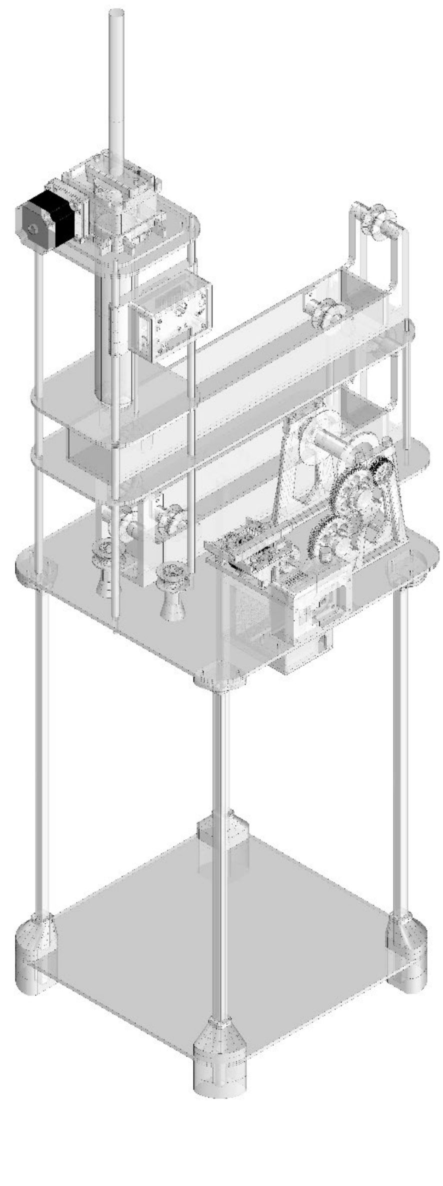
Bio-Yarn Extruder Manual

Nikoletta Karastathi, Zimeng Tan



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Introduction

This manual presents the bio-yarn extruder project, authored by Nikoletta Karastathi and Zimeng Tan. The project was developed as part of Ars Electronica 2024 and reflects our collaborative efforts in exploring innovative fabrication techniques. Both authors are from the UCL Design for Performance and Interaction (DfPI) program, where Nikoletta serves as a tutor.

The bio-yarn, a sustainable and biodegradable material, is extruded through a nozzle, immediately reacting with calcium chloride to form a solid thread. This thread is then collected by a winding mechanism, designed to maintain consistent tension and speed. The entire system exemplifies a blend of mechanical and digital technology, allowing for both efficient material production and potential scalability.

The main structure of the extruder is constructed from 5mm acrylic boards for stability, 10mm OD steel tubes, and 6mm threaded rods, providing a durable frame for the extrusion process. The project also incorporates 3D-printed PLA components, which offer customizability for specific mechanical parts. Additionally, Arduino-based components are integrated to control and automate various aspects of the extrusion and winding process, ensuring smooth and precise operation.

The purpose of this manual stems from a personal interest in ensuring the project is fully documented and completed. Beyond this, it is intended to serve as a guidance material for future students who share an interest in fabrication techniques or bio-yarn production. By providing detailed documentation, we hope this manual can be used, shared, and even adapted to continue advancing work in these areas.

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High strength and strain alginate fibers by a novel wheel spinning technique for knitting stretchable and biocompatible wound-care materials

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ARTICLE INFO

Keywords:
Alginate hydrogel
Wound-care
Materials
Wet spinning
Knitting
Egg-box dimers

ABSTRACT

Alginate fibrous materials have been applied as wound dressing to enhance wound healing due to its nontoxic, biodegradable, and hemostatic nature. Conventional nonwoven fabrication tactics, however, showed weakness in inflammation, degradation stability and mechanical properties. Herein, the wet-spun alginate fibers were prepared by a novel wheel spinning technique, then knitted into wound dressing. Benefiting from optimized wet spinning parameters and the agglomeration of alginate multimers, the fibers were endowed with elevated mechanical performances and biodegradability, which allowed for the feasibility of knitting wound care materials. Using the new wheel spinning technique, high strength alginate fibers with 173 MPa were produced with breaking strain up to 18% and toughness of 16.16 MJ*m^{-3}. Meanwhile, alginate fibers with high breaking strain reaching 35% were produced with tensile strength of 135 MPa and toughness of 37.47 MJ*m^{-3}. The overall mechanical performances of these alginate fibers with high breaking strain are significantly higher (up to 2 times) than those published in the literature in term of toughness. In vitro degradation evaluation revealed that this wet spun fibrous dressing had good aqueous absorbency (50%) and sustained biodegradation properties. Furthermore, the consequent cell viability study also proved that this alginate knitted fabric is biocompatible for being applied as wound dressing.

1. Introduction

Wound dressing has been regarded a clinical and daily consumable to protect and regenerate injured skin tissue for thousands of years [1,2]. Current wound dressing strategies always involve functionalized anti-infective or inflammatory components, depending on whether the wound is chronic or acute [3,4]. Developing topological formulations including sponges, films, bandages and nano/micro fibers is another focus for improving present therapeutic modalities [5–7]. Alginate nonwoven fabric is one of the mainstream dressing products especially for acute wounds [8]. However, nonwoven alginate hydrogel pads, as forms of mature wound dressing, suffered from poor mechanical properties, nor are they able to withstand external damage [9,10]. Further, the non-woven structure results in an unsatisfactory tissue adhesiveness due to a poor young's modulus, low toughness and highly rough morphology [11,12].

Regarded as a replacement option, wet spinning is a reliable technology in biomaterial manufacturing [13]. Widely recognized for being a traditional textile technique, the efficacy of wet spinning has been proven in the case of manufacturing biomedical polymers from single fiber to 3D scaffolds and even in cellular structures [14,15]. It is also favored due to alginate's resemblance of a hydrogel matrix texture and stiffness, which is comparable to the extracellular matrix though this could lead to another drawback concerning nonwoven dressing, namely, poor degradation behaviors [16]. Profiting from the topological structures, knitting fibrous fabric could kept highly stretchable structure and elastic modulus during dressing period towards transitional clinical applications [17].

