher flow rate will ensure that all regions visited by the extruder will at least have some amount of gelatin ink deposited. In general, over-extrusion is preferable than under-extrusion to prevent issues with support material not being present [11].

Paste Extruder

Having determined the general optical and viscometric properties of our desired materials, we turn our attention to the extruder required for such printing. Generic paste extruders have existed alongside additive manufacture technologies since their inception, but can be described under a multitude of terms including direct ink writing [12] and 3D extrusion technologies [13]. In general, they offer the selective deposition of a large range of materials through the utilization of a both the standard XYZ positioning of many 3D printing platforms and a reservoir pumping system, that usually consists of an air pressure pumping method, a syringe pump under compression or an auger driving method in order to feed material to the printhead [14]. These systems are powerful in broadening the range of printable material; however, this commonly means that the print process and ink recipe must be carefully considered and tailored for that specific setup in order to produce a printable solution.

Many designs exist, including Ref. [14], however here we modify the Creality Ender 3 to use a paste extruder head, utilizing the aforementioned syringe pump method for the material feeding process. This syringe pump is based on the Poseidon Pump setup detailed in Ref. [15] and driven by the extruder stepper motor on the original Ender 3 design. The only other attachments needed are a nozzle holder designed to keep the nozzle in place during the print process, a syringe reservoir, connecting tubing and nozzle. All these parts are intended to be modular and swappable depending on the material being extruded – for the gelatine printing we use a 1.15 mm diameter nozzle and 5 mm connecting tubing.

Again, the three components of printability for a generic material ink are the extruder, the G-Code and the material. Having decided the recipes we can use to provide a suitably optically transparent gelatine for Woodburytype process and the rough design of the extruder, we focus primarily on the G-Code and the material parameters that are externally affectable, most notably the temperature [16].

Commonly the printing of soft materials and hydrogels rely on a structure-enhancing component, such as printing into a support medium or photo-crosslinking [17], however here, due to the low-lying variation in the z-dimension, we can attempt to print directly, using only the printed material as support. The obvious downside to this is the loss of resolution in the print process, whereby stacking mismatches and general flow will broaden any printed line. For instance, the step-wedge print within Fig. 2 would be far more achievable than the structured image below it.

As such, we seek a combination of printing parameters that will minimize this resolution loss. Within the extruder, this is done by choosing a nozzle that limits the print width, taking into account the inherent broadening at the nozzle tip caused by a die-swelling-like behaviour [18]. A narrower nozzle tip results in diminishing returns between the ratio between the printed line and the nozzle diameter, but with increasing likelihood of defects and aberrations. Within the G-Code manipulation, this is achieved by producing a Slic3r profile that takes into account:

- Broadening of individual printed line.
- Broadening of the layer height.
- Addition of a brim loop to induce more consistent flow during print.
- Reducing the number of perimeters required for an external edge to one.
- Allowing for cold extrusion.
- Removing bed heating.
- Increasing extrusion per mm (1.5x).
- Reducing the overall speed of nozzle movement during print instructions (20 – 40 mm/s).

This ensures that the print process takes into account the inherent limitations of the material extrusion, whilst still providing a nozzle path that attempts to replicate the input image. Finally, with the material, we ensure an initial temperature of 40c for the reservoir of gelatin. Meaning that the gel-ink flows enough to be extruded, but equally sets rapidly whilst on the build plate. This does however mean that the print needs to undertaken in quick succession, as there is currently no method for heating the reservoir or nozzle.

Fig. 6 shows one such example of a Woodburytype print with the paste extruder, stemming from the step-wedge image in Fig. 2. The ink in this particular print is simply gelatine and water, with no pigment component, so that the overall structure can be more clearly seen. The high gelatin content means that the layers are set by the time it moves onto the layer above, however there is still some obvious flow taking place after deposition, manifesting in a smoothing of the sharp steps of the original image into a smooth incline. Typically, extruded gels have the opposite issue, as described in Ref. [16], in which the surface of the gel becomes rough during extrusion, a consequence of attempting to extrude the set gel, resulting in a structure that loses optical transparency. Woodburytype prints (and other types of bioprinting [19, 20]) require this optical clarity, in order to display their full tonal range and therefore this is one obvious advantage that the direct printing of the gel-ink has over the 3D printed plate.

Conclusions

We propose two routes toward a faster and more automated Woodburytype printing process, both involving an additive manufacture component. The first involves 3D printing the relief plate from which the print is produced. This was promising, however the loss of a smooth surface texture due to the quantization of the z-dimension and the way in which flat surfaces are filled in on standard 3D printer platforms resulted in a rough surface and overall loss of image quality. The latter involves deposition of the gel ink directly, via a 3D printing platform modified with a paste extruder. Ink characterization displayed a range of gelatin-based inks with very similar optical properties, showing we are free to choose the formulation with the most ideal printability. Additionally, due to the liquid properties of the ink directly after extrusion, the optical transparency is maintained, at the expense of the possible resolution of the print. Further improvement could be made to both processes, including post-processing methods for the smoothing of 3D printed plates and further refinement of the heating/cooling methods for the direct deposition of gelatin.

