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Purls of Wisdom: Machine Knitting as a Fast Prototyping Tool

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CONTEXT

Fast prototyping provides a cost-effective and time efficient approach for engineering solutions, but textiles are often missing from discussions about rapid prototyping tools and material. This can be attributed to a combination of stigma within the engineering field, and the focus of rapid prototyping being dominated by 3D printers. In this paper, we propose that knitting machines are a suitable rapid prototyping tool. This project shall demonstrate the ability of knitting machines to produce cost-effective prototypes, and engage with students to incentivise the use of these machines for their own projects.

PURPOSE

Knitting can be found in various aspects of engineering, such as specialised clothing like personal protective equipment, structural applications within soft robotics, geo-textiles in civil engineering, and more esoteric uses such as wearable electronics. Yet, it is often overlooked as a rapid prototyping technology, due to being perceived as a quaint hobby. Our paper aims to showcase the applications of machine knitting in engineering and further enhance student involvement with this technology.

APPROACH

First, we explored the limits of our model of knitting machine, the Brother KH910. We then created documentation and prepared inductions for interested parties. To determine the efficacy of knitting machines as a rapid prototyping tool, we knitted proof of concepts, in an attempt to replicate existing projects from various engineering fields.

OUTCOMES

We have prototyped several projects originally completed using industrial grade knitting machines, instead using vintage, low-cost knitting machines. This demonstrated the capabilities of knitting machines as a rapid prototyping tool. We developed training materials and procedures that will allow future students to upskill in knitting and encourage the use of this technology in solving engineering problems. Furthermore, we challenged the current perception of knitting and encouraged students to change their perception of engineering and its associated technologies, in hopes of boosting innovation by teaching non-conventional engineering manufacturing techniques.

CONCLUSIONS

The project aimed to explore the limits of knitting machines for engineering purposes, with the ultimate goal of introducing knitting machines as a valid tool to engineering students. Additionally, documentation and tutorials were created to help students design their future prototypes.

KEYWORDS

Knitting machines. Fast prototyping. Textiles.

1 Introduction

Rapid prototyping provides a cost-effective and time efficient approach for iterating engineering solutions, but textiles are often missing from discussions about rapid prototyping tools and materials. This can be attributed to a combination of stigma, high entry costs of the technology, and the focus of rapid prototyping being dominated by 3D printers. The lack of interest in the prototyping applications of knitting restricts innovation within the engineering field, and various related industries. This is especially concerning because knitting is the second most popular technique for textiles manufacturing (Pandit et al., 2021). The purpose of this project is to demonstrate the ability of knitting machines to produce cost-effective prototypes, and engage with students to both incentivise and enable the use of these machines for their own projects.

Society broadly views knitting as a hobby, failing to see its applications within the engineering field (Kępa, 2019). This perception is not helped by the fact that the main demographic of knitters is older women, which clashes with the stereotypical image one may have of an engineer. Furthermore, the industrialisation of the clothing industry means it is often cheaper, easier, and more time efficient to go to the store and buy clothes instead of manufacturing them at home. These factors have led to the younger generation losing interest in this technique, causing the knowledge and skills to be lost between generations. For these reasons, it is important to change this perception of knitting by educating people about the applications of knitting in engineering before the knowledge is lost.

The broad label of rapid prototyping encompasses many technologies such as: 3D printing, laser cutting, paper prototyping and wireframing. While 3D printing is a popular technology used for rapid prototyping, the end products cannot achieve the same material properties as knitted fabrics. The differing material properties of yarn and the plastics commonly used in filament 3D printing lend themselves to different applications. For example, the advantages of knitting include the ability to manufacture complex-shaped textiles due to yarn possessing a low resistance to deformation (Leong et al., 2000). Additionally, knitted fabrics provide greater strength when in tension, compared to conventionally 3D printed shapes (Chen et al., 2018). These material properties make knitting a valuable technology in a broad range of fields and applications, such as soft robotics and medical devices.

