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E-Textile Haptic Feedback Gloves for Virtual and Augmented Reality Applications †

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Abstract: This paper outlines the development of e-textile haptic feedback gloves for virtual and augmented reality (VR/AR) applications. The prototype e-textile glove contains six Inertial Measurement Unit (IMU) flexible circuits embroidered on the fabric and seven screen-printed electrodes connected to a miniaturised flexible-circuit-based Transcutaneous Electrical Nerve Stimulator (TENS). The IMUs allow motion tracking feedback to the PC, while the electrodes and TENS provide electro-tactile feedback to the wearer in response to events in a linked virtual environment. The screen-printed electrode tracks result in haptic feedback gloves that are much thinner and more flexible than current commercial devices, providing additional dexterity and comfort to the user. In addition, all electronics are either printed or embroidered onto the fabric, allowing for greater compatibility with standard textile industry processes, making them simpler and cheaper to produce.

Keywords: e-textiles; haptic feedback glove; screen-printing; TENS; virtual reality; wearable

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1. Introduction

Haptic feedback gloves are wearable devices that provide a touch response to simulate tactile sensations of virtual objects [1]. Some methods employed to produce the haptics include force, vibrotactile, and thermal feedback—these are often very bulky or expensive to manufacture and limit the level of hand movements and natural feeling for the user. This research attempts an electro-tactile approach using TENS [2] due to the simplicity of the circuit required to achieve its signals, making it a suitable choice for an e-textile. The gloves aim to improve user interaction with VR/AR environments while also maintaining flexibility and breathability [3]. This study demonstrates the glove's functionalities through its interaction with a Graphical User Interface (GUI) via Bluetooth Low Energy (BLE).

2. Haptic Feedback Glove Control and System Design

The glove prototype consists of six IMUs (MPU6050—6 axes gyro + accelerometer) and six haptics channels, both located at the centre of the palm and on each fingertip. An additional electrode—the common ground of all channels—is located on the edge of the glove.

The IMUs communicate via the I2C protocol, but each IC has the same address, so the data line is controlled via a multiplexer (SN74LV4051A). A microcontroller sends data from each IMU to the GUI and controls the haptic stimulation when contact points in the GUI change.

TENS Circuitry

The TENS unit provides a tingling sensation to the user's skin at areas in contact with its electrodes by transmitting high-voltage electrical pulses. The circuit mainly consists of a boost converter (LT3467), a transistor (BC846BM3T5G) and a multi-channel high voltage analogue switch (MAX14866), as shown in Figure 1. This simplistic design minimises the overall circuit size.

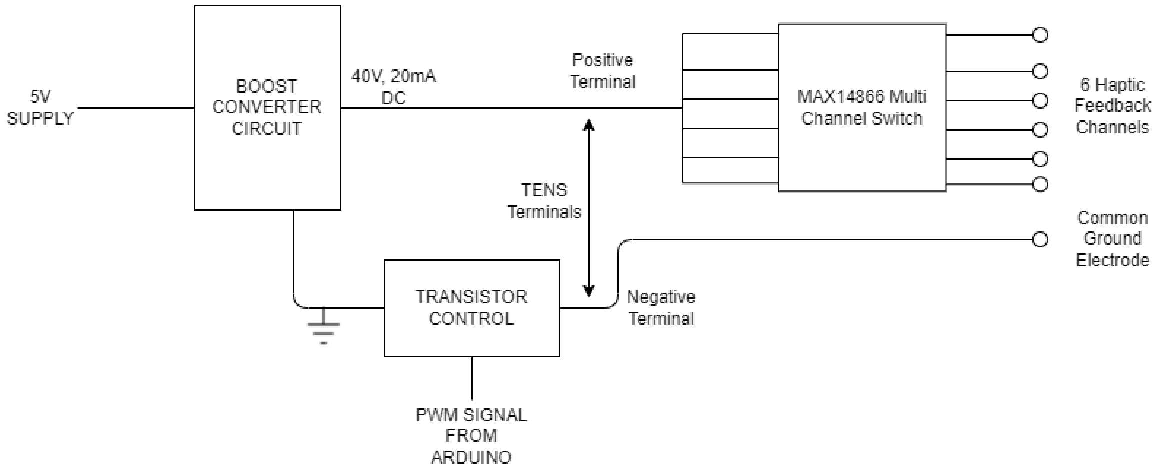


Figure 1. TENS unit system and control block diagram.

