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Electronic Sensory Glove

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ABSTRACT

The human hand is vital for daily and social functions, and its loss can significantly impact quality of life, often necessitating psychological intervention due to isolation, anxiety, or depression. While prosthetic hands restore essential mobility, challenges remain in achieving natural appearance and sensory feedback. This study presents the development of an electronic sensory glove (e-glove) system that seamlessly integrates multimodal sensors—capable of detecting pressure, temperature, and moisture—into a commercial stretchable nitrile glove. Leveraging a hybrid screen- and transfer-printing fabrication method, the e-glove conforms to various prosthetic hand shapes and sizes, offering realistic tactile qualities and real-time data transmission via a wristwatch interface. Both experimental and computational analyses validate the glove's mechanical and functional efficacy, demonstrating its potential to enhance prosthetic hand interactions in diverse daily and social contexts.

Keywords: - *Electronic Sensory Glove, Gesture Controlled, Prosthetic Limb, Sensors*

1. INTRODUCTION

The human hand is a critical organ for performing both functional and social tasks, acting as a highly adaptable interface for physical interaction with the environment. Amputation or significant disfigurement of the hand can lead to profound impairments, including reduced manual dexterity, loss of sensory perception, and a deviation from the natural anatomical appearance. These physical limitations are frequently accompanied by psychological distress; approximately 50% of individuals with upper-limb amputations experience mental health challenges such as depression, anxiety, fatigue, social withdrawal, and in some cases, suicidal ideation. Current evidence-based rehabilitation approaches emphasize the use of prosthetic hands to restore fundamental motor functions and facilitate essential interactions such as grasping, handshakes, and gentle tactile expressions. Recent progress in soft and stretchable electronic materials has introduced opportunities for restoring sensory capabilities by enabling detection of external stimuli, including pressure, temperature, and hydration. However, the integration of these materials into prosthetic hands remains technically challenging due to the anatomical complexity of the hand, often resulting in poor mechanical conformity and continued visual disfigurement.

In this study, we present a fully integrated electronic sensory glove (e-glove) system, fabricated directly on a commercially available stretchable nitrile glove. This approach leverages the glove's intrinsic ergonomic design, enabling conformal coverage across a broad range of prosthetic hand geometries within typical adult size ranges. The e-glove incorporates advanced materials, sensor configurations, and fabrication techniques to deliver a seamless, wearable platform capable of real-time sensory perception. This system not only enhances the functional utility of prosthetic hands but also improves their aesthetic integration, thereby contributing to the physical and psychological rehabilitation of users. The e-glove system integrates a network of flexible, stretchable multimodal sensors capable of detecting pressure, temperature, and moisture, while mimicking the natural appearance, softness, and thermal properties of human skin. This dual functionality—tactile sensing and human-like aesthetics—enables more lifelike interaction and improves user comfort and acceptance. Sensor data are displayed in real time via a wrist-mounted interface and can be wirelessly transmitted to an external device for further processing. These capabilities offer intuitive feedback and enable seamless monitoring of hand-environment interactions. Fabrication of the e-glove leverages a scalable, cost-efficient hybrid printing process that combines screen printing and transfer printing to layer electronic circuits directly onto commercially available stretchable gloves. This approach accommodates complex surface geometries without compromising mechanical conformity or flexibility.

Experimental validation, supported by computational analysis, highlights the mechanical reliability and sensitivity of the integrated system. The e-glove demonstrates effective performance in real-world tasks, enhancing the control of prosthetic hands during object manipulation and social interactions. Unlike traditional approaches that focus solely on mechanical function, this work emphasizes emotional and psychological rehabilitation. Developed by researchers at Purdue University, the e-glove seeks to restore the tactile experiences of natural hands, fostering a sense of touch and warmth that supports mental health and social reintegration in individuals with upper-limb amputations.