As a typical natural polysaccharide extracted from *Sargassum*, alginate has had many applications in the textile, food, and biomedicine industries [18]. Alginate meets the criteria for good biocompatibility, biodegradability and hemostatic properties [19]. Due to alginate fibrous fabric can interact with wound effusion caused by tissue fluid leakage, as well as generate hydrophilic sodium alginate/calcium alginate gels

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Dry-jet wet spinning and encapsulating for preparing multifunctional fibers based on anti-Rayleigh-Plateau-Instability solution

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HIGHLIGHTS

- A novel open wet spinning and encapsulating method was proposed for preparing fibers.
- A Na-Alg solution with property of anti-Rayleigh-Plateau-Instability was developed.
- Hollow and knotted fibers with different size and morphology can be fabricated.
- Reagents droplets ranging from 1 to 200 μm can be encapsulated into the fiber.

GRAPHICAL ABSTRACT

ARTICLE INFO

Keywords:
Dry-jet wet spinning
Anti-Rayleigh-Plateau-Instability fibers
Sodium alginate
On-demand encapsulation
Inkjet

ABSTRACT

Diverse functional alginate fibers have played irreplaceable roles in life science, precision measurement, etc., drawing considerable attention from numerous researchers. However, further application of multifunctional fibers is greatly restricted by the preparation efficiency and the flexibility of equipment. Herein, modified anti-Rayleigh-Plateau-Instability sodium alginate solution filament and homemade piezoelectric ejector have been prepared to develop an efficient dry jet wet spinning and encapsulating system for preparing functional fibers. This method has two working modes, which can readily realize the fabrication of conventional hollow fibers or fibers wrapping super large bubbles and functionalized fibers encapsulating reagents with on-demand size (ranging from 1 to 100 μm) and interval distance (ranging from several microns to a few centimeters) with excellent flexibility. Furthermore, the fiber size can be facilely tuned by regulating the flow rate and the rolling speed, up to 1 m s^{-1}, higher than all the wet spinning techniques ever reported. Functional reagents with different sizes and shapes have been encapsulated in fibers to verify the feasibility and practicality of this approach, demonstrating the potential for further applications in drug delivery, even cell encapsulation and culture.

1. Introduction

Inspired by the wonders of nature, microfibers with complicated hierarchical structures containing multifunctional substances have been yielded out by a group of professional experts to meet the urgent needs of modern science and technology [1–5]. As a kind of natural polysaccharide with many excellent characteristics (superior biological compatibility, excellent stability and safety, easy to be obtained, and so on) and can instantly crosslink with calcium chloride ($CaCl_2$) to form the calcium alginate (Ca-Alg) hydrogel [6,7], sodium alginate (Na-Alg) has

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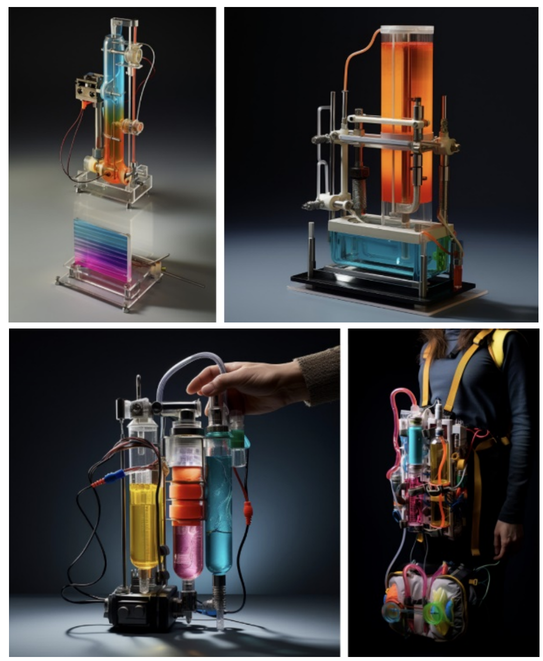
The design of the extruder system was significantly informed by existing research on dry jet wet spinning techniques. In particular, the work of Chen et al. (2021), which introduced a novel wheel spinning technique for creating high-strength, stretchable, and biocompatible alginate fibres, provided key insights into the mechanical design considerations for spinning and collecting fibres. Additionally, Li et al. (2022) contributed valuable knowledge on anti-Rayleigh-Plateau-Instability solutions in fibre spinning and encapsulation techniques. These studies have deeply influenced the way the extruder system was conceived and constructed, guiding decisions around material handling, spinning method of the final product.

While the research papers were essential for the technical design, the case studies included in this manual primarily serve to provide references for interaction design and aesthetic considerations. Among these case studies are a series of concept images generated by Nikoletta Karastathi using Midjourney, which offer inspiration on visual and experiential aspects. These concept images, along with other case studies, explore how similar projects approach user interaction and aesthetics, complementing the technical aspects of this project.

Lanna Factory by THINKK Studio

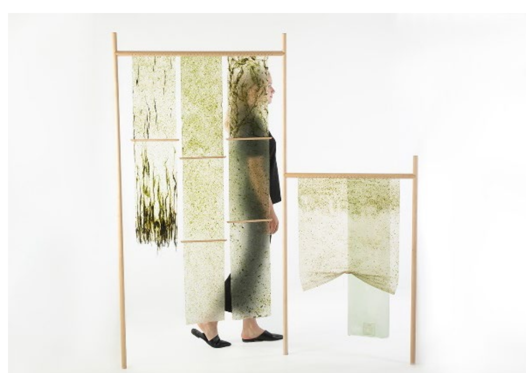
The Idea of a Tree by Mischer’Traxler

System for a Stain by Candice Lin



Extruder Concept Images by Nikoletta Karastathi

Opus et Domus by Maja Smrekar

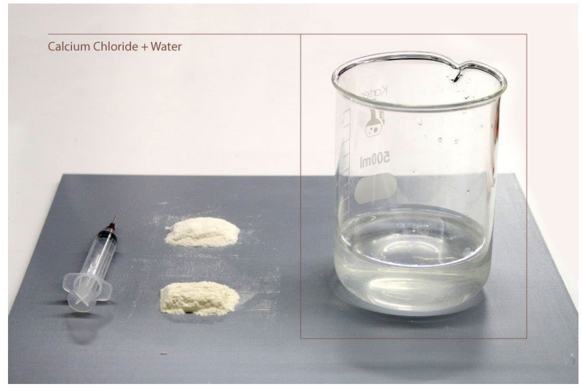


SEAmpathy by Daniel Elkayam

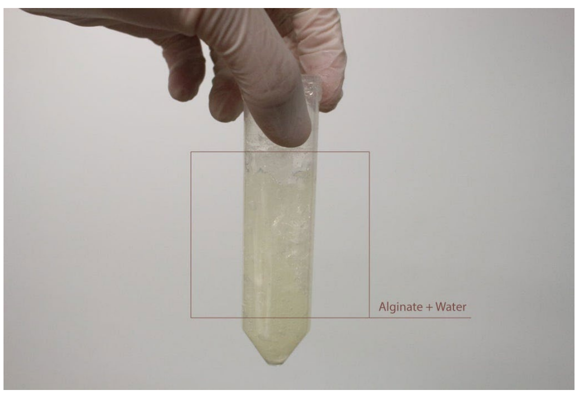
How to Make Bio-Yarn

Link Available at: https://www.instructables.com/Create-Bio-yarn/.