References

[1] D. J. Leech, W. Guy, & S. Klein, “The optical properties of the Woodburytype—an alternative printing technique based on a gelatine/pigment matrix,” Journal of Physics Communications, 4(1), 015018 (2020).

[2] D. J. Leech, W. Guy, & S. Klein, “The optical properties of the Woodburytype—an alternative printing technique based on a gelatine/pigment matrix,” NIP & Digital Fabrication Conference, Printing for Fabrication, pp. 42-47(6) (2019).

[3] D. J. Leech, W. Guy, & S. Klein, “The Polychromatic Woodburytype—Colour Tracking in Translucent, Patterned Gelatin/Pigment Films”, Molecules, *25*(11), 2468 (2020).

[4] P. McCallion, “The Development of Methods for the Reproduction in Continuous Tone of Digitally Printed Colour Artworks”, PhD thesis, University of the West of England, Bristol (2017).

[5] C. Parraman, “The development of vector based 2.5 D print methods for a painting machine,” Color Imaging XVIII: Displaying, Processing, Hardcopy, and Applications (Vol. 8652, p. 86520R). International Society for Optics and Photonics (2013).

[6] A. Skardal & A. Atala, “Biomaterials for integration with 3-D bioprinting”, Annals of biomedical engineering, 43(3), 730-746 (2015).

[7] J. Sun, W. Zhou, D. Huang, J. Y. Fuh & G. S. Hong, “An overview of 3D printing technologies for food fabrication”, Food and bioprocess technology, 8(8), 1605-1615 (2015).

[8] S. Calixto, N. Ganzherli, S. Gulyaev, & S. Figueroa-Gerstenmaier, “Gelatin as a photosensitive material”. Molecules, 23(8), 2064 (2018).

[9] M. A. F. Basha, “Optical properties and colorimetry of gelatine gels prepared in different saline solutions”, Journal of Advanced Research, 16, 55 - 65 (2019).

[10] J. Schanda, “Colorimetry: Understanding the CIE System”, CIE Central Bureau, Vienna (2006).

[11] R. Comminal, M. P. Serdeczny, D. B. Pedersen, & J. Spangenberg, “Motion planning and numerical simulation of material deposition at corners in extrusion additive manufacturing,” Additive Manufacturing, *29*, 100753 (2019).

[12] J. A. Lewis, "Direct ink writing of 3D functional materials." Advanced Functional Materials 16.17, 2193-2204, (2006).

[13] Q. Li, X. Guan, M. Cui, Z. Zhu, K. Chen, H. Wen, D. Jia, J. Hou, W. Xu, X. Yang & W. Pan “Preparation and investigation of novel gastro-floating tablets with 3D extrusion-based printing”. International Journal of Pharmaceutics, 535(1-2), 325-332 (2018).

[14] K. Pusch, T. J. Hinton, & A. W. Feinberg, “Large volume syringe pump extruder for desktop 3D printers”. HardwareX, *3*, 49-61 (2018).

[15] A. S. Booeshaghi, E. da Veiga Beltrame, D. Bannon, J. Gehring, & L. Pachter, “Principles of open source bioinstrumentation applied to the poseidon syringe pump system”. Scientific reports, 9(1), 1-8 (2019).

[16] M. Kahl, M. Gertig, P. Hoyer, O. Friedrich, & D. F. Gilbert, “Ultra-low-cost 3D bioprinting: modification & application of an off-the-shelf desktop 3D-printer for biofabrication”. Frontiers in bioengineering and biotechnology, *7*, 184 (2019).

[17] D. M. Kirchmajer, & R. Gorkin III, “An overview of the suitability of hydrogel-forming polymers for extrusion-based 3D-printing”. Journal of Materials Chemistry B, *3*(20), 4105-4117 (2015).

[18] R. Suntornnond, E. Y. S. Tan, J. An, & C. K. Chua, “A mathematical model on the resolution of extrusion bioprinting for the development of new bioinks”. Materials, *9*(9), 756 (2016).

[19] B. Zhang, Q. Xue, J. Li, L. Ma, Y. Yao, H. Ye, Z. Hui & H. Yang, “3D bioprinting for artificial cornea: challenges and perspectives”. Medical engineering & physics, 71, 68-78 (2019).

[20] A. Isaacson, S. Swioklo, & C. J. Connon, “3D bioprinting of a corneal stroma equivalent”. Experimental eye research, 173, 188-193 (2018).

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