First, the boost converter generates a 40 V, 20 mA DC signal from a 5 V output of the microcontroller. A transistor is then connected between the ground and the negative terminal of the TENS output, while the 40 V output forms the stimulator's positive terminal. When the switching transistor is on, the negative terminal of the stimulator is grounded, giving rise to a 40 V potential between the two terminals. In contrast, zero potential exists between the terminals when the transistor is off. Therefore, the transistor is controlled by a PWM signal from the microcontroller to shape and generate the electrical pulses of the stimulator.

The negative terminal of the stimulator is connected to the common ground electrode, whereas the positive terminal is further connected to one end of each channel of the high-voltage, multi-channel analogue switch, allowing six independent haptic feedback channels.

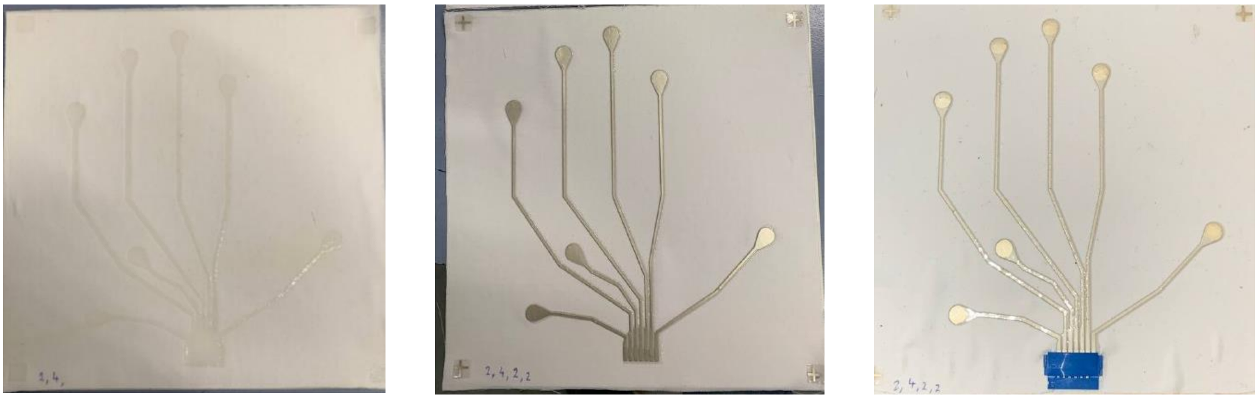
The full 5 V to 40 V boost converter circuit diagram can be found in the LT3467 datasheet; the final strip circuit design layouts can be seen in Section 3.2.

3. E-Textile Fabrication

The IMU, TENS and control circuits are embedded into the glove via flexible 'strip circuits'—these are flexible circuits orientated in a strip form to aid integration into the textile [4]. Each strip design contains pads to solder copper Litz wires (embroidered on the glove), enabling connections with other circuits [5]. The IMU circuits are located on the fingers and the back of the hand; all other circuits are located on an extended wrist fabric attached to the glove.

3.1. Fabrication of Screen-Printed TENS Electrodes

Figure 2 shows the screen-printed electrode tracks on a polyester cotton fabric (Whaley's, Bradford, UK—OpticWhite Polyester/Cotton). These tracks are screen-printed to connect to the TENS to ensure the fabric in contact with the user's hand is continuous and flexible without impeding hand movement. The conductive silver ink tracks are printed between a 'primer', used to smooth the fabric where printed, and an 'encapsulation' coating, both of which use the same ink (Smart Fabric Inks Ltd., Southampton, UK—Fabinks UV-IF1004) [6]. The 'primer' consists of four printed layers providing a smooth base for the silver ink. The 'encapsulation' consists of two layers to electrically insulate the tracks from the user's skin and increase their durability.