There is an increasing awareness that the inclusion of quality of life as an outcome measure is important in ensuring a client-centred and holistic assessment. This review outlines the benefits of quality of life as an outcome measurement in the field of prosthetics. It introduces the key concepts and challenges in the definition and assessment of quality of life post-amputation, including the relative advantages and disadvantages of adopting generic, disease/condition specific, dimension specific and individualized measures of quality of life. In conclusion, the review delineates and recommends issues and guidelines for consideration when undertaking quality of life research and assessment. A co-ordinated approach by practitioners in the field of prosthetics is necessary to ensure the inclusion of quality of life as an outcome measure and to ensure its measurement in a standardized and rigorous manner.

2. GESTURE CONTROLLED ELECTRONIC GLOVE

This paper presents an electronic glove (e-glove) system designed to augment prosthetic hands with human-like properties, including mechanical softness, thermal warmth, natural appearance, and multimodal sensory feedback. Unlike conventional prosthetic devices that primarily restore gross motor functions, the proposed e-glove enhances the user experience by integrating tactile realism into daily and social interactions—potentially contributing to improved psychological well-being and social reintegration. The e-glove is fabricated using a commercially available stretchable nitrile glove as the substrate, onto which ultrathin, flexible electronic sensors and miniaturized silicon-based integrated circuits are assembled. These components enable real-time detection of environmental stimuli such as pressure, temperature, and hydration. The system interfaces with a custom-designed wrist-worn unit that facilitates real-time data visualization and supports wireless transmission for remote monitoring and post-processing. This work represents a significant step toward multifunctional, wearable electronic systems that merge prosthetic functionality with enhanced sensory and perceptual capabilities.

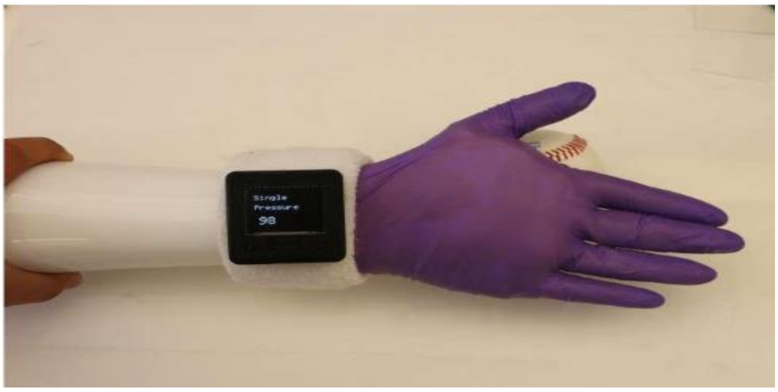

Fig 1: Electronic glove with wristwatch

The electronic glove (e-glove) system is equipped with a stretchable architecture of multimodal sensors designed to acquire a range of physiological and environmental data, including pressure, temperature, humidity, and electrophysiological bio signals. In parallel, the system replicates key physical characteristics of the human hand—such as softness, natural appearance, and thermal warmth—thereby enabling a more lifelike interface for prosthetic and robotic applications. Tactile interaction is a fundamental component of human social behavior, encompassing gestures such as handshakes, congratulatory pats, and high-fives. These forms of physical communication are deeply ingrained in human culture and are likely to persist even in future scenarios involving human-robot interaction. However, existing artificial hands, often fabricated from rigid materials and capable of exerting grip forces up to 100 N, may pose psychological and physical discomfort during such social exchanges.

For artificial hands and sociable robotic platforms to be accepted in socially interactive settings, the development of skin-like mechanical compliance and warmth is critical. The e-glove addresses this challenge by integrating soft, compliant electronics that not only enable sensory feedback but also promote more natural and socially acceptable human-machine interactions. This system has the potential to significantly improve user experience, particularly in applications involving prosthetic limbs and humanoid robotics designed for direct physical engagement with humans.

3. RECORDING OF PRESSURE, TEMPERATURE AND HYDRATION

3.1 Pressure and Temperature

Arrays of pressure and temperature sensors were configured to enable distributed multimodal sensing across the e-glove surface. Each sensor was driven by a custom-designed, miniaturized constant current source circuit, comprising operational amplifiers and bipolar junction transistors, which maintained a stable excitation current of 100 µA.

