The Development of a Wearable Sensing Glove and Sensory Feedback Device for Rehabilitation and Improved Control of Impaired Upper Limbs and Prosthetics - A Review

Alicia Molina, MS[1,*], Carl Demolder, MS[1,+], Frank L. Hammond III, PhD[1,!], and W. Hong Yeo, PhD[1,@]

[1]Georgia Institute Of Technology, George W. Woodruff School of Mechanical Engineering, Atlanta, 30332, USA
[*]aml3@gatech.edu
[*]cdemolder3@gatech.edu
[*]frank.hammond@me.gatech.edu
[*]whyeo@gatech.edu

ABSTRACT

Recent technological advancements in soft actuators, flexible electronics, and system integration technologies have enabled the creation of a portable, low cost, and unobtrusive wearable sensor glove that is used in conjunction with a sensory feedback device. This combination of technologies has the ability to advance the status quo of healthcare, prosthetics, and rehabilitation. The application of a wearable sensor glove and sensory feedback device has emerged as a promising paradigm to enhance the care provided to patients with neurological and musculoskeletal conditions. The integration of soft and biocompatible materials with miniaturized electronics, sensors, and actuators is undoubtedly an attractive prospect to develop a wearable sensor glove and sensory feedback device. The development of soft pneumatic actuators that are used in conjunction with micro-motors provides one with the ability to physically actuate patients with perceived sensory transfer signals. A sensory feedback device that has a high performance requires a high degree of mechanical flexibility, low weight, and a simple user interface. This paper includes the most up-to-date materials, sensors, actuators, and system-packaging technologies to develop a wearable sensing glove and sensory feedback device. This paper presents a summary of the requirements for the material properties, sensor capabilities, electronics performance, and user interaction. Details of the mechanical, electrical, system architecture, and material properties are discussed in regards to their application in healthcare, prosthetics, and rehabilitation. Additionally, the limitations of the current materials and technologies are discussed, as well as the key challenges and the future direction of how a wearable sensor glove is used in conjunction with a sensory transfer device. Overall, this paper is used as an all-inclusive review of the technologies used to develop a wearable sensor glove and a sensory feedback device.

Introduction

Sensory impairment is a symptom of a variety of neurological conditions such as spinal cord injuries (SCI), cerebral palsy, peripheral neuropathy, sclerosis, and diabetes. Amputee patients face a similar issue with their prosthetics which are, up to date, unable to sense or feel. The lack of tactile, proprioceptive, and temperature feedback from a limb (whether human or artificial) often leads to a feeling of disembodiment over the limb, resulting in reduced use of the limb or rejection (in the case of prosthetics) [Design and evaluation of a sensory...][7]. Patients with sensory impairments rely solely on vision as a feedback mode to determine the state of their limbs, this can be greatly inconvenient [4]. The need for a device that is able to communicate the sensory and physical states of a sensing-less limb is evident. text[?]

Sensor Glove

Up to three levels of **subheading** are permitted. Subheadings should not be numbered.

Subsection

Example text under a subsection. Bulleted lists may be used where appropriate, e.g.

- First item
- Second item

Third-level section

Topical subheadings are allowed.

Sensory Feedback Devices

The Discussion should be succinct and must not contain subheadings.

Feedback Modes

Electrocutaneous

Vibrotactile

Mechanotactile

Conclusions

Topical subheadings are allowed. Authors must ensure that their Methods section includes adequate experimental and characterization data necessary for others in the field to reproduce their work.