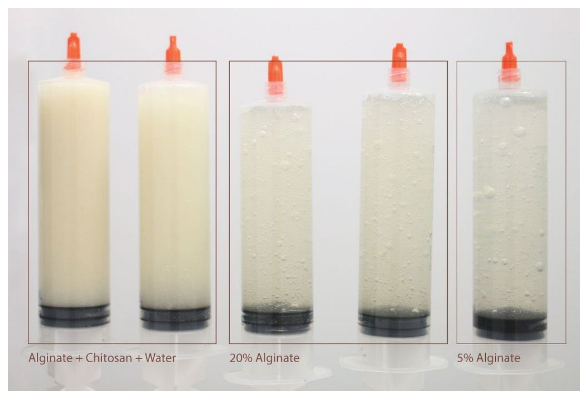
Required Materials



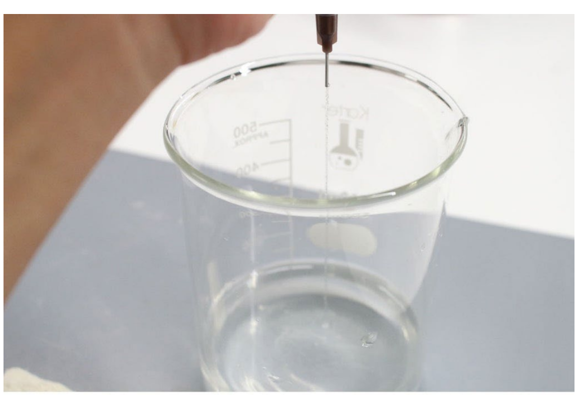
Mixing



Alginate Based Hydrogel



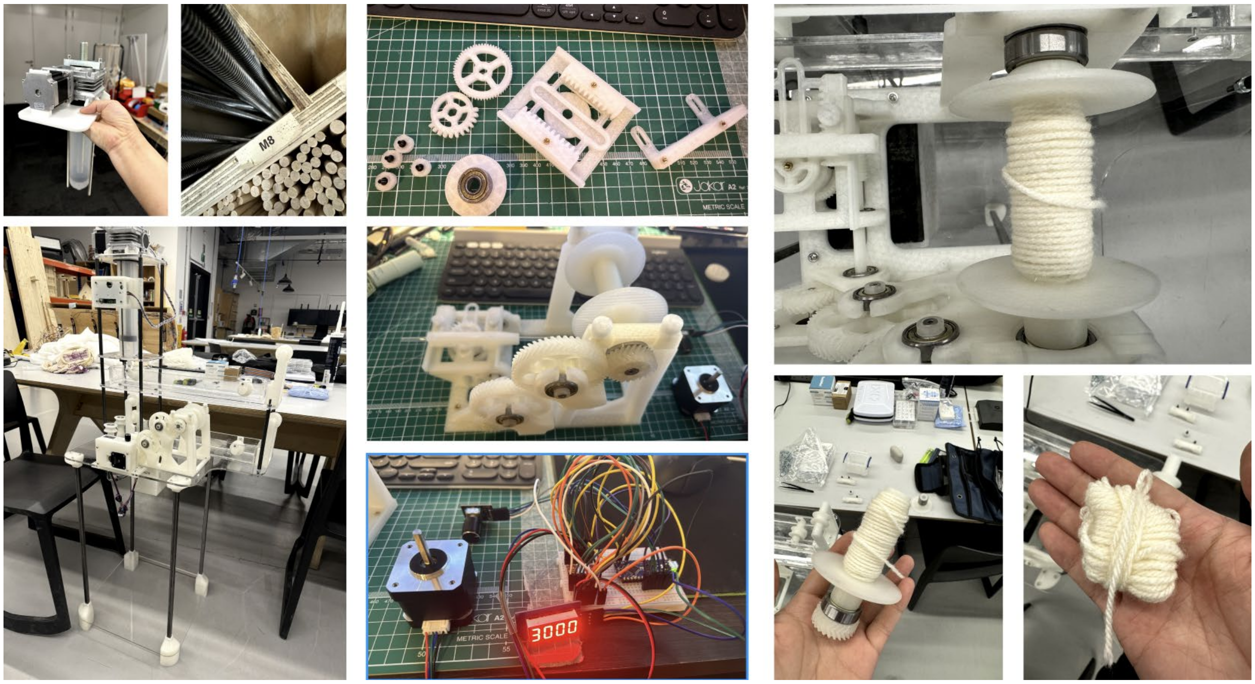
Variations of Hydrogel



Extruding into Bio-Yarn

Different Types of Bio-Yarn

Prototyping



The overall structure of the installation was created using 5mm acrylic boards and steel rods, providing the necessary stability and support for the extruder system. The core of the system, the extruder itself, is the Eazao Zero. However, for this project, we utilized only the extruder component, excluding the printing platform. To achieve optimal functionality, the extruder needed to be positioned vertically. This was addressed by designing and printing a custom platform that supports the extruder and positions it correctly. The platform was designed in Rhino, as was most of the overall design for the installation.

To ensure the required precision in creating the custom platform, we first 3D-scanned the extruder. This process allowed us to capture the precise coordinates of the vertices, enabling accurate modeling of the extruder in Rhino. With this data, we were able to recreate a 3D model of the extruder, ensuring a perfect fit for the custom platform.

Another critical component of the installation is the yarn winder, essential for collecting the bio-yarn. The winder we used is a remix of the "Awesome Filament Spool Rewinder - Upgraded," an open-source project by a user named Diplomator on printables.com. During the research phase, we explored various automatic yarn winders, and while more advanced options are available, the project's time constraints led us to adapt an open-source solution to meet our needs. These other options will be discussed in the conclusion section of the manual.

