A New Approach for Volumetric Knitting

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ABSTRACT

Unlike 3D printers, which offer the ability to fabricate nearly arbitrary geometric forms, most textile fabrication processes are limited to the creation of sheets or hollow surface-based forms. This poster presents a new machine architecture to directly produce volumetric (solid 3D) knitted forms using a 2D bed of knitting needles, rather than the 1D line of needles used in conventional knitting. We describe a small prototype with 4x4 needles, and demonstrate that it can create fully volumetric knits, including overhangs.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**.

KEYWORDS

Knitting machines, additive manufacturing, 3D printing

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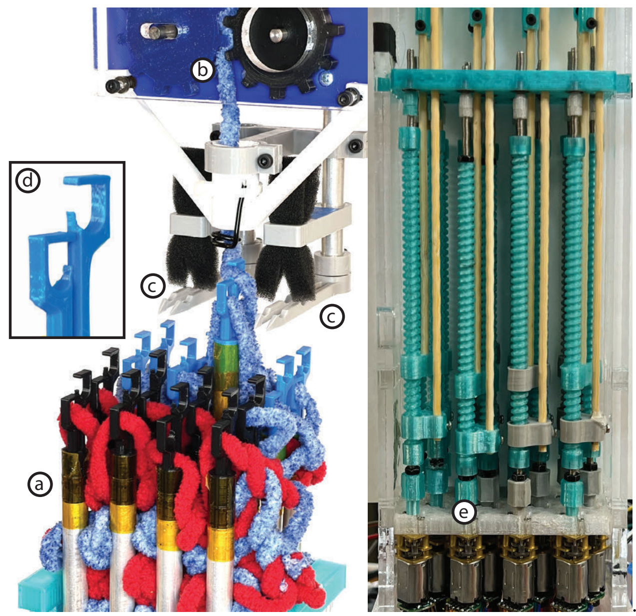

Figure 1: Our prototype in the process of assembling a 3D form. Our proof of concept implementation includes a 4x4 bed of needles (a), a yarn feeder (b) and two loop transfer tools (c). Each needle includes two hooks (d), that are independently actuated using 3D printed lead screws (e). As the fabrication proceeds, the form is pushed downward.

1 INTRODUCTION

While most knitting machines have been optimized to create surface-based forms [6, 8, 9, 11], in this poster, we consider a new approach to machine knitting which is volumetric. Knitting is performed at the top of the 2D array of needles and the form is pushed downward as the knitting progresses. This approach is related to a recent push to create volumetric textile forms [1, 5, 10, 12–14], and is most closely related to Hirose's solid knitting machine [2–4, 7] which can create prisms. Yet, because we are using a bed of needles, our approach offers more freedom of connection within the volume and allows for a variety of new micro-structures arising from stitch-to-stitch connections to be fabricated. Figure 1 shows a 4x4 prototype used to validate our approach.

2 PRINCIPLE OF OPERATION

As illustrated in Figure 1d, our machine uses a unique new form of double hook *compound* (or *slide*) needle along with a new type of *loop transfer tool* (Figure 1c) and an active yarn feeder (Figure 1b). Performing a basic stitch proceeds as follows: We begin the stitch from a standard configuration with an existing loop held inside the closed front hook (Figure 2a). As a first step, the back hook catches a new segment of yarn from the yarn feeder mechanism moving past it, to form a new loop (Figure 2b), and the stem of the front hook is raised to close the hook. The loop transfer tool is then used to help move the existing loop over the new loop (Figure 2c,d).

The loop transfer tool is used again to tighten the loop by holding the previous loop down (Figure 2e). Finally, to restore the standard configuration, the transfer tool is used to transfer the loop from

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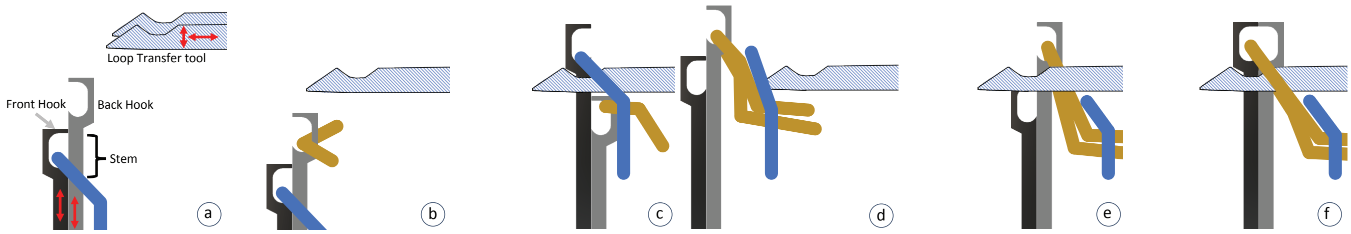

Figure 2: Steps for a simple purl stitch using our approach.

