Loom-Based Mechanized Crochet

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Abstract

Textiles are increasingly recognized in architecture and robotics for their adaptability to diverse shapes, low environmental impact, and lightweight character. While flatbed knitting has enabled the production of complex 3D composites and formwork, the low internal strength and geometric limits of knitted fabrics restrict their structural potential. Crochet, by contrast, offers higher tensile strength, greater three-dimensional extensibility, and the ability to generate arbitrary topological surfaces through its variable stitch geometry. However, the craft has yet to be mechanized due to its complexity and dense stitch structure. This project introduces a new framework for robotic crochet, which translates the handicraft into a loom-based fabrication process. A robotic arm equipped with a latch-needle end effector builds stitches from any point in a constrained fabric matrix, supported by a passive yarn tensioning system. This approach enables the reliable automation of crochet for producing intricate three-dimensional morphologies in architectural composites, soft robotics, and biomedical applications.

1 Introduction

Historically, textiles were often overlooked in architecture and engineering due to their low structural integrity, tendency to deform or act nondeterministically, and poorly understood mechanical properties. To this day, the industrial production of textiles is often limited to commercial production of clothing or consumer textiles. However, recent work in architecture, robotics, medicine, and a variety of other fields has begun to expand the usage of textiles. This work has revealed a need for more complex computational and mechanical tools to create and evaluate complex fabric forms. This is particularly evident in the adoption of flatbed knitting machines for the production of complex architectural composites [14] [13][8][21][1] and the creation of three-dimensional knit textiles as standalone structures [7], plush infill [10], and wearable electronics [3]. In each of these cases, knit fabric was utilized for its ability to take a variety of forms and adapt to user needs, as well as its low weight and environmental impact. However, limitations still exist in the extensibility and strength of knit fabrics due to their relatively low tensile strength [19], and limited ability to create complex three-dimensional shapes, particularly at small scales when stitches are limited.

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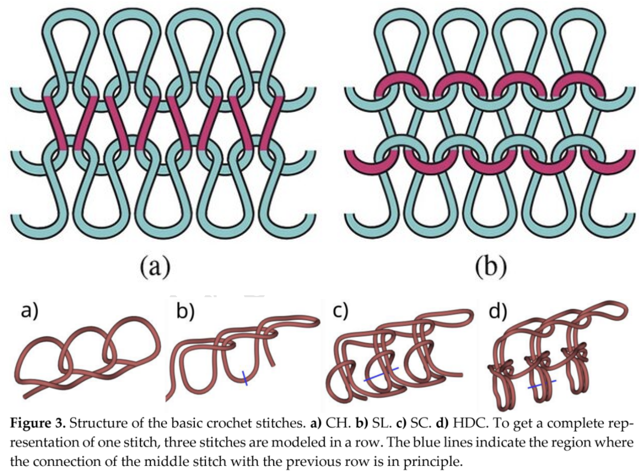


Figure 1: Comparison of knit and crochet stitches, via Wadekar 2020 & Storck 2024

Crochet is a stitch forming technology that departs from knitting in its mode of fabrication and its inherent complexity. In both the handicraft and its mechanized form in knitting machines, a single thread is pulled through an entire row essentially in parallel (Figure 1). This relatively simple geometry has allowed knitting to be mechanized for centuries and achieve high speed and reliability for industrial fabric production [6][2]. Crochet, in contrast, uses a single hook to build fabric out of a series of complex knots. Each stitch is interlooped with the previous stitch, a base stitch in a previous row, and the following stitch. This makes crochet much more complicated to automate, due to the multitude of possible stitches and the complicated motions required to build from variable points in a fabric. However, the craft's complexity also makes crochet fabrics far more extensible for three-dimensional forms, and increases the strength of crocheted fabric [19]. Moreover, because of crochet's variable stitch types and variability in build location, crochet can replicate any topological surface [15][18]. Due to these features, crocheted fabric has been explored as an alternative to knit fabrics or cables in artificial robotic joints[24][23], for the production of large scale furniture[9] and three-dimensional shells [11][20], as polyester composites [5][22], and as soft grippers for robotic arms[4].

Despite this promise, crochet has yet to be fully automated, and current applications of crochet for robotics rely on handcrafted pieces with high variability and low opportunity for mass production. Textile fabrication across industry still relies almost exclusively on industrial knitting machines. The challenges facing crochet's mechanization are threefold - the stitches are complex, the fabric created is dense, and traditional crochet hooks are unreliable when mechanized. Such challenges make crochet difficult to translate directly from a handicraft to robotic motion, as seen in the several existing attempts to mechanize the craft.

The Croche-Matic and the CroMat are the two most successful physicalized crochet machines to date. The Croche-Matic, from the Harvard Graduate School of Design, was able to create chain stitches, single crochet stitches, increases, and decreases in the round, and could thus produce cylindrical fabric [12]. However, the machine's mechanism to hold the fabric, and its use of a traditional style crochet hook, made its stitch creation highly unreliable due to failures gripping the thread and inserting the hook into the correct part of the fabric. Building on Perry's advancements, the CroMat from the University of Dresden utilized a line of latch needles to hold the most recent crochet row stationary, and pulled a custom crochet needle through the latch needles to form stitches [17]. This machine is capable of robustly creating a high variety of stitches (chains, slip stitches, single crochets, half double crochets, turn stitches, increases, and decreases), though the authors continued to struggle with accurate hook insertion into the dense fabric. Moreover, the flatbed knitting style of the machine means stitches can only be built out of the most recent row, requiring manual repositioning to crochet complex shapes.