Unfortunately, new computer numerically controlled (CNC) knitting machines cost upwards of US$100k, creating a further barrier to entry for interested parties. This has led the hobbyist knitting community to develop a software/hardware package “All Yarns are Beautiful” (AYAB), which enables 1980’s electronic Brother knitting machines to be controlled from a computer. Our project will utilise this package in combination with a Brother KH910 knitting machine to showcase the capabilities of machine knitting. This lowers the cost of entry to a few hundred dollars.

In light of the above barriers to knitting in engineering, our project has three main aspects:

- Set up the foundation within the Monash Makerspace for future students to utilise knitting machines in their engineering projects.
- Test the capabilities and limitations of our knitting machines by looking at previous research papers and attempting to replicate their results.
- Teach students how to use these knitting machines by showcasing the applications of knitting through inductions and demonstrations.

Beyond this project we hope to increase the interest in this technology and kickstart knitting as a prototyping method at Monash University, thus allowing educators to teach students about this manufacturing method. This paper shall review existing applications and methods for implementing knitting hardware and processes, as well as outcomes of this project.

2 State of the Field

2.1 Engineering Applications of Machine Knitting

There are applications of knitting that span several fields of engineering, from electronics using esoteric yarns to medical fabrics. Furthermore, despite knitting and filament 3D printing both being examples of additive manufacturing (Sanchez et al., 2023), there is virtually no publicly available content on how to achieve said applications using knitting machines, which is in stark contrast to the abundant resources available on 3D printing.

The following sections detail some of the key engineering fields where knitting plays an invaluable role.

2.1.1 Digitisation

Digitisation of knitting machines has expanded into the research space, with interest in machines capable of 3D knitting becoming more prominent. In the paper "Visual Knitting Machine Programming", researchers developed a visual program for creating 3D objects on industrial knitting machines (Narayanan et al., 2019). The program is capable of generating knittable stitch meshes out of 3D models, and scheduling its execution to be knitted, similar to CAD software and 3D printers. Yuichi Hirose is also developing a custom knitting machine capable of knitting 3D solid shapes. He describes knitting as "digital because it is divided by loops", believing that knitted shapes have potential to be more robust than even 3D printed shapes — by unravelling the yarn, knitted objects can be changed and reshaped into different objects, meaning unlike a 3D printed object which is final and static, it is possible to undo any actions you aren't satisfied with during knitting ("Reshape and Reprint: the Potential of a 3D Solid Knitting Machine", 2020).

2.1.2 Electrotextiles

Core-spun yarns are yarns made by spinning traditional yarn over a different fibre, such as carbon fibre or copper, to create a thread with special properties and are often used in electrotextiles (Mogahzy, 2009). Researchers have used such a technique to create a hybrid yarn using carbon nano-springs (Li et al., 2020). This results in a yarn with better mechanical properties than if either material was used on its own, and allows yarn to be used in applications such as active heating and EMF shielding.

Significant time has been invested in the development and use of electrotextiles (Ozgur et al., 2013), with one study investigating the use of knitting in integrated energy storage devices (Jost et al., 2013). Using a Shima Seiki computerised knitting machine, carbon staple fibre yarn was knitted into a fabric which can act as a current collector. This research shows promising applications in wearable electronics, achieving the highest reported capacitance per area for an all-carbon textile-supercapacitor. However, the use of other more conductive carbon nanomaterials such as graphene have been found to improve specific capacitance and performance which should be investigated further.

Electrotextiles are also being adopted in the soft robotics field, by embedding conductive yarns into knitted structures to create textile-based strain sensors. (Luo et al., 2022) fabricated a glove made of pneumatic actuators with integrated sensing. Both resistive pressure sensing and swept frequency capacitive sensing are enabled by knitting conductive fibres at specific locations. These sensors provide information about the glove interaction, and influence the pneumatic actuators. Additionally, the direction and force of the actuators are determined by the elasticity of the sheath. By using machine knitting, the extensibility of the fibre can be programmed at a stitch level, allowing for precise control of the actuators (Luo et al., 2022,). While their manufacture method offers rapid fabrication, they utilise an industrial V-bed weft knitting machine which costs thousands of dollars.