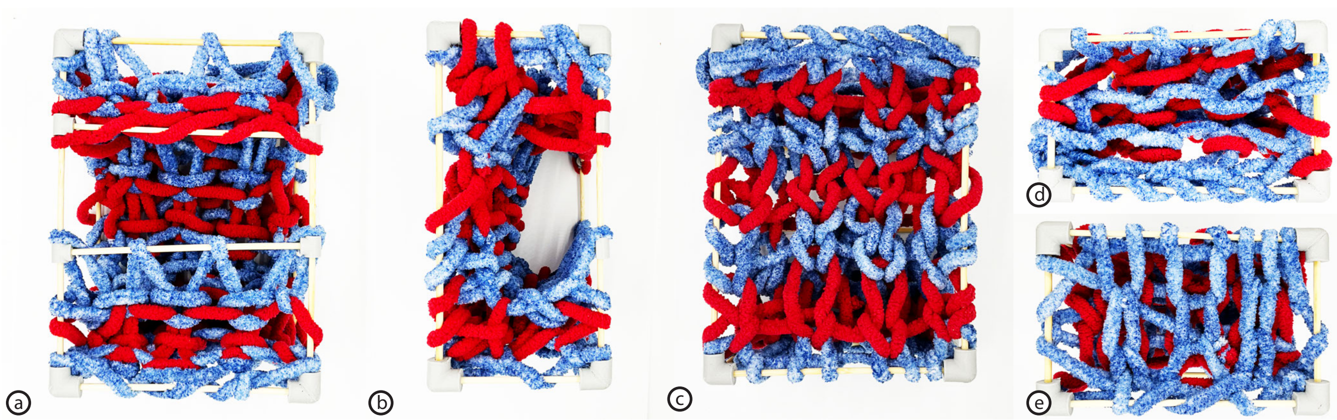

Figure 3: A ⊏ shape form (a = back view, b = side view, c = front view) was created on a 4x4 needle configuration, using alternating colors for each layer. It is displayed on a frame of 7cm(D) x 12cm(W) x 16.5cm(H). Each segment was created by connecting horizontally knitted layers and adding vertical stitches on the back and front. After creating the blue 4x4 base in horizontal knit (e) and continuing with two additional 4x4 layers, we added two 4x2 layers, and finished with two 4x4 layers, casting off at the top (d). Note the evidence of diagonal yarn transfers during horizontal knitting seen in (e).

the back hook to the front hook (Figure 2f). The back hook is then raised to return the needle to the standard configuration (Figure 2a) where the loop is held until the next operation. Our design can also perform cast-on and cast off.

Conventional knitting using a linear row of needles forms a nominally flat fabric below the bed of needles, and in our context can be considered *vertical* knitting. In addition to this type of row over row knitting, in our volumetric knitting approach, we also have the capability to knit *horizontally* across the 2D bed of needles. This horizontal knitting forms a 2D layer, rather than a 1D row. Creating a horizontal stitch is similar to a basic stitch, but the original loop is kept in the same needle and the newly created loop is transferred to a nearby destination needle. Note that for horizontal knitting, stitches can be connected to neighbors in all three directions, not just left or right along a row. This new ability opens up new possibilities for the creation of functional properties, such as anisotropic elasticity (e.g., by making connections front to back but not right to left, or vice versa), and engineered stiffness through selective overstitching and/or creation of patterned voids within a solid.

Figure 3 shows a fully volumetric knit with a ⊏ profile created on our 4x4 configuration. The base of the form was constructed using three horizontal knitted layers connected together, adding vertical knits on the back and front row to form a single volume. We then dropped the loop of the two back rows (blue needles in Figure 1); then knitted the two 4x2 horizontal knitted layers connected together (and to the base), again adding vertical knits, on the back and front rows. Finally, we capped the volume with two more full 4x4 layers before dropping the loops of the three back rows and casting off the loops in the front row.

3 CONCLUSION AND ACKNOWLEDGEMENTS

The new knitting architecture presented in this paper creates volumes rather than only planar or surface-based objects. Our approach adds greater flexibility of possible connections between stitches. As a result, a substantial number of new micro-structures with different micro-level material properties can be created. These, in turn, should facilitate a range of new functional patterns that can be embedded in the resulting solid, but soft, objects.