(**a**) (**b**) (**c**)

Figure 2. Screen-printed electrode tracks on polyester fabric: (**a**) 'Primer' layer; (**b**) Conductive layer printed on the 'primer'; (**c**) Final encapsulated electrode tracks with Amphenol Clincher crimped connector.

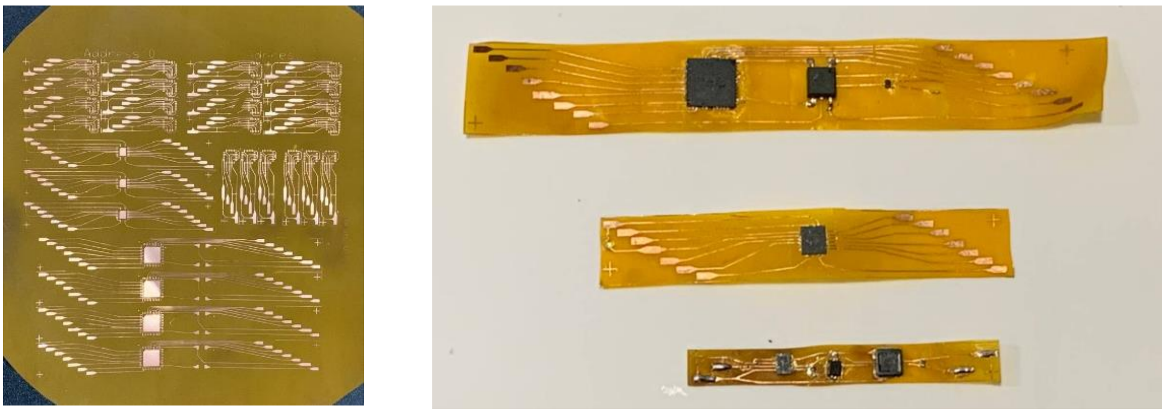
The conductive track is exposed at each end to allow contact. Hydrogel pads are attached to the rounded ends of each track to stimulate the fingertips and back of the hand. A crimped connector connects the printed tracks to the electrical stimulator.

3.2. Fabrication of Flexible Strip Circuits

The strip circuits are fabricated from copper laminated polyimide (Kapton) film (GTS Flexible Materials Ltd., Ebbw Vale, UK) due to its flexibility and thinness (25 µm), reducing its noticeability when integrated with the glove.

The conductive tracks are etched from the copper using a photolithography process developed previously at the University of Southampton [4] based on standard PCB processes. The strips were then cut out for component soldering.

Figure 3 shows examples of the circuit wafer and strip circuit. With single-layer copper, strip circuit designs are limited with no vias, creating significant design constraints. Hence, each strip design is simple, using embroidered wires for external connections. This e-textile fabrication technique allows for complex circuits to therefore be distributed around the garment, connecting to create more complex systems.