These knitting machines have two needle beds instead of one, forming a V-shape, hence the name. We may be able to replicate this using our ribber attachment with our flat bed knitting machine, which transforms the machine into one that resembles a V-bed.

2.1.3 Smart Memory Alloys

Smart fibres such as smart memory alloys have also played a part in the evolution of soft robotics, and more specifically, soft morphing structures. One study designed these structures entirely with knitting techniques, and achieved 3D volumetric transformation by reconfiguring the knitted loop geometries (Han & Ahn, 2017). This was done by using a thermally reactive shape memory alloy wire to create the smart textile structure. The wire can then be contracted by either applying an electric current or heating the wire above its austenite temperature. This morphs the structure in a constrained fashion, determined by the types of stitches used. A significant limitation of this technique however is that the deformation is unidirectional, meaning the structure cannot recover its original shape without external intervention (Han & Ahn, 2017).

2.1.4 Medical Textiles

The role of knitting has also been explored in the field of medical textiles (Gokarneshan & Dhatchayani, 2017). The structural flexibility and looped mesh geometry of knitted structures have proven useful properties for knitting cardiac stents (Singh & Wang, 2016). Further, the use of knitting in tissue engineering, such as for the construction of engineering cardiac patches to treat cardiovascular disease, have shown better properties compared to traditionally constructed patches (Yin et al., 2020). One issue faced by medical textiles is the erosion of soft tissue around the area they are implanted (Ha & Zehn, 2019). The same study also found that fabrics with heat sealed or laser cut edges cause more erosion than fabrics with mechanically cut edges.

Core-spun yarns are also used for the creation of textiles with antibacterial properties in medical fabrics (Fan et al., 2023). By preprocessing regular cotton yarn with various chemicals, then knitting it into a fabric, it gains antibacterial and photoelectric properties.

2.1.5 Metamaterials

Metamaterials are engineered types of materials whose structure dictates the overall properties, not the base materials themselves (Albaugh et al., 2021). Spacer fabrics are another knitted structure with utility in medical textiles (Gong, 2015), padding orthotics, and soft robotics (Albaugh et al., 2021). Composed of two knit faces with a filler region in between, it is springy, with low density, mimicking properties of a sponge. When fabricated using a V-bed knitting machine however, the dual-layer structure of the spacer fabric creates significant challenges in producing tubes, restricting the potential applications of these metamaterials (Albaugh et al., 2021).

2.1.6 Geotextiles

Another engineering application of knitting is in the geotextiles domain, where they are used for reinforcement, filtration, and separation. Knitted geotextiles are lightweight and easier to handle than geotextiles produced by other methods (Pandit et al., 2021). However, because the fabrics must be able to withstand stress in both the longitudinal and transversal direction, knitted geotextiles are usually manufactured using the warp knitting method, with weft knitting being reserved for filtration socks (Pandit et al., 2021). These socks can decrease the risk of a drainage pipe getting clogged by sediment (Ghane et al., 2022), as well as lower entrance head loss in some soils (Ghane et al., 2022), while exacerbating erosion in others (Byrne et al., 2023). The studies on weft knitted geotextiles mainly focus on filtration socks, with little attention given to other applications of weft knitting within other geotextile domains.

2.1.7 Automotive Industry

Knitting also has several applications in the automotive industry. Most obviously, knitting is used to produce seat covers and trim components often using nylon yarns (Hunter, 2018). Under the hood however, there are further applications of knitting using various materials such as steel, aluminum and copper to create a wire mesh textile. This wire mesh is used for sealing cords due to its high temperature resistance, and also offers efficient storage and protection of sensitive components such as catalytic converters. Knitted wire filters are also present in several components such as oil mist separators and fuel filters (Knitting Industry, 2011).