Material List and Cost

Estimated Total Cost: 243£ (without the extruder and extruder controller)

Materials:

1. 5mm Acrylic Sheets – 1000mm * 600mm x 1, 395mm * 600mm x 1 (60£)
2. 6mm Threaded Rods – 540 mm x 4, 240mm x 2 (6£)
3. 10mm OD 7mm and above ID Steel Tubes (15£)
    a. 45mm x 2
    b. 78mm x 4
    c. 125mm x 2
    d. 163mm x 6
    e. 240mm x 2
4. 12.75mm OD 9.5mm ID 600mm in length Square Steel Tubes (15£)
5. 3D Printing Filament – Approximately two full spools of filament (25£)

Accessories:

1. M3 * 20mm Nuts, Bolts, Washers (5£)
2. M3 * 5mm Round Hex Socket Screws (5£)
3. M3 Threaded Heat Set Inserts (6£)
4. M6 Nuts and Washers (5£)
5. M5 * 30mm Flat Hex Socket Screws (5£)
6. Silicone Grease (9£)
7. 10mm ID * 30mm OD * 9mm width 6200ZZ Ball Bearings (12£)
8. Plastic Solvent Cement (10£)
9. Transparent Hybrid Polymer Sealant Adhesive (10£)
10. Black Cable Straps and Hook/Loop Tape Strips (10£)

Electric Components:

1. Arduino Every x 1 (15£)
2. Small Bread Board or Terminal x1 (1£)
3. Jumper Wires (5£)
4. AC to DC 12V 3A Power Source x 1 (10£)
5. TM1637 LED Display Module x1 (5£)
6. KY-040 Rotary Encoder x1 (2£)
7. Nema 17 Stepper Motor 42x38mm x1 (5£)
8. A4988 Stepper Motor Driver Module x1 (2£)
9. Eazao Extruder Controller x1
10. Eazao Zero (Extruder) x1 Available at: https://www.eazao.com/product/eazao-zero/

Fabrication

3D Printing:

As mentioned earlier, the bio-yarn winder was a remix of the "Awesome Filament Spool Rewinder - Upgraded," an open-source project by a user named Diplomator on printables.com.

The project is available here: https://www.printables.com/model/515427-awesome-filament-spool-rewinder-upgraded/files.

Manual assembly videos are available from the original author, Miklós Kiszely's YouTube channel: https://youtube.com/@mikloskiszely514?si=oFWX3LARfx2LSvL_

On both websites, you can find more in-depth information about the winder project. The assembly instruction videos from the original author were especially helpful. The design files of "Awesome Filament Spool Rewinder - Upgraded" are attached along with this manual only for reference purposes.

For our remix edition, available in the Rhino7 .3dm file, we adapted the design so that all parts could be optimally printed on smaller print-bed 3D printers, such as the Ender 3 V3 SE, which we were using. This winder project requires precise tuning of the 3D printer, and it is advised to test your printer's accuracy before printing this project. It is essential to print everything from the .3dm file for the winder to function properly within the installation. In other words, you must convert the individual parts from Rhino to .stl format on your own before printing the .stl files.

Cutting Steel Tubes:

Due to the structure's requirements, steel tubes need to be cut with precise measurements, ideally accurate to a tenth of a millimetre (e.g., 100.0 mm). This level of precision is critical for proper assembly and alignment.

Water Tank Construction:

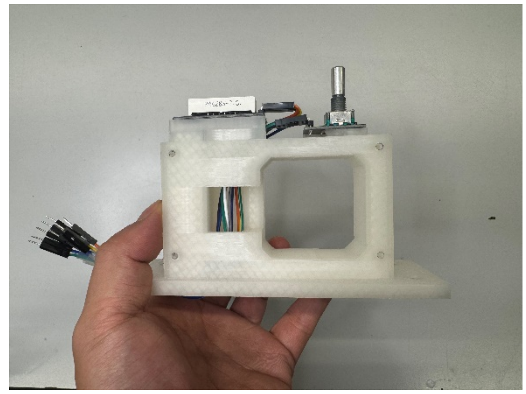
The acrylic boards for the water tank were adhered together using plastic cement or plastic weld. Please consult the manufacturer before attempting to bond the acrylic boards. The tank was then water-sealed using Transparent Hybrid Polymer Sealant Adhesive to ensure it was leak-proof.

Heat Set Threads:

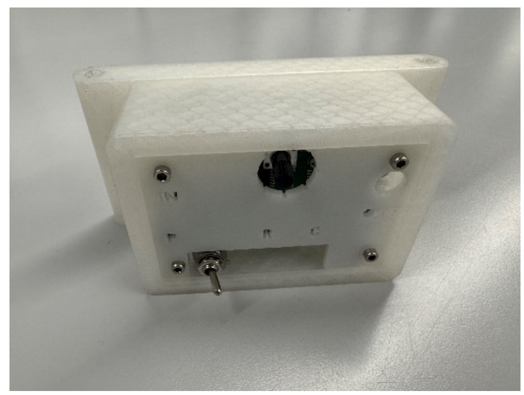
Generally, 4.25mm holes on any 3D-printed parts are left for heat-set thread inserts. There are numerous instructional videos that demonstrate how to properly set these inserts into PLA filament material. At the time of creating this manual, we recommend the following YouTube video: *How to Install Heat Set Inserts into Your 3D Prints* by Markforged, available here: https://youtu.be/P7nHyI1TwKY?si=0Lp692cOSt9yOecr.

Assembly

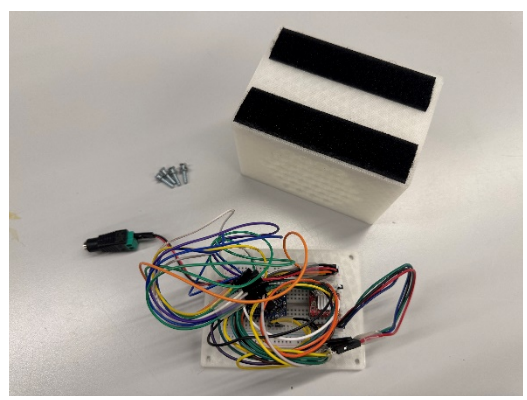
1. This is the winder motor controller. The Arduino components are super glued onto the controller frame. The stepper motor needs to be installed during the assembly of the installation structure. The controller cap can be secured by friction, but glue can also be used to permanently seal the Arduino components in the controller. Before sealing the components make sure to keep track of wire colours.