Our approach to automated crochet relies on translating crochet from a freeform handicraft to a constrained, loom-based process. Using a loom to hold all existing stitches in place, a custom Universal Robotics (UR) end effector will move a latch needle through existing fabric to pick up thread and create new stitches. This framework will allow for accurate hook placement by constraining previous stitches, and it will permit new stitches to be built out of any part of the existing fabric by keeping track of all previously made stitches at any given time. These advancements will allow for the robust automatic translation of diverse 3D morphologies into fabric for the first time.

2 System Description

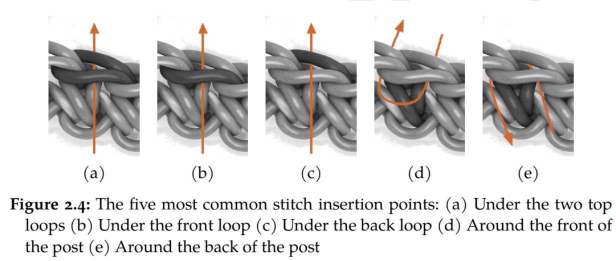


Figure 2: Entry points for crochet stitch creation, via Seitz 2021

The core of our design is the translation of crochet from a free-hand craft into a loom-based craft. Though crochet stitches can be built out of many different parts of a previous stitch [16], the most common insertion point is point (a) in Figure 2, under the two top loops. In our initial prototype, we are building a loom which holds crochet fabric on pegs through this insertion point. This permits the latch needle to move through the correct point in the fabric without requiring the highly precise motion encoded in the CroMat, and removes the need for holding the fabric correctly in free space encountered by the Croche-Matic. At the point of writing, we completed the manual testing and geometric analysis of loom crochet. We are currently prototyping the loom assembly and the passive tensioner, with toolpath testing underway in Grasshopper.

2.1 Manual Testing

We established the preliminary toolpaths and mechanical design through a study in manual loom crocheting using a rainbow loom (a product often used for rubber band based bracelet creation) to hold stitches in place (Figure 3). The rainbow loom's open pegboard design allows the crochet hook to move through the loom to pick up thread from below the matrix before pulling it through the existing stitches. We then translated our hand motions into robotic toolpaths. Our toolpaths support stitch creation through the combination of a needle held by a robotic arm moving in three dimensions, and a yarn shuttle on a two-dimensional CNC axis below the static loom (Figure 4).

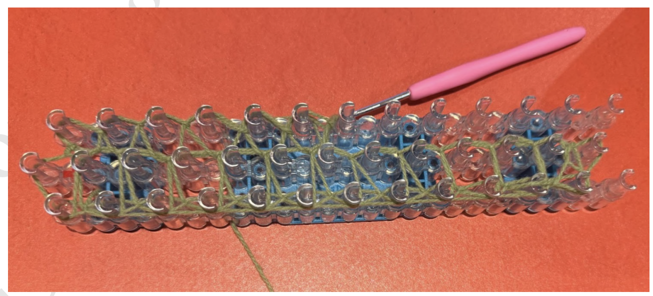


Figure 3: Manual loom crochet

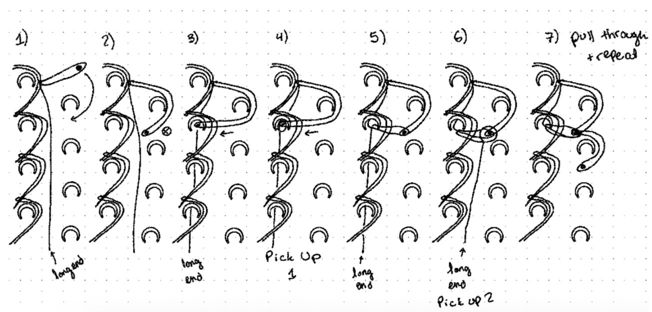
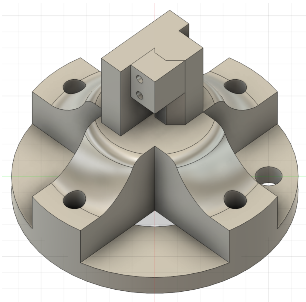


Figure 4: Toolpath developed from manual study

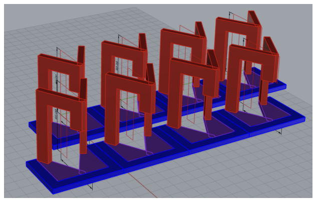
2.2 Machine Components

The machine is composed of three core components - a UR3 end effector holding a latch hook, a custom loom which holds stitches in place and allows the hook to move through stitch openings, and a lower yarn pickup assembly with passive tension control.