A 32-channel analog multiplexer, controlled by an on-board microcontroller unit (MCU), was employed to sequentially address individual sensors within the array. During operation, the voltage drop across each sensor was measured to capture the response to external pressure and temperature stimuli.

The analog signals were digitized using a high-resolution 16-bit analog-to-digital converter (ADC), ensuring precise signal acquisition. The processed data were displayed in real time on a wrist-mounted control unit and simultaneously transmitted wirelessly to an external device—such as a smartphone or tablet—via Bluetooth communication for extended data visualization and post-processing.

3.2 Hydration

A capacitive hydration sensor utilizing inter digitated microelectrode arrays was fabricated and integrated onto the index fingertip area of the e-glove. To facilitate direct interaction between the sensor and ambient moisture, a 3 × 3 array of micro perforations, each approximately 1 mm in diameter was introduced through the outermost glove layer at the fingertip. Capacitance signals were captured via a capacitance-to-digital converter interfaced with a microcontroller unit (MCU). The MCU processed the acquired data and provided real-time feedback by displaying the hydration levels on the wrist-mounted control unit. Additionally, the data were wirelessly transmitted to an external reader, such as a smartphone or tablet, enabling remote monitoring and further analysis.

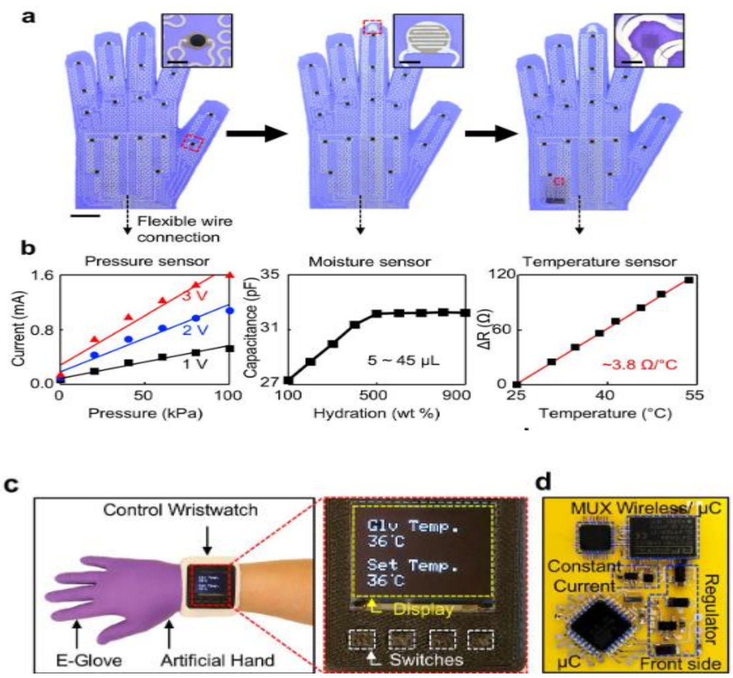

Fig 2: Different Sensory Figures of Electronic Glove

4. BLOCK DIAGRAM AND DESCRIPTION

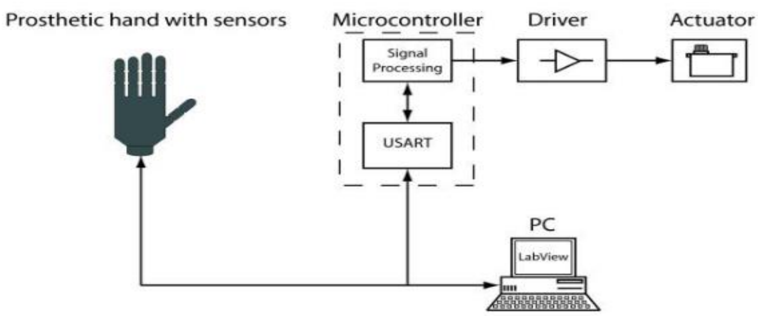

Fig 3: Block Diagram

Communication between the microcontroller and a host computer is essential for system programming and updates, facilitated by the USB PIC Boot loader. This resident boot loader is specifically designed for the PIC18 series of Enhanced Flash USB microcontrollers, enabling users to program application firmware directly into the microcontroller's memory via standard USB connectivity. The boot loader firmware is write-protected; preventing accidental overwrites during normal operation. Mode selection between firmware update and application execution is controlled through software and/or hardware switches.