2. This is the extruder controller. We bought the controller from the manufacturer. For more information please visit: https://www.eazao.com/product/eazao-zero/. The controller frame is also secured by friction. Just slide the controller in without using glue.



3. The Arduino components are attached to the bottom plate of the Arduino box using the built-in breadboard sticker. The box can then be sealed using four M3 screws. Two strips of hook-and-loop tape should be attached so the box can be temporarily secured under the installation. This method of attaching and reattaching allows easy access to the Arduino components, making it easier for people to fix or adjust the Arduino as needed.



4. Arduino Components Assembly and Coding

The Arduino code is provided along with this manual. Please refer to the folder named: Arduino Code. The code controls a stepper motor using a rotary encoder and an A4988 stepper motor driver. It allows you to adjust the motor's speed smoothly through ramping, with the delay value controlling the speed of the motor. The range of the motor's delay values is from 20 to 5000 microseconds, which corresponds to the fastest to slowest speeds, respectively.

Physical Components Needed:

a. Arduino: The microcontroller to run the code.
b. A4988 Stepper Motor Driver: A motor driver to control the stepper motor.
c. Nema Stepper Motor 42x38mm: This will be controlled by the driver and the Arduino, allowing for precise movement.
d. KY-040 Rotary Encoder: To adjust the speed of the motor by rotating it.
e. TM1637 4-Digit Display: A simple 7-segment display to show the current speed setting.
f. Push Button (built into the rotary encoder): This button is used to start and stop the motor.
g. Power Supply: AC to DC 12V 3A.

Pin Configuration:

a. Rotary Encoder:
   clkPin (5): Connected to the CLK pin of the encoder.
   dtPin (6): Connected to the DT pin of the encoder.
   swPin (7): Connected to the SW (button) pin of the encoder.

b. Stepper Motor:
   stepPin (3): Controls the stepping signal to the A4988 driver.
   dirPin (4): Controls the direction of the motor's rotation.
   sleepPin (10): Controls the sleep mode of the motor driver, putting it into low-power mode when the motor is off.

c. TM1637 Display:
   displayClkPin (8): Connected to the CLK pin of the TM1637.
   displayDioPin (9): Connected to the DIO pin of the TM1637.

How to Use the Motor Driver (A4988):

a. A4988 Pin Connections:
   VDD and GND: Connect to the 5V and ground pins of the Arduino for logic power.
   VMOT and GND: Connect to the external power supply that will drive the stepper motor.
   STEP Pin: This pin receives pulses from the Arduino to control the movement of the motor. Each pulse corresponds to one step.
   DIR Pin: This pin controls the direction of the motor (clockwise or counterclockwise).

SLEEP Pin: The sleep pin can be connected to the Arduino to put the driver into low-power mode when the motor is not running, which reduces heat and power consumption. RESET Pin: This can be connected to the sleep pin so that when the driver goes to sleep, it also resets itself.

b. A4988 Microstepping:
   To configure the A4988 driver for microstepping, you will need to set the MS1, MS2, and MS3 pins correctly. By default, the driver operates in full-step mode. For more precision, you can enable microstepping by connecting the MS1, MS2, and MS3 pins to the desired logic level: 1/2 step, 1/4 step, 1/8 step, etc. This installation uses full-step mode.

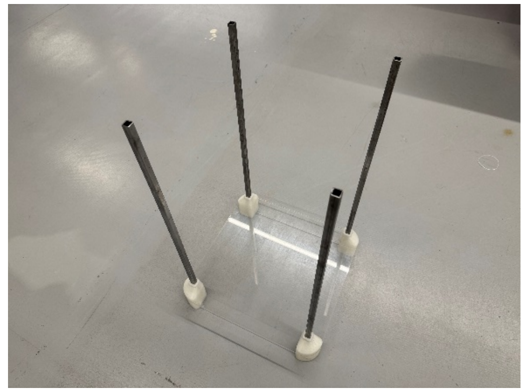
Code Logic:

In the main loop, the rotary encoder's input is read to detect any changes in its position. The clkPin and dtPin signals determine the direction of rotation, which in turn adjusts the motor's speed. When the encoder is turned clockwise, the delay value decreases, increasing the motor's speed. When the encoder is turned counterclockwise, the delay value increases, slowing down the motor. The code sets the delay value based on the encoder's position, with changes in increments of 5 microseconds for delay values between 20 and 100 and increments of 10 microseconds for values above 100. The delay value is capped between 20 and 5000 microseconds to ensure the motor operates within a safe speed range.

The motor speed transitions smoothly due to the ramping logic. Rather than instantly jumping to the new speed when the delay value changes, the motor gradually adjusts to the new target delay value. The actual delay value is incremented or decremented by 1 microsecond at a time until it reaches the target, allowing for smooth acceleration and deceleration. This helps prevent mechanical stress on the motor and reduces noise. While the speed is being adjusted, the TM1637 display continuously shows the current target delay value, giving the user real-time feedback on the motor's speed setting.

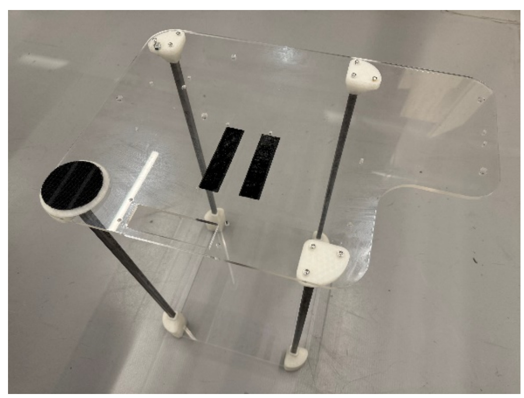
The push button integrated with the rotary encoder controls whether the motor is running or not. Each time the button is pressed, the motor's state is toggled between on and off. When the motor is off, the A4988 driver is placed in sleep mode, reducing power consumption and preventing the motor from heating up unnecessarily. When the motor is turned on, the driver is awakened from sleep mode, and the motor starts moving based on the current delay value. If the motor is running and the delay value is valid (above 20 microseconds), step pulses are generated. Each pulse moves the motor by one step, and the delay between pulses determines the motor's speed. The ramping ensures that even when the speed is changed, the motor transitions smoothly to the new speed.

5. Several 3D-printed components are glued to the base acrylic board using standard UHU glue. After the glue has set, simply slide the four metal square rods into the designated slots. The height of these rods can be cut and adjusted depending on the desired height of the installation.

