Design of Soft Wearable Massaging Device for Lymphedema (WMD-L): A Step towards the Development of a Remote Diagnosis and Treatment Robotic Tool for Therapists and Patients

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***Abstract*—Breast cancer removal surgery (mastectomy) survivors often suffer from a chronic condition known as lymphedema, characterized by swelling of the body. Being a chronic condition, there is no full cure, which is why swelling management is very important. Swelling is managed by draining the lymph with a specialized "massage" technique which consists of a gentle skin stretch to stimulate the superficial lymphatic system. This lymphedema management is the most effective when performed the moment the symptoms arise anytime and anywhere. Therefore, a low-profile and comfortable device that can be worn for an extended duration during daily life is necessary. Soft wearable robotics technology is employed in this research to develop a soft wearable massaging device that can be worn under regular clothing. Origami-based folding technique is directly implemented on a balloon-like 1D inflation of a fabric pouch to develop the Origami-Z-folded Soft Shear Actuator (Z-Ori), which creates a combination of shear and normal forces along a stroking displacement under a compression constrained environment. A parameterization study is conducted, and three main actuator parameters are selected to control two actuator outputs, shear force and stroking displacement. Results are discussed, and future research direction is provided that is required to realize the ultimate research goal of remote diagnosis and management of lymphedema.**

Keywords- Soft Wearable Robot, Massage, Lymphedema, Healthcare robotics, Assistive robot

I. Introduction

Millions of patients worldwide suffer from a chronic condition known as lymphedema [1, 2]. Lymphedema patients have low quality of living because of the symptoms of lymphedema which deter daily life activities. If left untreated, severe lymphedema can lead to serious complications such as permanent skin damage, infections, and even skin cancer [3, 4, 7]. A specialized method of gentle massage known as Manual Lymphatic Drainage (MLD) is effective (figure 1), but treatments are greatly hampered by distance – often having to travel long distances; high cost – the cost of regular treatment sessions is an issue for chronic patients; and the accessibility of specialists – lack of available lymphedema therapists [5, 6, 20]. Another form of treatment using a mechanical device, lymphedema compression pump, is an alternative method. However, the method of milking the limbs to drive lymphatic flow by sequential compression of multiple air chambers requires a complex and bulky system [7]. It is also questionable that the

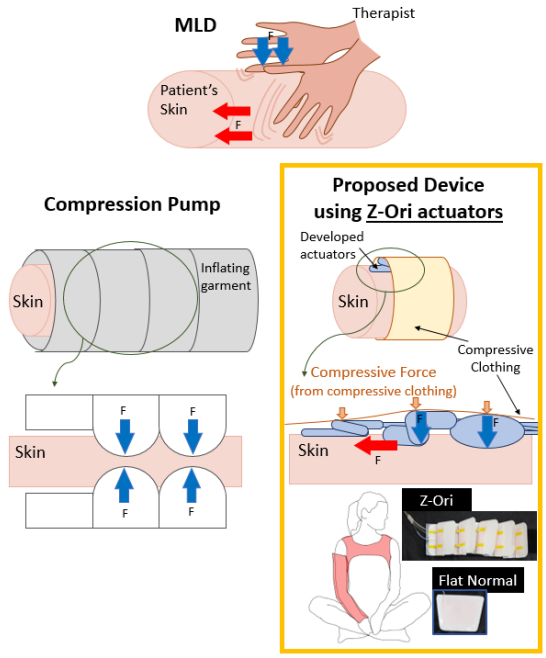

Figure 1. Pictorial representation of manual lymphatic drainage (MLD); Compression pump with inflating garment on the left; and the proposed Wearable Massaging Device for Lymphedema (WMD-L) using the developed Z-Ori actuators on the right

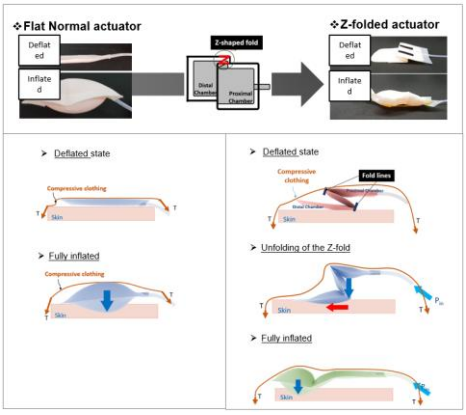

Figure 2. Schematics and Principles of Flat Normal Actuator and Origami-Z-folded Soft Shear Actuator (Z-folded actuator).