References

1. Jayme Knutson, R. W. J. C., Douglas Gunzler. Contralaterally controlled functional electrical stimulation improves hand dexterity in chronic hemiparesis: A randomized trial. *Stroke* DOI: https://doi.org/10.1161/strokeaha.116.013791 (2016).
2. John C.S. McCaw, R. K.-B., Michelle C. Yuen. Sensory glove for dynamic hand proprioception and tactile sensing. *ASME 2018 Int. Des. Eng.* DOI: https://doi.org/10.1115/DETC2018-85703 (2018).
3. Zhong Shen, X. L. M. H. P. L. M. Z. Q. C. Y. H. Z. W., Juan Yi. A soft stretchable bending sensor and data glove applications. *Robotics Biomimetics* DOI: https://doi.org/10.1186/s40638-016-0051-1 (2016).
4. Kahye Song, S. J. S. K. S. L. J.-S. K. J.-M. P. . Y. C., Sung Hee Kim. Pneumatic actuator and fexible piezoelectric sensor for soft virtual reality glove system. *Sci. Reports* DOI: https://doi.org/10.1161/strokeaha.116.013791 (2019).
5. Josie Hughes, M. C. G. C. W. M. D. R., Andrew Spielberg. A simple, inexpensive, wearable glove with hybrid resistive-pressure sensors for computational sensing, proprioception, and task identification. *Adv. Intell. Syst.* DOI: https://doi.org/10.1002/aisy.202000002 (2020).
6. Siyi Xu, W. H. J. O. T. W. J. R. F. S. K. S. V. C. S. A. W. R. E. C. G. R. J. W., Daniel M. Vogt. Biocompatible soft fluidic strain and force sensors for wearable devices. *Adv. Funct. Mater.* DOI: https://doi.org/10.1002/adfm.201807058 (2019).
7. Jaemin Kim, H. J. S. R. G. H. R. C. D. S. Y. H. J. M. S. C. C. S. J. K. C. D. J. S.-T. L. J. H. K. S. H. C. T. H. D.-H. K., Mincheol Lee. Stretchable silicon nanoribbon electronics for skin prosthesis. *Nat. Commun.* DOI: https://doi.org/10.1038/ncomms6747 (2014).
8. Todd Hester, D. M. S. B. K. M. A. J. S. P. B., Richard Hughes. Using wearable sensors to measure motor abilities following stroke. *IEEE Xplore* DOI: https://doi.org/10.1109/BSN.2006.57 (2006).
9. Ivana Cuberovic, L. J. R. D. J. T. E. L. G., Anisha Gill. Using wearable sensors to measure motor abilities following stroke. *Front. Neurosci.* DOI: https://doi.org/10.3389/fnins.2019.00853 (2019).
10. Xiaoshi Chen, L. W. S.-C. Y. L. D. X. L. Z. Z. Z., li Gong. A wearable hand rehabilitation system with soft gloves. *IEEE Xplore* DOI: https://doi.org/10.1109/TII.2020.3010369 (2020).
11. Leire Francés, M. I. R.-A. C., Paz Morer. Design and development of a low-cost wearable glove to track forces exerted by workers in car assembly lines. *Sensors (Basel)* DOI: https://doi.org/10.3390/s19020296 (2019).
12. K. Niazmand, A. K. U. M. F. J. H. M., K. Tonn & Lueth, T. C. Quantitative evaluation of parkinson's disease using sensor based smart glove. *IEEE Xplore* DOI: https://doi.org/10.1109/CBMS.2011.5999113 (2010).
13. Dae Seok Lee, B. G. L., Teak Wei Chong. Stress events detection of driver by wearable glove system. *IEEE Xplore* DOI: https://doi.org/10.1109/JSEN.2016.2625323 (2017).
14. Boon-Giin Lee, W.-Y. C. Wearable glove-type driver stress detection using a motion sensor. *IEEE Xplore* DOI: https://doi.org/10.1109/TITS.2016.2617881 (2016).

Acknowledgements

Special thanks to Dr. Yeo and Dr. Hammond for their guidance and assistance while drafting this literature review. This literature review is sponsored by a grant provided by Scott Kozin, M.D., a clinician at the Shriners Children Hospital in Philadelphia, PA.

Author contributions statement

A.M. and C.D. wrote the literature review and developed a list of possible references. W.Y. and F.H. reviewed the literature review and provided guidance on how the technology can disrupt the status quo. All authors reviewed the manuscript before publication.

Additional information

There is no additional information at this time.

Figure 1. Legend (350 words max). Example legend text.

Table 1. Published Examples of Wearable Sensor Glove Technology

Sensor Model	Sensor Technique	Conclusion	Reference
Strain	Resistance	CCFES used to stimulate paretic hand using signals from strong hand	Kutson et. al[1]
	Capacitance	Wearable glove to measure finger bending for hand gesture location	McCaw et. al[2]
	Liquid Metal Resistance	Wearable sensor glove with custom soft, stretchable sensors	Shen et. al[3]
Strain; Pressure Feedback	Piezoelectric material; Electrostatic actuator	Wearable VR glove to interact with VR environment	Song et. al[4]
Temperature; Pressure; Strain	Resistance; Fluidic pressure	Resistance and fluidic glove for user and environmental sensing and task classification	Hughes et. al[5]
	Resistance	Fluidic resistance glove for human motion capturing	Xu et. al[6]
	Capacitance; Resistance	Web of nanoribbon sensors placed on a prosthetic hand to transfer signals to internal nerves	Kim et. al[7]
Motion	IMU	IMU placed on hands, fingers, and arm for human motion capturing	Hester et. al[8]
Pressure; Strain	Resistance	Resistive force sensors placed on prosthetic hand to transfer signals to internal nerves	Cuberovic et. al[9]
	Resistance	Wearable sensor glove for object and grasp detection	Chen et. al[10]
Pressure	Resistance	Resistance force sensors placed on hand to determine forces applied by subjects	Frances et. al[11]
Pressure; Frequency; Motion	Resistance; IMU; Electrodes	Wearable sensor glove to detect symptoms of Parkinson's Disease	Niazmand et. al[12]
Motion; Photoplethysmogram	IMU; Fingertip PPG	Wearable sensor glove to detect driver stress events	Lee et. al[13]
Motion; GSR	IMU; GSR Sensor	Wearable sensor glove to detect driver stress events	Lee et. al[14]
Pressure; Strain	Resistance	Wearable sensor glove for object and grasp detection	Chen et. al[10]