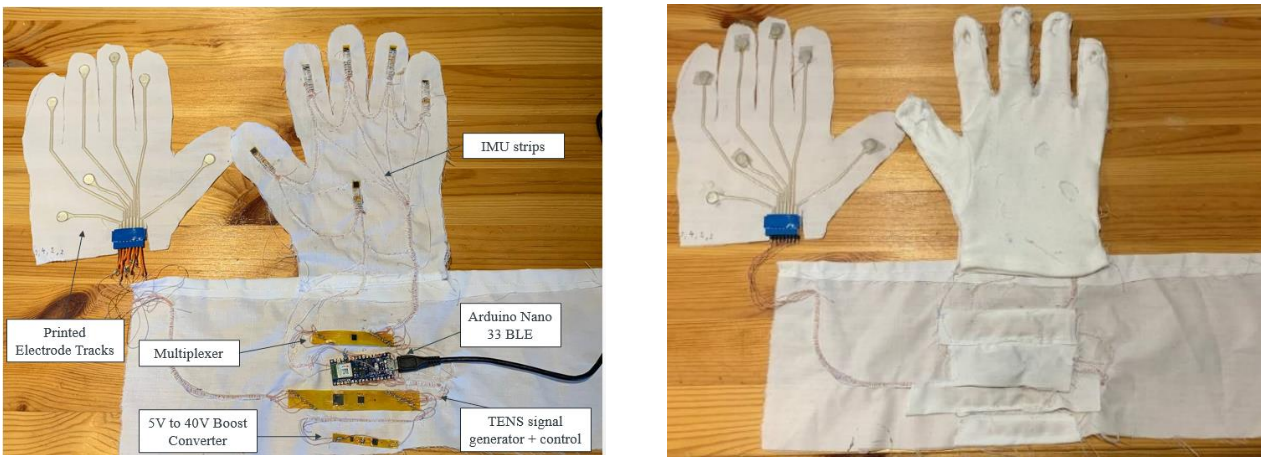


(**a**) (**b**)

Figure 3. Electronic strip circuits: (**a**) Copper tracks on Kapton after etching stage; (**b**) Final strips with components soldered: high-voltage multiplexor (top), digital multiplexor (middle), boost converter (bottom).

4. Finished E-Textile Haptic Feedback Glove Prototype

The finished glove prototype is shown in Figure 4. The wrist extension attached to the glove contains an Arduino Nano 33 BLE, the TENS circuitries and a multiplexer connected to the IMUs. The IMU strip size is 24 × 5.7 mm; hence, they were easily embroidered onto the glove and can be fitted on each fingertip. All other strips are secured to the wrist with pockets stitched over them. A cotton glove is also stitched over the fabric of the IMU strips to be worn by the user. For this prototype, to make it easier to test, the electrodes were printed on the fabric separately to ensure that if one part failed, the entire e-textile was not lost. However, for future mass manufacturing, all of these parts could be combined.



(a) (b)

Figure 4. Finished haptic feedback glove prototype: (**a**) All electronics exposed for illustration; (**b**) Final glove design.

Figure 5 shows the functionalities of the glove. In this example, haptic feedback was provided to the wearer at the thumb and index finger channels as they are in contact with the sphere. The user's hand movements are tracked, and the haptic feedback is updated every frame to reflect events occurring in the GUI in real time.

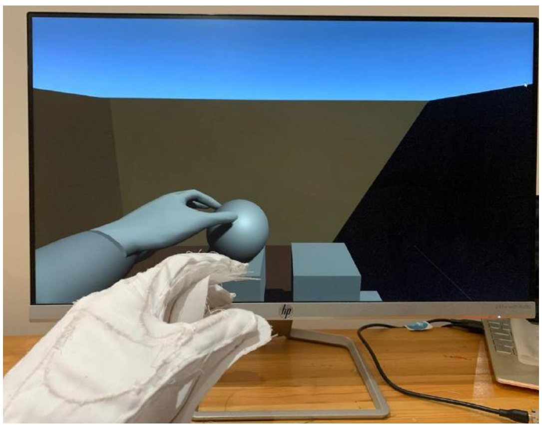


Figure 5. Demonstration of the e-textile glove's interaction with the GUI.

5. Conclusions

This paper demonstrates the development of simple and comfortable e-textile haptic feedback gloves using TENS. The technologies of screen printing and flexible strip circuits are integrated into the design, using embroidered wires to make any necessary connections. The strip circuits ensure small but robust e-textile circuitry while implementing screen-printed electrode tracks provides additional dexterity and comfort. Currently, the prototype can track wrist and finger movements and provide haptics at six channels, but these can be improved with additional IMUs and electrodes.

Future developments include reducing the size of ICs used to further reduce the overall circuit and replacing the electrodes with carbon electrodes printed directly on the glove along with their tracks. Additionally, multiple haptics patterns can be implemented by varying the stimulator pulse width and frequency to allow for different touch sensations.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study and their permission to publish this paper.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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