2.2 Industrial Knitting

Most of the current literature review on engineering applications of knitting make use of either industrial knitting machines or custom made machines. Currently, there are only two mainstream options for industrial machines. The first is Shima Seiki, with prices ranging from US$7k to US$50k for second hand machines, and brand new machines selling for more than US$180k. Their range of machines spans from computerised flat bed knitting machines, to whole garment machines capable of printing wearables in one print (Shima Seiki, 2023). The only other commercially available alternative is Knitterate, priced at US$16k. Presumably, the lack of competition and decline of the textiles industry within Australia (IBISWorld, 2022) further drives up the entry costs for computerised knitting, making experimenting with knitting machines prohibitively expensive. In comparison, the Brother machines are incapable of producing full garments in one knit, and require more manual labour, however this means they are only a few hundred dollars.

As can be seen, there is a clear interest in knitting within the engineering domain, and the technology has relevant applications. However, many educational institutions still fail to teach students about the applications of knitting, and as a result do not have the necessary equipment for students to explore this technology. Furthermore, the lack of material available on how to use knitting machines for prototyping makes the exploration of knitting in the engineering domain difficult, hence the need for our project.

3 Project scope

The purpose of this project was to introduce knitting machines as a potential rapid prototyping tool for engineering purposes. To achieve this, we attempted to replicate the following projects: strain sensor, spacer fabric and pneumatic soft robotics. Additionally, to facilitate the use of these machines by other students, we developed a set of safe work instructions, documented the use of these machines and conducted inductions for the supervisors of the Monash Makerspace so that they may help students in the future. Furthermore, a set of sample knits were created to help characterise the final product i.e. the number of rows and columns per centimeter. This will allow future users of the machine to apply proper design principles.

Figure 1: From left, spacer fabric (Albaugh et al., 2021), soft robotic glove (Luo et al., 2022), diagram of strain sensor (Atalay et al., 2016)

4 Approach

To establish a machine knitting work area within Monash Makerspace, the KH910 Brother knitting machines were first assembled for operation using setup manuals provided with the equipment, as well as online video tutorials which provided more detailed information on the machines' functionality. These videos, made by the hobbyist community, were invaluable as there is a lack of modern resources due to the discontinuation of the machines in the 1990s. Once these machines were operational, supplementary equipment such as a ribber, garter carriage, and AYAB package were set up. Risk assessments and safe work instructions on the usage and maintenance of the knitting machines and related equipment could be formed.

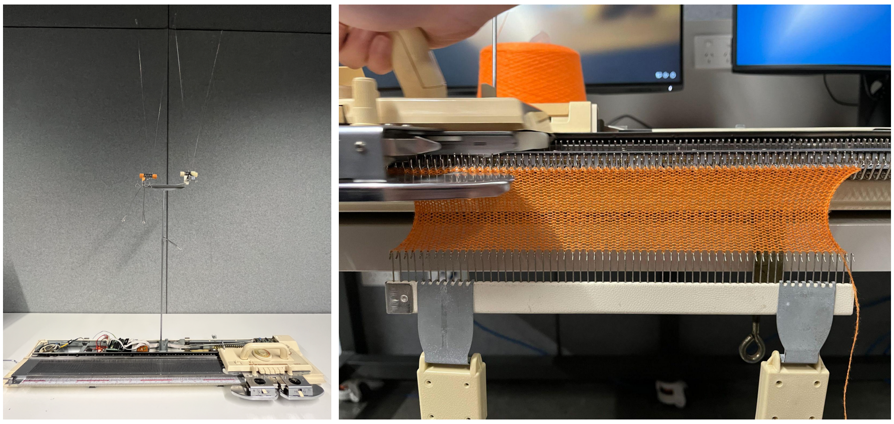

Figure 2: From left, fully assembled Brother KH910 knitting machine, plain knit on knitting machine

With assistance from online tutorials and knitting machine user manuals, we created reproducible samples and tested the limitations of the knitting machines. Using this knowledge, we experimented with different knitting techniques and different materials to recreate published fabrication techniques usually done with industrial-grade machines on low-cost hardware instead. With these fabrication techniques, we knitted proof of concepts by recreating simplistic versions of knits done in the papers (see State of Field), therefore demonstrating the powerful capabilities of the knitting machines in engineering prototyping.

