

4D Knitting Grip Assist Glove Based on Shape Memory Alloys: Wearable Device Development and Functionality Assessment

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Introduction

Recently, there is an increasing demand for soft wearable assistive devices using pneumatic, tendon-based actuation that can assist finger grip for the elderly and disabled people who have weakened hand functions (Kang et al., 2019; Yap et al., 2017). In particular, Shape Memory Alloys (SMAs), which transform themselves and return to their original shape by temperature changes, have been integrated into the development of wearable device actuation. Among them, NiTi-based SMAs are considered the most promising materials for their unique self-fitting properties (Granberry et al., 2019). Jeong et al. (2019) developed a glove-type wearable device that helps wrist motions by putting SMAs coils in a polymer tube. In addition, Ma et al. (2019) and Wang et al. (2019) have proposed spring-like SMAs to create air gaps and functional clothing that prevents the temperature rise in the body from external heat. These materials have been developed by adding the fourth element (i.e., time), in the three-dimensional (3D) configuration through shape deformation such as contraction, expansion, folding, and unfolding. To explain, 4D is formed when a 3D shape has a dynamic function, which corresponds with changes in shape deformation over time (Toi et al., 2020). Wearable devices have been developed to assist the human body using this response of materials over time. However, these forms are mostly in the form of actuators attached to textiles, not flexible textiles themselves. Moreover, beyond the concept of rigid robots and devices attached to the human body, the use of flexible and malleable fabric materials as a mean to fit on the body is currently in the spotlight. Through the use of relatively flexible and lightweight fabrics, it is possible to reduce risks caused by the load burden on the body and discomfort of body movement than conventional wearable devices. Albaugh et al. (2019) developed a tendon-based actuator using a weft knitting machine by placing tendons between the loops and combing them into the fabric. Further, Han and Ahn (2017), who developed SMAs in the form of textiles, derived the deformation behavior of SMAs textiles according to knitting techniques, and presented a plain pattern of blooming knit flowers. Additionally, Granberry et al. (2019) developed SMAs garments to be fit according to the wearer's body temperature. These previous studies also suggested the possibility of using the shrinkage function of SMAs textiles in wearable device applications (Hadi et al., 2018). Therefore, in this study, we developed a 4D knitting grip assist glove, as well as a 4D knitting soft gripper, based on SMAs; and analyzed grip functionality of the integrated grip system using its curvature ratio during the shape changing of its knitting module.

Methods

We transformed 2D material of SMAs into a 3D fabric using knitting techniques and utilized the characteristics of the curvature when the 3D shape changes over time as a role to assist the function of the human body. That is, we first made plain pattern modules of hand-knitting using the SMAs (55wt% Ni and 45wt% Ti) yarn wrapped with polyester fibers (Ahn & Han, 2019), and measured the curvature ratios and times of the modules by supplying the current controller. We compared the Collaborative Robot M1013 (Doosan Robotics, Korea) and the soft gripper attached to this robot about whether soft and lightweight objects such as fabrics can be lifted. Additionally, applying the development method of the soft gripper to the grip assist glove, three plain knitting modules were produced in the same way. We analyzed the ratios of the curvature change over time in the knitting module and a grip assist glove by placing and attaching these modules to the index, middle, and ring fingers. The module was divided into three equal lengths in the wale direction, and curvature changes were measured based on 1/3 (top), 2/3 (middle), and 3/3 (bottom) points. The ratio of curvature change was calculated as [The curvature ratio (times) = $(b-a)/a$; a = curvature before change, b = curvature after change] Wang & Wang (2015).

Results

The SMAs modules of plain knitting pattern (3 courses x 18 wales, $n=10$) showed curved shape in the wale direction when supplying a current of 0.3A, and the total time was an average of 17.83 ± 4.12 s. In order to give the ability of the end of the knitting modules to face each other so that objects can be picked up, a mold was made with a 3D printer (FDM 3D Printer, Stratasys F270) and poured with silicone to form a nail shape and attached to the tips of the gripper. A current controller was added to three modules attached to the Collaborative Robot (Figure 1). It took 12.01 ± 4.46 s on average from starting the gripper's driving until lifting small objects such as fabric pieces, ping pong balls, plastic bags, and so on. While gripping objects, a different curvature ratio was observed in the range of 45 to 90 degrees (or even higher).

The course and wale ratio of the plain knitting modules were adjusted to place and attach to the nylon glove (5 courses x 21 wales). These modules showed the curvature of 180 degrees or higher in the wale direction when a current of 0.3A was supplied. After 35 seconds, the curvature ratio of the top had changed to as much as 14.82 times, the middle 16.09 times, and the bottom 9.29 times, compared to the baseline state (i.e., before the change occurred). When driving modules on a grip assist glove in the same way, that top point of the glove showed the curvature first, followed by the middle point and then the bottom point (Figure 2). After 35 seconds, the curvature ratio of the top was 8.10 times, the middle was 8.27 times, and the bottom was 8.52 times, compared to before the change. Compared to driving only the knitting module without the current controller, the curvature ratio of the glove had decreased, compared to when it was driven with the current controller, as it changed as much as 8 times before driving.

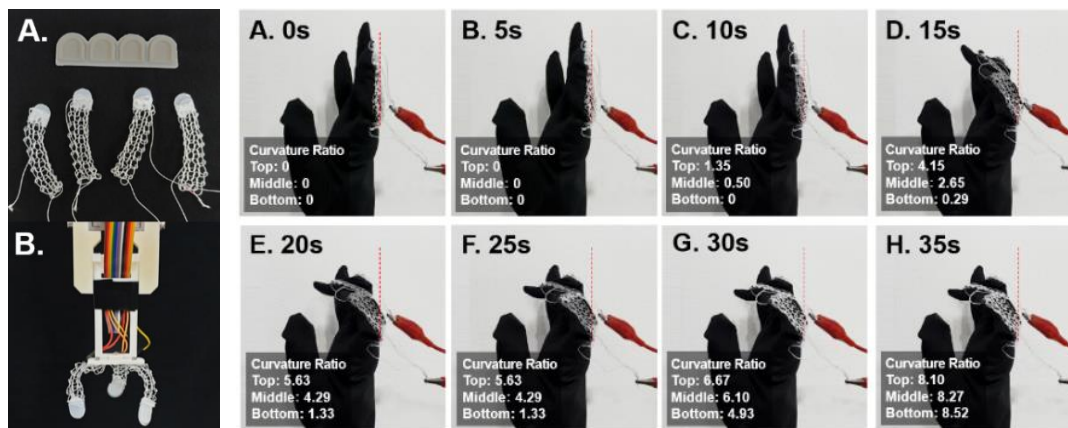


Fig 1. (left) SMAs knitting modules and a soft gripper: A. A mold and silicones attached to the knitting modules, B. A soft gripper attached to the Collaborative Robot

Fig 2. (right) The ratio of the curvature according to time in SMAs knitting modules on glove

Conclusion

We have successfully developed a grip assist glove that can assist grip to people with weak finger strength, as well as a soft gripper that can grip soft objects that are typically difficult to grip with existing robot-type machines, using 4D knitting modules based on SMAs. The results of this study suggested the application potential of SMAs in such wearable assistive devices that could be worn or attached to the human body. In the future, it is recommended to conduct usability assessment of the devices on user safety and performance enhancement in real-world contexts.

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