Our proof-of-concept machine offers the opportunity to explore these interesting possibilities. However, it should be noted that it has many limitations and cannot run unassisted. The small 4x4 bed of our machine is clearly limiting, but it could easily be extended to larger settings. We believe that the current prototype provides initial evidence for the feasibility of this new approach to volumetric knitting and provides a solid basis to explore a new space of applications for knitted objects that has been opened up with our design. This work was supported in part by NSF grant IIS-1422106.

REFERENCES

[1] Xiaogang Chen. 2011. Mathematical modelling of 3D woven fabrics for CAD/CAM software. *Textile Research Journal* 81, 1 (2011), 42–50. https://doi.org/10.1177/0040517510385168 arXiv:https://doi.org/10.1177/0040517510385168

[2] Yuichi Hirose. 2021. *Solid Knitting Machine - Machine Which Makes Physical Objects Updatable.* https://www.youtube.com/watch?v=vWMN-c_F3-o

[3] Yuichi Hirose. 2022. Knitting machine and knitting method. https://patents.google.com/patent/JP7103557B2/en Japanese Patent JP7103557B2.

[4] Yuichi Hirose, Mark Gillespie, Angelica M. Bonilla Fominaya, and James McCann. 2024. Solid Knitting. *ACM Trans. Graph.* 43, 4, Article 88 (jul 2024), 15 pages. https://doi.org/10.1145/3658123

[5] Scott E. Hudson. 2014. Printing teddy bears: a technique for 3D printing of soft interactive objects. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Toronto, Ontario, Canada) *(CHI '14)*. Association for Computing Machinery, New York, NY, USA, 459–468. https://doi.org/10.1145/2556288.2557338

[6] Yuki Igarashi, Takeo Igarashi, and Hiromasa Suzuki. 2008. Knitting a 3D model. In *Computer Graphics Forum*, Vol. 27. Wiley Online Library, 1737–1743.

[7] Junko Kuboki. 2019. *InnoUvators Interview | Reshape and Reprint: the Potential of a 3D Solid Knitting Machine.* INNO-vation Program. https://innouvators.com/en/article/10242/

[8] James McCann, Lea Albaugh, Vidya Narayanan, April Grow, Wojciech Matusik, Jennifer Mankoff, and Jessica Hodgins. 2016. A compiler for 3D machine knitting. *ACM Trans. Graph.* 35, 4, Article 49 (jul 2016), 11 pages. https://doi.org/10.1145/2897824.2925940

[9] Vidya Narayanan, Lea Albaugh, Jessica Hodgins, Stelian Coros, and James Mccann. 2018. Automatic Machine Knitting of 3D Meshes. *ACM Trans. Graph.* 37, 3, Article 35 (aug 2018), 15 pages. https://doi.org/10.1145/3186265

[10] Huaishu Peng, Jennifer Mankoff, Scott E. Hudson, and James McCann. 2015. A Layered Fabric 3D Printer for Soft Interactive Objects. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. Association for Computing Machinery, New York, NY, USA, 1789–1798. https://doi.org/10.1145/2702123.2702327

[11] Mariana Popescu, Matthias Rippmann, Tom Van Mele, and Philippe Block. 2018. Automated generation of knit patterns for non-developable surfaces. In *Humanizing Digital Reality: Design Modelling Symposium Paris 2017.* Springer, 271–284.

[12] Michael L. Rivera and Scott E. Hudson. 2019. Desktop Electrospinning: A Single Extruder 3D Printer for Producing Rigid Plastic and Electrospun Textiles. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland UK) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300434

[13] Rundong Wu, Claire Harvey, Joy Xiaoji Zhang, Sean Kroszner, Brooks Hagan, and Steve Marschner. 2020. Automatic structure synthesis for 3D woven relief. *ACM Trans. Graph.* 39, 4, Article 102 (aug 2020), 10 pages. https://doi.org/10.1145/3386569.3392449

[14] Rundong Wu, Joy Xiaoji Zhang, Jonathan Leaf, Xinru Hua, Ante Qu, Claire Harvey, Emily Holtzman, Joy Ko, Brooks Hagan, Doug James, François Guimbretière, and Steve Marschner. 2020. Weavecraft: an interactive design and simulation tool for 3D weaving. *ACM Trans. Graph.* 39, 6, Article 210 (nov 2020), 16 pages. https://doi.org/10.1145/3414685.3417865