Exploring a Software Tool for Biofibers Design

Xin Wen
ATLAS Institute
University of Colorado Boulder, USA
xin.wen@colorado.edu

Eldy S. Lazaro Vasquez
ATLAS Institute
University of Colorado Boulder, USA
eldylazaro@colorado.edu

Michael L. Rivera
ATLAS Institute & Computer Science
University of Colorado Boulder, USA
mrivera@colorado.edu

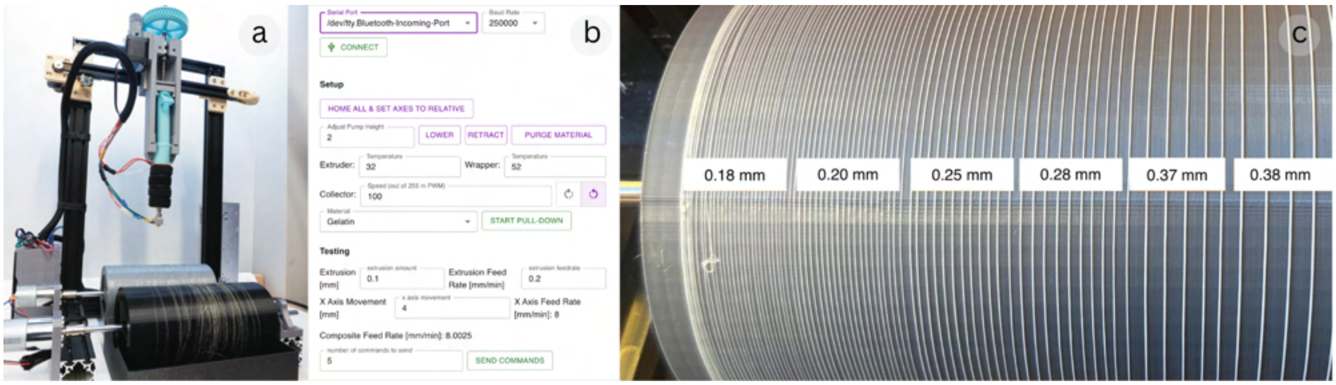

Figure 1: (a) Biofibers Spinning Machine; (b) our interface that abstracts low-level machine control; (c) spun biofibers of varying diameter via machine parameters.

ABSTRACT

The Biofibers Spinning Machine produces bio-based fibers (biofibers) that are dissolvable and biodegradable. These fibers enable recycling of smart textiles by making it easy to separate electronics from textiles. Currently, prototyping with the machine requires the use of low-level commands, i.e. G-code. To enable more people to participate in the sustainable smart textiles design space and develop new biofiber materials, we need to provide accessible tools and workflows. This work explores a software tool that facilitates material exploration with machine parameters. We describe the interface design and demonstrate using the tool to quantify the relationship between machine parameters and spun gelatin biofibers.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; • **Applied computing** → **Computer-aided manufacturing**.

KEYWORDS

sustainable smart textiles, exploratory digital fabrication

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1 INTRODUCTION

We encounter textiles in all aspects of our lives, from the clothes we wear everyday to houses we live in. Due to their prevalence and useful properties (e.g., flexibility), various industries, including fashion [1], soft robotics [11], and healthcare [6], have explored integrating electronics to create smart textiles for different functional applications. Both textiles and electronics create significant waste. In 2018 alone, 11.3 million tons of textiles were landfilled in the United States, and only 15% of textiles were recycled [21]. Similarly 62 billion kg of e-waste was generated globally in 2022 and only 22.3% was recycled properly [7]. Given these environmental impacts, there's a need for more sustainable materials, manufacturing processes, and end-of-life strategies for smart textiles [9].

In prior work, we developed the open-source Biofibers Spinning Machine [13] to enable the creation of dissolvable bio-based fibers that support the recycling of smart textiles. Currently, the machine is controlled with low-level commands, i.e. G-code. To enable more people to participate in the sustainable smart textiles design space and to develop new bio-based materials, we need to provide more accessible tools and workflows for the machine. To this end, this work explores the design and use of a software tool to facilitate exploring how machine parameters influence spun biofibers.

2 RELATED WORK

The HCI and Computer Graphics communities have been interested in textile structures given their pervasiveness and flexibility. Researchers have explored integrating sensors and other electronics into textiles via weaving [10, 16], knitting [14, 22], and embroidery

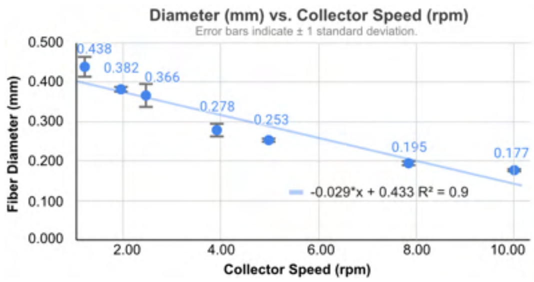

Figure 2: Relationship of fiber diameter to collector speed.

