WeFiTS: Wearable Fingertip Tactile Sensor

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Abstract. Thimble/glove-based wearable systems are opportunistically placed on fingertips/hands and enable haptic devices, robotic/prosthetic hands to gather valuable information about physical interaction with the environment in an easy way. In particular, incipient slip detection and force acquisition are two important phenomena for human/robotic fingertips to successfully manipulate the real or virtual objects. In this study, a wearable fingertip tactile sensor (WeFiTS) capable of sensing incipient slippage and force variation in various directions to enhance interaction and manipulation while performing tasks is proposed. The fundamental design criteria of WeFiTS are also evaluated with FEA feasibility analysis and experimental evaluation.

1 Introduction

Human hand characteristics have been a perfect model for robotic studies which have been devoted to augment the interaction/manipulation success with the environment. In particular, wearable devices for fingers have been developed inspired by the properties of human fingers to be employed by haptic robotics, robotic/prosthetic hands for real/virtual object manipulations and also human gesture analyses. Recent studies [1,2] have designed to acquire information about force/torque measurement by means of force/torque sensors and also contact points with the aid of contact centroid algorithm.

Considering stable manipulation with both robotic fingers (grippers) and human fingertips, slip perception is thought to be another important design criteria. Human is capable of detecting slippage, particularly incipient slip, by means of various types of receptors placed in fingertips. In literature, some groups have focused on human-like slip sensible fingertip design to realize robust manipulation [3]. However, such devices [4,5] are not easily adaptable to some studies, such as human integrated research, and specifically designed for respective robotic hands.

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In this study, WeFiTS is presented as a wearable fingertip tactile sensor to be worn by human or robotic fingertips, adaptable to many types of manipulation based studies, and provides essential information about exerted force upon object and incipient slip detection at fingertip, which are achieved by means of force sensing resistors and non-contact rotary encoders, respectively without requiring complex algorithm and prior knowledge regarding object or environment.

2 Problem Definition

The sophisticated problem of fingertip design endowed with slip detection and force sensing properties can be addressed with an easier and practical solution. WeFiTS is proposed as a simple but functional wearable tactile sensor, that allows adequate nest for distal phalanges and can be worn by gloves or fixed by straps as illustrated in Fig. 1.

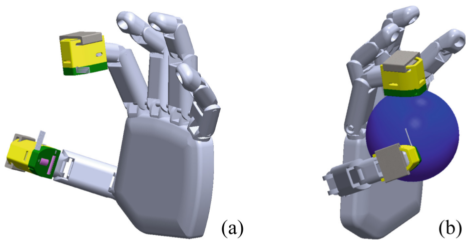

Fig. 1. Illustrative representation of WeFiTS (a) worn by a robotic hand (b) grasping an object

WeFiTS includes two different sensor types, position and force sensors, which are responsible for slip detection and force measurement in different directions, respectively. The simplified views of WeFiTS and its working principle are depicted in Fig. 2. In the top view (a), force sensors represented with two dots are placed on inner surface of WeFiTS in order to be directly connected with fingertips. In the front (b) and left (c) views, two slip sensors are placed in perpendicular to each other to sense the possible object slippage occurred in two directions (d, e).

3 Materials and Methods

WeFiTS addresses to the requirement of simultaneous and independent slip and force sensations for robotic/human fingers by means of a wearable easy-to-use design.

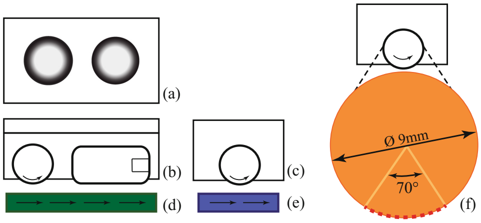

Fig. 2. This figure shows top view and cross-section of right and front views of WeFiTS together with the working principle of the sensors. In (a), two force sensors represented with two dots are placed on the surface of the WeFiTS. In (b) and (c), two slip sensors assembled to the bottom part of WeFiTS. In (d) and (e), the motion of objects in different directions are schematically represented. In (f), the red dashed curve shows the ratio of the interacted section of the circle with an object.

3.1 Design Criteria

Some important design criteria needs to be tackled to satisfy the requirements. Lightness is a quite important design criterion to minimize the effort for lifting WeFiTS. Size and shape are also two coupled primary design criteria requiring meticulous attention to well suit to the fingertip's geometry and customizable to any-size of user. Ergonomy is imperative requirement to be considered in order not to prevent the motion of fingers in a space. Finally, sensibility is the fundamental design criteria such that WeFiTS senses the incipient motion of an pinched object and the force variation exerted by fingertips. This criteria should also cover ease in detection of the force and slippage without requiring complex algorithms.