Upon system reset, the boot loader executes first, providing the capability to load a complete application program into the microcontroller's memory. The USB PIC Boot loader operates in two distinct modes: firmware update mode and application mode. The active mode is determined by monitoring an EEPROM flag and/or the state of a hardware switch, ensuring flexible and secure management of firmware deployment and execution.

5. WHY ELECTRONIC SENSORY GLOVE?

Prosthetic hands perform a wide range of complex tasks during daily and social interactions, including handshakes, tapping or punching objects, and handling surfaces with varying thermal and moisture conditions [4]. Under these diverse scenarios, real-time detection of pressure, temperature, and hydration provides valuable sensory feedback to the user. To demonstrate this capability, the e-glove system was evaluated on a 3D-printed artificial hand serving as a prosthetic surrogate under representative daily use cases. Experimental results show that the e-glove system can accurately detect subtle variations in pressure within a dynamic linear range up to approximately 100 kPa, closely mimicking the tactile sensitivity of a natural human hand. The influence of skin layer thickness (ranging from 100 to 500 μm) and environmental temperature fluctuations (30 to 50 °C) on sensor performance was systematically investigated. Additionally, the repeatability and reliability of the sensors were characterized under cyclic loading at various pressure levels, demonstrating robust operation suitable for real-world applications.

The system further enhances user interaction by providing real-time sensory data visualization via a custom-designed wristwatch control unit, and by enabling wireless data transmission to external devices such as commercial smartphones or tablets for post-processing and analysis. Figure 1c depicts the control wristwatch unit, which connects to the e-glove through a flexible anisotropic conductive film (ACF) cable. A close-up view highlights the organic light-emitting diode (OLED) display used for presenting sensor information, navigating the user interface, and controlling operational settings. The control wristwatch unit houses an internal circuitry comprising a 32-bit ARM Cortex-M0 microcontroller responsible for data acquisition and Bluetooth wireless communication. Power is supplied by a rechargeable battery measuring 3.6 × 2.0 × 0.56 cm with a capacity of 350 mAh. Signal conditioning is achieved through a differential amplifier that serves as the front-end for detecting and amplifying electrical sensor outputs. The entire assembly is enclosed within a 3D-printed ABS plastic casing, providing a compact and durable housing solution. This wristwatch interface offers immediate visual feedback to the prosthetic user, enabling customizable two-dimensional data visualization tailored to individual preferences and requirements.

The findings demonstrate that complex electronic circuits and sensor arrays can be directly printed onto commercially available stretchable nitrile gloves, which inherently possess ergonomic designs compatible with diverse hand morphologies. This direct integration addresses longstanding challenges faced by conventional methods that rely on multiple flexible sensors affixed separately to prosthetic hands to accommodate their intricate geometries, thereby improving the seamlessness and functionality of prosthetic interfaces. The user interface provided by the wristwatch unit offers real-time visualization of sensory data, wireless transmission to external readers for data post-processing, and consolidated multisensory feedback—including two-dimensional mapping of temperature, pressure, and humidity across the palm—thereby enhancing user convenience and operational efficiency. The integration of additional sensory feedback modalities, such as auditory or vibrotactile cues, represents a promising avenue to further augment the interface's functionality. The e-glove system's biomimetic properties expand the functional repertoire available to prosthetic hand users in daily life and hold potential to improve psychological well-being by facilitating more natural social interactions. While this study focuses on passive prosthetic hands, the demonstrated approach is readily extendable to active prosthetic systems controlled via neural, voice, or myoelectric inputs, enabling more comprehensive and intuitive user control.

6. SENSORY FEATURES OF ELECTRONIC GLOVE

A critical sensory function for replicating human hand-like perception is the ability to detect moisture and temperature. The e-glove system incorporates an embedded capacitive hydration sensor positioned near the fingertip to identify dampness, demonstrated through detection of a wet diaper surface. Representative measurements reveal a marked increase in capacitance upon contact with the moist region. These findings are corroborated by control experiments using a commercial moisture sensor, which exhibit consistent behavior. Additionally, capacitance variations over time correspond to differing moisture levels, indicating dynamic sensing capability.