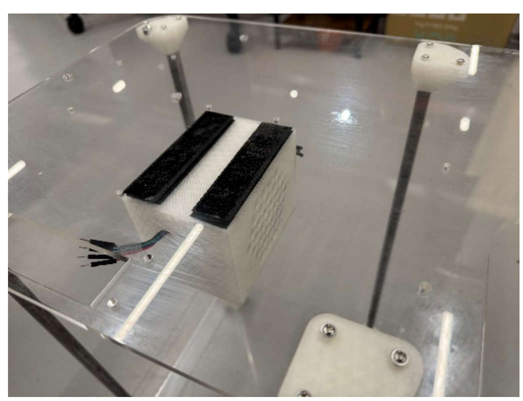


6. Notice that one of the 3D-printed stands for the upper main plate has a slot for a set of M6 nuts and washers. These can be secured by friction. Unlike the printed parts for the base plate, these parts are secured onto the main plate using M3 screws and washers.

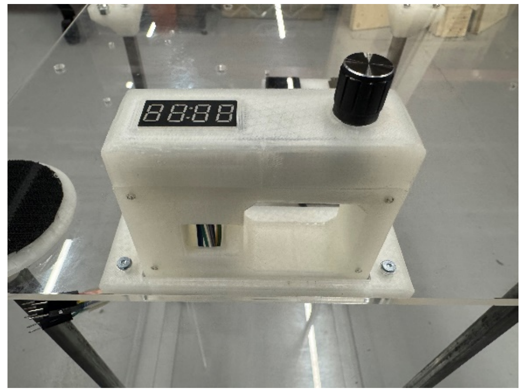
7. The main acrylic plate is then slotted in onto four of the square steel rods.



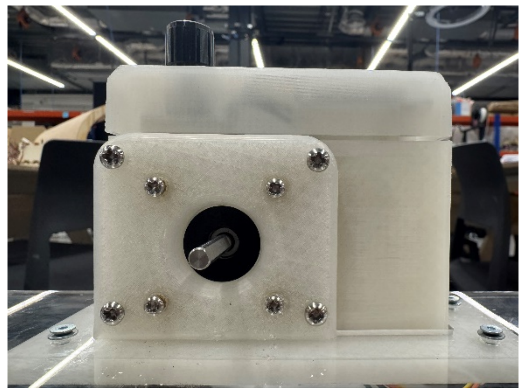
8. Secure the Arduino box underneath the main acrylic plate.



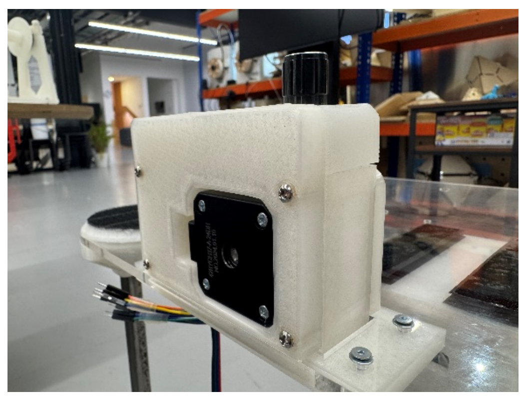
9. Secure the motor controller with M3 screws. Note, do not install the motor before completing this step.



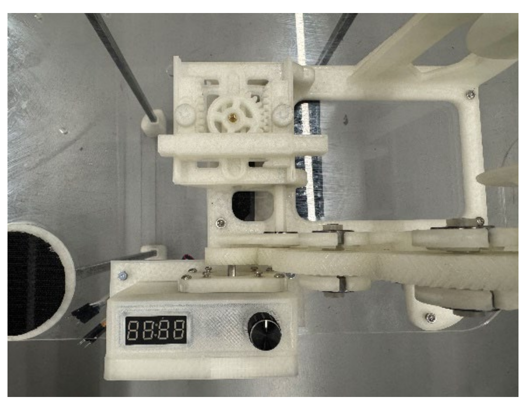
10. Now, install the motor. Secure it along with the small attachment plate with 8 screws. 4 x M3 inner ring and 4 x M4 outer ring. These screws should ideally be around 10-11 mm in length.



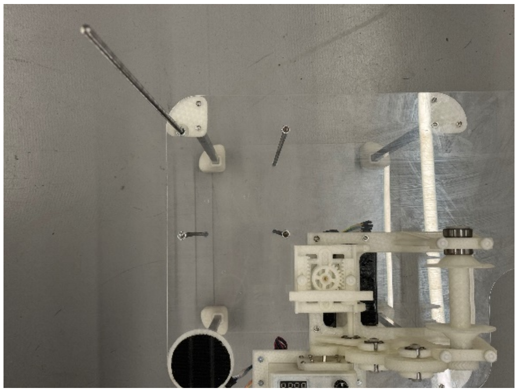
11. Install the large attachment plate with 4 x M3 screws. Before installing, check all the wires are properly secured. This can be accomplished with soft silicone tape. Make sure the tape is non-conductive. The wires should all run through the bottom hole of the controller. The motor controller is now complete; it should be sitting flush against the edge of the table.



12. Install the gear onto the moto without glue; it should be a tight enough fit that ensures the gear does not slide around the motor shaft during operation. Note, the arrows on the gear of the motor should be pointing towards the left-hand side. After that, install the winder with 5 x M3 screws. Apply some silicone grease to the gears and power on the winder for several minutes.

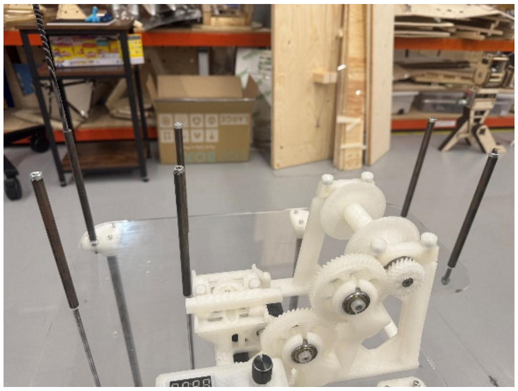


13. Install the 4 x M6 540mm threaded rods with M6 nuts and washers. These M6 rods are positioned around the top-left hand side. For individuals working on this project, installing M6 nuts on both ends could help stabilize the structure.