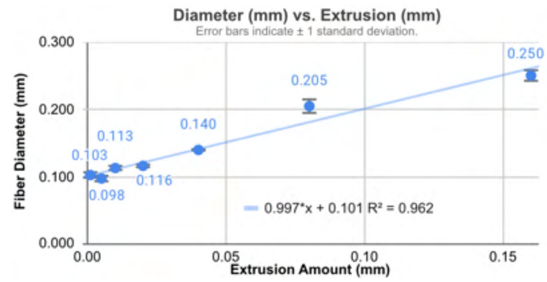

Figure 3: Relationship of fiber diameter to extrusion amount.

[5, 12]. In terms of design tools for supporting textile fabrication, past works have focused on parametric design and simulation for complex textile structures, including combining abstractions for electronics and weaving [10], weaving multi-layered structures [23], and supporting knit colorwork [20]. These tools allow users to parametrically design high-level textile structures. In contrast, our work focuses on designing at the basic unit of all textiles—fibers.

Since no existing tools exist for fiber design, we examined other digital fabrication tools for reference, in particular those that use computational abstraction of fabrication toolpaths. HCI researchers have proposed toolpath planning systems that prioritize material exploration and prototyping through creative programming [8, 15, 17] as well as to support learning and sharing customized fabrication workflows [18, 19]. Working directly with machine toolpaths and parameters can help users better understand how machine parameters influence fabricated outputs. Building on prior works, we designed our software tool to enable more people to explore bio-based materials and tuning their properties when spun as fibers.

3 IMPLEMENTATION

Our software tool (Figure 1b) has two main components, Setup and Testing, designed around the fiber spinning workflow (see section 3.2 of the Desktop Biofibers Spinning paper [13]). The app is implemented in javascript using Electron [2] and SerialPort [3] for serial communication between the interface and the machine.

In the setup process, a user sets the nozzle temperature, syringe heater wrap temperature, and the collector speed. The user then conducts a pull-down process where they manually pull material from the tip of the nozzle onto the spinning collector. Typically a user must perform several attempts before they can successfully stretch a continuous strand of material from the nozzle to the collector. This process is challenging as the user has to simultaneously enter G-code commands. Our tool abstracts this process to a simple pick-and-click. The user picks the material from a drop-down menu, and then clicks the "Start Spinning" button. The interface then successively sends a series of move commands (e.g., `G1 E0.1 F0.2`) to continuously extrude a small amount of materials until the pull-down is completed and the user clicks "Stop Spinning".

Once setup is done, the user can test spinning fibers. In the Testing component, the user can set the extrusion amount, extrusion feed rate, and X-axis movement distance (X). The X movement feed rate (F_x) and the composite feed rate are calculated based on the ratio of X-to-E, and the extrusion feed rate. The user can also specify the number of commands to send with their parameters to adjust how much fiber is made. After clicking "Send command", the tool processes the movement (G1) commands. This portion of the interface supports the user in finding optimal parameters for different materials and exploring how they impact fiber properties.

4 EXPERIMENTS

We used our tool to conduct a series of experiments with pure gelatin biofibers to characterize the relationship between machine parameters and the fiber properties, namely length and diameter. The parameters tested were X-axis movement in mm, extrusion amount in mm, the X-axis feed rate, and the collector speed (S) out of 255 and proportional to collector motor's max RPM.

The length of fiber produced by each G1 command is determined by the collector speed S, the X distance traveled and X movement feed rate F_x. We model the fiber length in millimeters, L, as a helix [4] with a rise per revolution, H, for N revolutions, based on a roller of circumference, C:

$$L = \sqrt{C^2 + H^2} * N, \text{ where}$$
$$C = \pi * 100 \text{ mm}; H = X/N; N = S/255 * 10 \text{ RPM} * (X/F_x)$$

We conducted length tests with the same G1 command at four collector speeds (100, 150, 200, 250). We cut off full revolutions of fibers produced and compared measured fiber length with calculated length using Eq. 1. The average error in length of the samples was -0.32%. For the diameter tests, we produced a full revolution of fibers at each variation of the collector speed (Figure 2) and extrusion amount (Figure 3). We then measured the diameter at five positions along each fiber's length and calculated the average and standard deviation. Similar tests could be run with other biofiber material candidates. With these results, we can add functionality to our tool for users to specify high-level design attributes (e.g., fiber length) and enable parametric design of biofibers.

5 CONCLUSION AND FUTURE WORK

We present a basic software tool to support exploring biofiber spinning with different machine parameters. We used the tool to examine the relationship between machine parameters and the properties of gelatin biofibers. From these results, we can implement high-level design parameters (e.g., fiber diameter) for users to control. Such parametric design can unlock new smart textile applications such as varying fiber diameter to encode data into fibers or changing a fiber's electrical resistance. This tool is the first step in enabling more people to develop biofiber materials and applications for sustainable smart textiles design.

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