Temperature sensing performance was evaluated using the e-glove system in contact with a cup containing hot water (~80 °C). The palm area integrates a 4 × 4 array of temperature sensors fabricated from 100 nm-thick gold (Au) films interconnected via filamentary serpentine Au traces (300 nm thick). Figure 2h illustrates the spatial temperature distribution captured by the sensor array during sustained contact with the heated cup surface.

For validation, simultaneous real-time temperature measurements were conducted using a commercial infrared (IR) camera (FLIR SC645, sensitivity: 0.05 °C), confirming the accuracy of the e-glove temperature mapping.

In these demonstrations, the sensory data are visualized in real time on the control wristwatch unit's display for single-point monitoring and simultaneously transmitted wirelessly to an external device, such as a smartphone, enabling multi-array data monitoring.

An additional notable feature of the e-glove system is its capability to extend beyond conventional human sensory modalities.

Specifically, the system can detect physiological signals including heart rate and muscle activity, facilitating on-demand health monitoring and assessment of muscle fatigue during or after physical exercise. Experimental validation includes recording electrical bio-signals, such as electrocardiograms (ECGs) and electromyograms (eEMGs), through direct skin contact using the e-glove system.

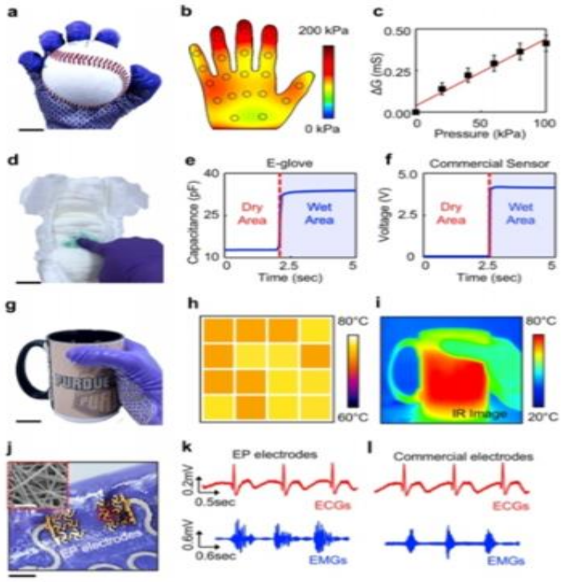

Fig 4: Sensor Features of Electronic Glove

7. WORKING OF THE MODEL

7.1 DHT Interfacing With Arduino Uno

First, connect the GND and VCC pins of the DHT11 temperature and humidity sensor to the GND and 5 V pins of the Arduino, respectively. Next, connect the data output pin of the DHT11 sensor to digital pin 2 on the Arduino board.

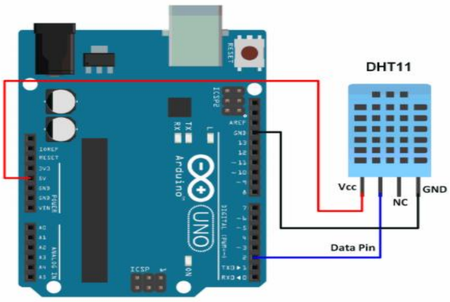

Fig 5: DHT11 Sensor Interface

7.2 Flex Sensor Interfacing

One terminal of the flex sensor is connected to ground (GND), while the opposite terminal is connected to the analog input A0 of the Arduino. A 22 kΩ resistor is connected between A0 and +5 V, forming a voltage divider circuit with the flex sensor.