3.2 Electromechanical Design of WeFiTS

The mechanical design of WeFiTs is mainly composed of two layers with integrated sensors presented in Fig. 3 as exploded view. Light-weight design criterion is met with the selection of PLA material, whose density is 1.25 g/cm^3, by avoiding more than required size for fingertips ($18 \times 27 \times 11$ mm) and designing the overall platform durable but thinner enough. In order to satisfy the size and shape criteria, two main bodies of WeFiTS are produced by means of 3d printer manufacturing technique, which avails in terms of custom-based production for any size of human or robotic fingertip. Ergonomy is addressed by designing the overall system to interact with the environment most efficiently and safely. As for the sensation criteria, force sensing is realized by placing force sensing resistors (FlexiForce A101 by Tekscan Inc.), which are sensitive up to 44 N, into the nest area of WeFiTs to measure the force in all axes as in Fig. 3. Feasibility of the aforementioned design criteria is tested with FEA analyses under overload (30 N). Figure 4 presents the response of body under the static nodal stress and displacement under static load. Negligible deformations with less than 1 mm ensures that proposed design is feasible to satisfy the design criteria. The slip sensation is realized by detecting the motion of rotary body placed in between two main bodies of WeFiTs as seen in Fig. 3 by means of 12 bit non-contact rotary encoders (RS08, RLS), which is sensitive enough to detect quasi-static motion (1 count for 0.09° revolution).

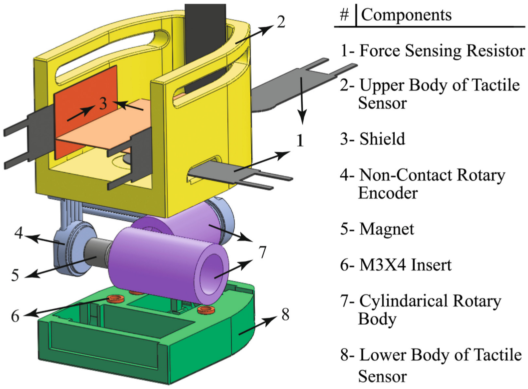

Fig. 3. This figure shows the exploded CAD view of WeFiTS with its descriptions.

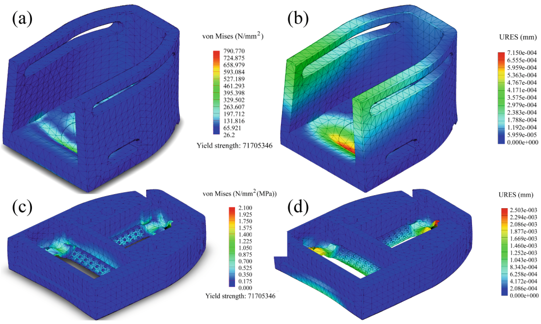

Fig. 4. (a) Von Mises result under the static nodal stress for upper body (b) Result of static displacement for upper body (c) Von Mises result under the static nodal stress for lower body (d) Result of static displacement for lower body

The experimental evaluation is presented in Fig. 5 under various conditions. In particular, when less than required force is exerted on an object, cylindrical rotary body moves in the direction of slippage. Here, the negative and positive signs on the y axis represent the direction of the rotation of cylindrical rotary body. In order to explicitly show incipient slippage, rotation of encoder is represented in terms of count rather than degree. In addition, as emphasized with the red and green arrows, the sufficient enough force stops the rotation of the cylindrical bodies and encoder sends the last number to the microprosessor at those moments.

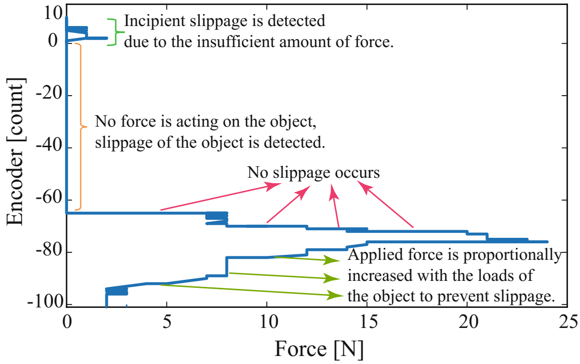

Fig. 5. The working principle of WeFiTs is presented in different cases.

4 Conclusion

This study presented a novel wearable fingertip tactile sensor sensible to slippage and force variation. The FEA results showed the feasibility analysis of the mechanical design and the experimental evaluation of WeFiTs also represents the proposed sensation criteria by showing the incipient slippage and applied force level to the object.

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