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compression pump can successfully duplicate the beneficial effects of MLD [1, 8].

Pneumatic chambers of lymphedema compression pump are designed as a pouch such that its inflation presses normally on the skin. Sequential inflation of these chambers create a continuous motion with discrete normal forces acting on the skin. However, the methodology by which these garments work differs from the MLD performed by lymphedema specialists. With forces indicated as stroking a newborn's head, MLD involves intricate and gentle hand strokes that stretch and release the skin with the friction between the therapist's hand and patient's skin, thereby stimulating the filaments attached to the skin and facilitating lymph absorption into the lymphatic vessels [3, 9, 10]. However, depending on the degree of lymphedema, the stiffness of the skin differs and stronger force might be required in the MLD process. Furthermore, the stretching stroke produces relatively large lateral stroke displacement with a single motion. In this point of view, giving an additional 'shearing' motion to pneumatic pouch chambers that mimics gentle skin stretching of MLD would bring new benefits such as drainage performance improvement, system simplification, and better human-device interaction. With the rapid developments in soft robotics, these human like "massage" motions can be re-created to assist the health care professionals in providing more of the high quality treatment to patients. And with the development in the form of a portable soft wearable, the robot can be used to bring specialist's treatment home and anywhere the patient goes.

In this paper, a wearable massaging device for lymphedema (WMD-L) is developed which consists of several origami-inspired soft fabric pneumatic actuators that were developed to create the shear force necessary in mimicking the therapist's gentle stretch of the patient's skin [11, 12]. This paper serves as an introduction into the hardware design of WMD-L, and future works will be conducted to realize autonomous detection of the patient's skin and lymphedema condition, such that once the WMD-L is worn by the patients, it could act as a robotic platform to conduct remote diagnosis of the state of the lymphedema to assist the long-distance therapy between patients and therapists afar.

II. Results

The developed WMD-L consists of several Z-Ori and Flat Normal actuators (figure 2). Each Z-Ori is initially in the Z-folded shape, and when actuated, it unfolds to create lateral strokes, while flat normal actuator only inflates to create normal force.

The Z-Ori actuator is capable of creating a maximum shear force of about 13 N and a stroking displacement of about 20 mm under compressive clothing tension of approximately 4 N as shown in figure 3. This result demonstrates the capability of the proposed WMD-L in creating sufficient shear force and stroking displacement to cater for the need of different lymphedema patients.

III. Future Works

With the hardware design of the WMD-L introduced in this paper, the next step is in collecting sets of data with the Z-Ori actuators to better control the device. With several Z-Ori actuators lined up serially, the pneumatic pressure data and the stroking displacement data of the Z-Ori, and the force data collected at each point of contact can be processed through machine learning techniques to make an estimate of the relative local skin stiffness. The skin stiffness data can act as an indicator to the strength of the lymphedema "massage" required for each patient and each body sections.

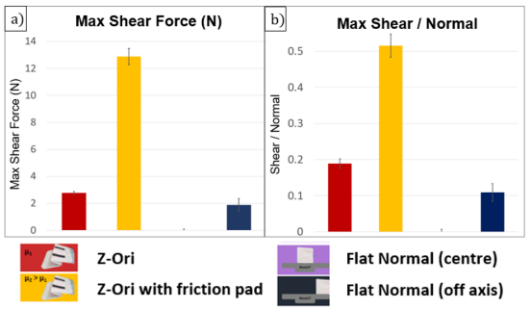

Figure 3. Experimental Characterization Results; a) Maximum shear force recorded for four different cases; b) The ratio of maximum shear force by maximum normal forces for all the four different cases.

As a user scenario, if a patient visits the therapist, the therapist can assess the patient's condition, and decide the appropriate setting of the WMD-L. If the WMD-L robotic system is prescribed to the patient, she can then go home and use the WMD-L to manage her swelling everyday. And on the date of the next appointment, instead of the patient making the long journey to the therapist's clinic, the therapist can check the data of the patient's lymphedema conditions and adjust the required settings on the WMD-L such that the patient can get her treatment at home.

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