The end effector holds a latch needle steady as the UR3 moves through its toolpath (Figure 5). Collision objects are encoded using Rhino and Grasshopper to help the hook avoid collision with the



(a) End Effector model in Fusion 360



(b) Loom model in Rhinoceros 7

Figure 5: End effector and Loom models

loom and meet the string held below the loom. Toolpaths and trajectories are created using Grasshopper's COMPAS Fab extension and the ROS framework.

The loom consists of linearly adjacent pegs with teeth that will hold loops steady while the fabric is being built. The pegs are hollow and hooked, allowing the latch needle to move through the loom and hooking any wrapped stitches in place (Figure 5). This loom design is heavily inspired by the loom design of Hirose 2024's solid knitting machine, which permitted similar stitch creation motions through two synchronized, rounded looms.

The final component, the string pickup, holds yarn steady and uses a belt drive to position the yarn beneath the end effector, allowing the latch needle to pick up new yarn and pull it through existing stitches (Figure 6). To keep the string taut beneath the needle for easy pickup, the gantry plate will employ two spring-based passive tensioners. The use of spring-based tensioners, commonly used in mechanical knitting machines to feed yarn into the machine at a constant rate, will allow adjustments for different materials and gauges.

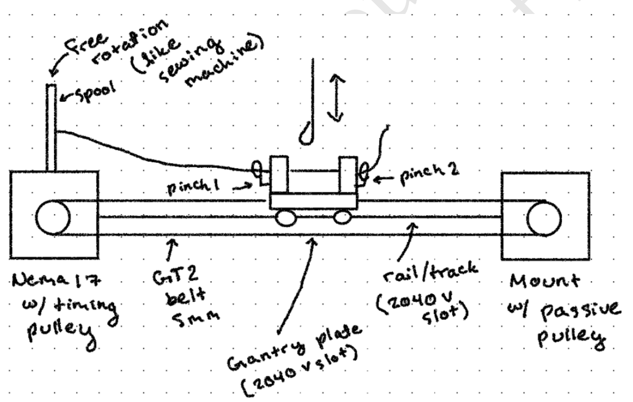


Figure 6: Yarn pickup sketch

The full assembly will enable us to translate the manual motion of loom crochet into a robotic toolpath, using synchronization of the several parts to reduce the necessary toolpath complexity and increase system robustness (Figure 7). Crucially, the loom keeps track of every previously made stitch and holds those stitches open to the end effector, and the yarn pickup and end effectors can easily move over any point in the matrix. This makes it possible to build a stitch out of any previously made stitch in the fabric, rather than just the most recent row or stitch, by picking up thread at one point in the existing fabric, and then anchoring the newly created stitch to any other point in the existing fabric. Thus, this framework enables unique advancements in the potential fabric shapes created through mechanized crochet.

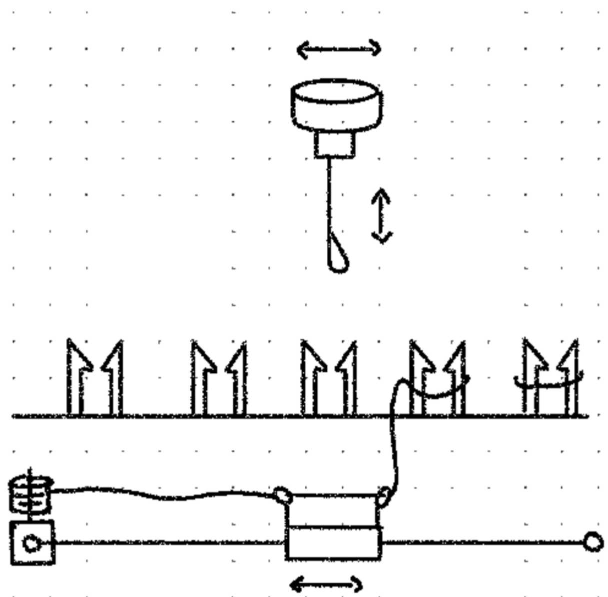


Figure 7: Full assembly sketch

3 Conclusion

This system reframes crochet as a constrained robotic process rather than a freehand one, allowing computational control of stitch creation. This will permit the mechanized creation of complex three-dimensional forms for a variety of applications across architecture, robotics, and medicine. We hope to extend the work done by researchers in the robotic crochet space by providing a framework to decrease the frequency of failed hook insertions caused by the density of stitches in crochet. Moreover, we hope to provide the first framework for truly extensible crochet by allowing stitches to be built out of any existing stitch within a fabric rather than just a previous row or round. As we move through the prototyping stage, we invite dialogue with the large community of architects and designers who are currently pushing the envelope with applications of complex three-dimensional fabrics. The SCF community includes many researchers (referenced above) who have worked with volumetric knit fabrics to create composites, end effectors, sensors, and much more. We hope to use this opportunity to develop robust methods of evaluation to help make crochet a viable option for complex fabric applications in research and industry, and to develop partnerships across the computational design space that will result in novel, far-reaching applications of mechanized crochet.

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