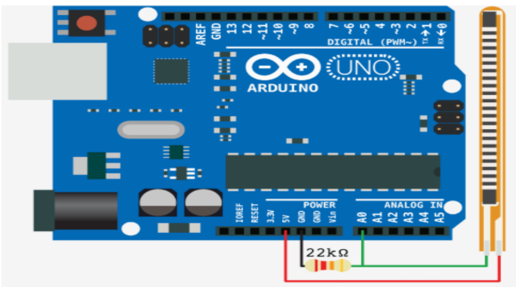

Fig 6: Flex Sensor Interface

7.3 Force Sensor Interfacing

A Force Sensing Resistor (FSR) is a sensor whose electrical resistance varies in response to applied force, pressure, or mechanical load. Also known as force-sensitive resistors, FSRs consist of two layers separated by a spacer. When pressure is applied, an increasing number of conductive “Active Element” dots make contact with the semiconductor layer, causing the resistance to decrease.

FSRs function as variable resistors, with resistance values (measured in ohms, Ω) inversely proportional to the applied force. These sensors are cost-effective and simple to implement; however, their accuracy is limited and subject to variability—typically within ±10% between individual sensors. Consequently, FSRs are best suited for detecting force ranges rather than precise quantification of applied weight. The FSR features two terminals: one connected to the 5 V supply and the other connected directly to the Arduino analog input A0, while also connected to ground through a pull-down resistor. The corresponding circuit diagram is illustrated below.

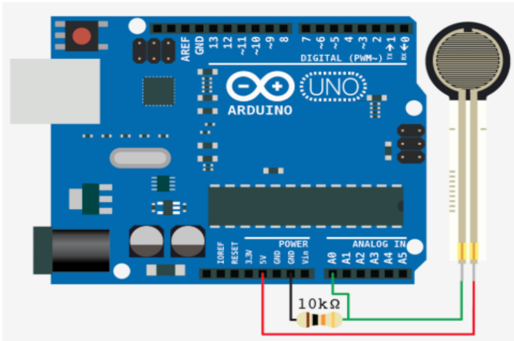

Fig 7: Force Sensor Interface

8. RESULTS AND DISCUSSION

The results presented herein demonstrate that various electronic circuits and sensors can be directly printed onto a commercially available stretchable nitrile glove, which inherently possesses the desired ergonomic design. This approach enables seamless integration with diverse hand geometries, overcoming challenges associated with conventional methods that typically rely on multiple flexible sensors wrapped around prosthetic hands to accommodate complex hand shapes.

The user interface, implemented via a wristwatch unit, offers several advantages, including real-time display of sensory data, wireless transmission to external devices for data post-processing, and consolidated multisensory feedback within a single platform (e.g., two-dimensional mapping of temperature, pressure, and humidity across the entire palm). Future enhancements incorporating additional sensory modalities, such as auditory and vibrotactile feedback, hold potential to further improve user experience and interface functionality.

9. APPLICATIONS AND ADVANTAGES

The e-glove system's realistic, human-like tactile and visual properties provide an enhanced range of functionalities for prosthetic hand users, potentially improving their mental health and social well-being by facilitating more natural interpersonal interactions. Importantly, no skin irritation or adverse effects were observed during use. The hybrid printing fabrication technique employed is both cost-effective and compatible with diverse electronic materials and complex design architectures, indicating promising applicability for a broad user population.

10. FUTURE SCOPE

This work primarily focuses on applications for conventional passive prosthetic hands; however, the results also indicate promising opportunities for integration with emerging active prosthetic hands controlled by neural, voice, or myoelectric signals. Future work should address the adaptation of the e-glove system to accommodate a broader range of hand sizes, including paediatric and extra-large adult users. Furthermore, the established e-glove platform can be extended to various applications, such as smart gloves for assistive robotic hands, automotive manufacturing, and home-based rehabilitation. The hybrid printing fabrication technique employed is cost-effective and compatible with a variety of electronic materials and complex design layouts, underscoring its potential for scalable implementation across diverse user groups.

11. CONCLUSION

Prosthetic hands that replicate the realistic appearance and warmth of a human hand can facilitate more natural social integration for users. While traditional prosthetic hands primarily restore mobility, the novel e-glove system enhances this functionality by providing lifelike tactile and visual features, thereby supporting daily activities and social roles. This advancement holds potential to improve the wearer's mental health and overall well-being through more seamless social interaction.

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