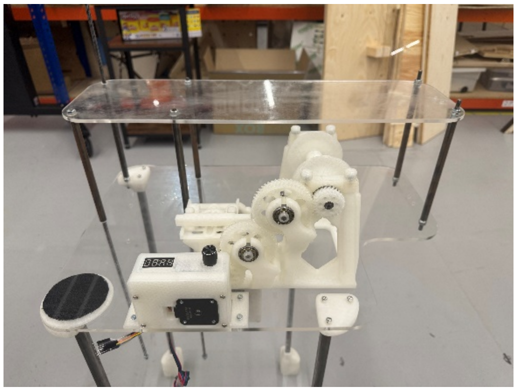


14. Similarly, install the 2 x M6 240mm threaded rods with M6 nuts and washers around the right-hand side of the main acrylic board.

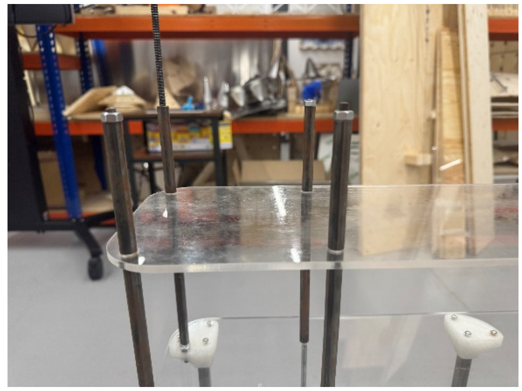
15. Install the 6 x 163mm steel tubes; unscrewing each M6 nuts as you install. Once installed, screw the M6 nuts back onto the top of the threaded rods.



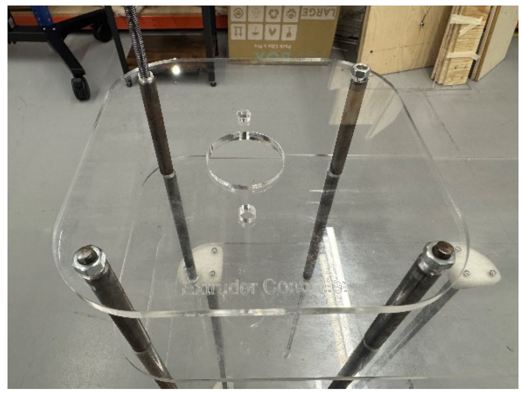
16. Install the next layer of acrylic sheet. After that, the 2 x M6 threaded rods on the right should be securely tightened.



17. Install the 4 x 78mm steel tubes using similar techniques.

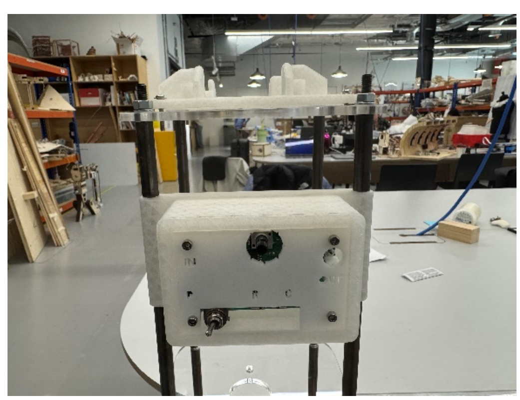


18. Install the extruder controller acrylic plate. The engravings help with finding the correct orientation of the plate.

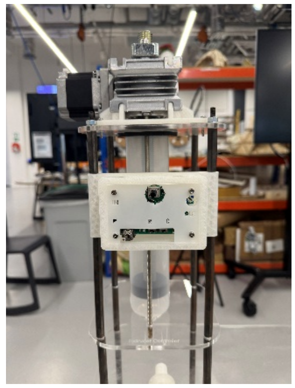


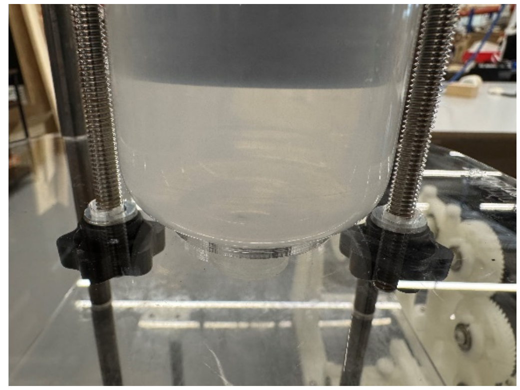
19. Install the 2 x 240mm steel tubes at the back and 2 x 125mm steel tubes at the front.

20. Install the extruder controller and the 2 x 45mm steel tubes. After that, install the extruder motor acrylic plate. Next, install the 3D printed extruder stand on to the acrylic plate. Tighten all the nuts when you are done.

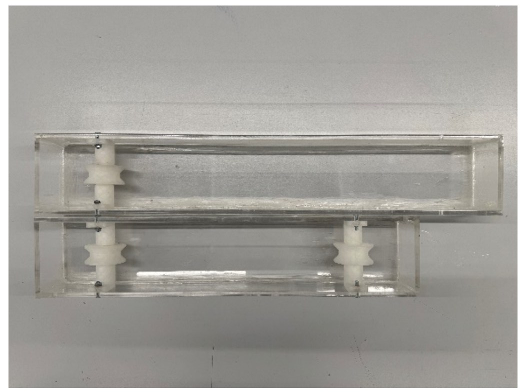


21. Carefully place the extruder onto the extruder stand. The motor should be pointing towards the left-hand side of the installation. Screw the plastic nuts and washers onto the 6mm threads that comes with the extruder.



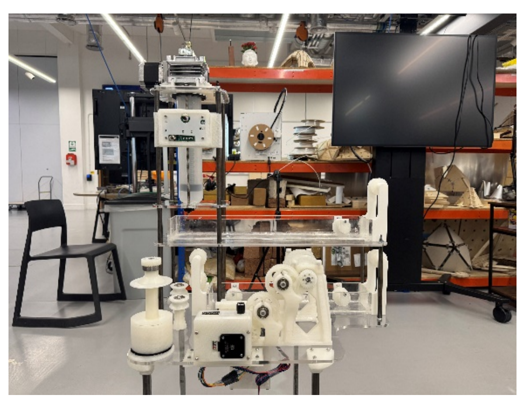


22. Make the water tanks and screw the yarn-guiding wheels on using M3 screws. For detailed water tank construction, please read the Fabrication section of the manual.



23. Install the rest of the yarn-guiding system using M3 screws. This can be done by hand; make sure the screws are not too tight.