After testing the knitting machines' functionalities, and their abilities to prototype engineering components, the next step was to educate Makerspace users on how to operate the knitting machines to achieve different outcomes. We created a checklist of basic activities users must complete to become qualified to operate the machines. This includes being able to perform basic techniques such as setting up the yarn, casting on/off, and creating different stitch types. We also taught these activities to Makerspace staff through inductions for these knitting machines. As we only have a limited number of knitting machines, inductions were conducted in batches and on a small scale, no more than five people per induction. Additional training material will also be supplied to demonstrate how to achieve different engineering components.

5 Outcomes

By the end of the project, we have:

1. Setup of knitting machines and hardware with completed documentation on how to use and maintain all machines and equipment such that anyone can use the equipment safely and effectively.
2. Conducted a comprehensive literature review of engineering domains where knitting techniques have been utilised with example proof of concept projects.
3. Motivated students to utilise knitting machines in their engineering projects via demonstrations and inductions.
4. Developed small scale replicas of the following projects:
    a. Strain sensors
    b. Spacer fabrics
    c. Simplified pneumatic soft robotics

We were able to knit proof of concepts of these works, however, faced significant challenges given the limitations of our domestic knitting machines. All three projects required extensive hand work which is otherwise not required when using automated industrial machines. This means that users must spend a significant amount of time learning basic knitting techniques before they can attempt to create their fast prototypes, thus creating yet another barrier that must be overcome.

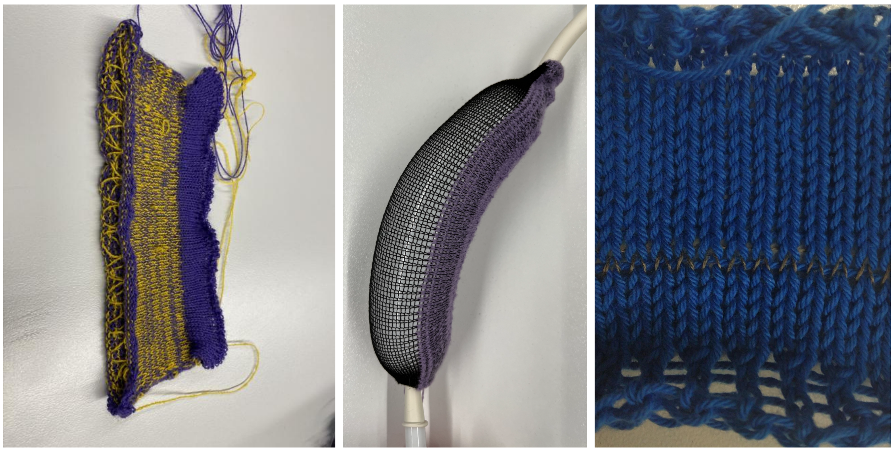

Figure 3: From left, replica spacer fabric, soft robotics pneumatic actuator, strain sensor done on domestic knitting machines.

6 Conclusion

Knitting as a manufacturing technique clearly has a role in the engineering world, and therefore students would benefit from exposure to this technology, and its applications. While we endeavoured to demonstrate proof of concepts for knitting using low-budget machines, the nature of our equipment is limited and therefore proved challenging to achieve the same calibre and scope of products industrial grade machines can produce. Even so, by showcasing the potential of knitting machines and documenting their use, this project served as a foundation for which future engineering students may build upon and utilise throughout their engineering studies.

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