24. Place the water tanks as well as the extra spindle display stand in place.



Operation

1. Fill both water tanks with calcium chloride solution.

2. Fill the extruder with sodium alginate hydrogel.

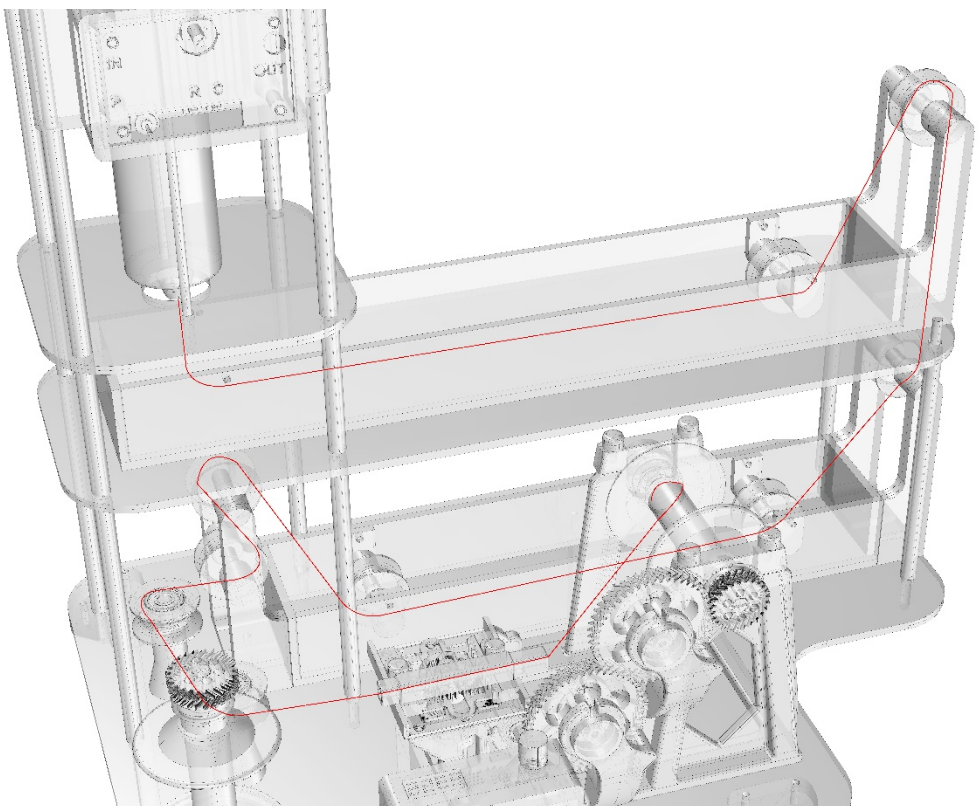
3. Connect all power supplies and power on both the extruder and the winder.

4. Slowly adjust speed of the extruder using the extruder controller until the hydrogel is being smoothly produced at a consistent rate.

5. Manually guide the bio-yarn through the system referring to the image below.

6. Feed the bio-yarn through the winder and tie it up onto the spool of the winder.

7. Adjust the speed of the winder so that it is in sync with the extrusion speed.



Cautions

1. Extruder Clogging: Stop the extrusion as soon as clogging happens. The extruder motor will put a lot of pressure on the acrylic plates if the clog isn't fixed immediately.

2. Water Spilling: Make sure that the entire structure is wiped relatively dry during operation. Be careful that water might damage the electronic parts of the installation.

3. Structure Integrity: Do not put any additional weight on the installation.

4. Mold Prevention: Clean the installation after use. The bio-yarn should be used right after collection. The spindle on the winder is design only for collecting, not store and preserve bio-yarn.

5. Rust Removal: The metal components will develop rust overtime. There are plenty of rust treatment guides on YouTube. The author of the manual recommends a product called: Evapo-Rust by CRC Industries. It is roughly 20£ on amazon.co.uk.

Conclusion

The bio-yarn extruder project represents one step forward in exploring sustainable materials and fabrication techniques. By integrating mechanical and digital systems, this project demonstrates the potential for scalable bio-yarn production through automated extrusion processes.

Throughout this manual, we have detailed the design and construction of the extruder, highlighting the critical components and methods necessary for its successful assembly and operation. From the custom 3D-printed parts to the integration of Arduino-based electronics, the extruder is a blend of precision engineering and adaptable design. The inclusion of open-source elements, such as the yarn winder, reflects both the project's collaborative nature and the practical constraints we faced in terms of time and resources.

We hope this manual serves not only as a comprehensive guide for replicating the bio-yarn extruder but also as a foundation for further innovation. Future students and practitioners interested in fabrication and biomaterials are encouraged to use, share, and adapt this work to explore new possibilities in sustainable production. The open-ended nature of the project allows for continued refinement, and we are excited to see how it may evolve in different hands.

As with any project, there are areas for improvement. In the future, there may be opportunities to optimize the winder design or explore more advanced extrusion methods to increase efficiency and precision. Nevertheless, this project offers a solid starting point for anyone looking to delve into the field of bio-materials fabrication.

With that said, here are some additional YouTube videos for your reference:

1. DIY Yarn ball Winder Machine | Arduino project by Mr Innovative
   Available at: https://youtu.be/nJKxa9mhLuI?si=YydlJApDZmAPgiIK

2. DIY Winding Machine with self-reversing screw by Mr Innovative
   Available at: https://youtu.be/sxsctBXCuGk?si=PFHRhhYYBGHnZUp-

3. Electric Yarn Ball Winder from Simplicity by Simplicity Video
   Available at: https://youtu.be/eQOrZ-vCah8?si=Q4HacQtUP0RZxYOh

4. Homemade Electric Skein Winder with Counter by Vampy X
   Available at: https://youtu.be/Xrsg-PmbdXc?si=OO9VGyNVaR0PASRr

5. Wet-Spinning Platform by Guillem Perutxet Olesti
   Available at: https://youtu.be/O_13pse-HwA?si=XQBmG-klWJs9ongh

6. Wet Spinning at Fashion Institute of Technology by Salvatore Giardina
   Available at: https://youtu.be/IQ96-hnoca8?si=jxjPHtsnXsWtFsSk

7. From Wood Cellulose to Textile Fibres by Tampere University of Technology
   Available at: https://youtu.be/GQM0DJ2t9E0?si=mrf8XnKh6Gbh5c7t

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