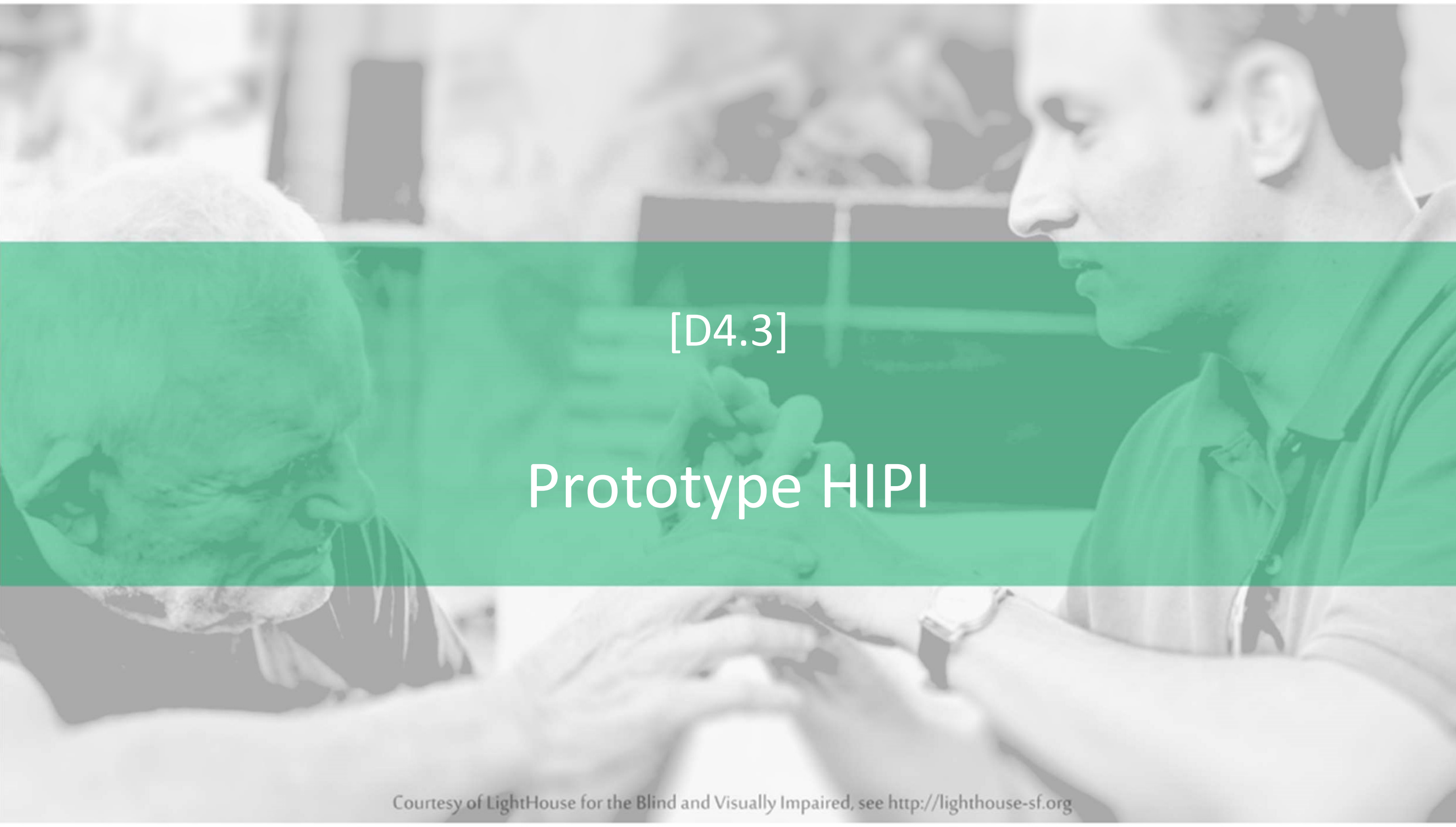
SUITCEYES

1 Jan 2018 - 31 Dec 2020

Smart, User-friendly, Interactive, Tactual, Cognition-Enhancer, that Yields Extended Sensosphere
Appropriating sensor technologies, machine learning, gamification and smart haptic interfaces



[D4.3]

Prototype HIPI

Courtesy of LightHouse for the Blind and Visually Impaired, see http://lighthouse-sf.org

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Dissemination level		
PU	PUBLIC, fully open, e.g. web	X
CO	CONFIDENTIAL, restricted under conditions set out in Model Grant Agreement	
CI	CLASSIFIED, information as referred to in Commission Decision 2001/844/EC.	

Deliverable Type		
R	Document, report (excluding the periodic and final reports)	
DEM	Demonstrator, pilot, prototype, plan designs	X
DEC	Websites, patents filing, press & media actions, videos, etc.	
OTHER	Software, technical diagram, etc.	

Deliverable Details	
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Lead member	Dr RJ Holt

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v0.2	26/3/2021	First draft for internal review	RJH/UNIVLEEDS
v0.3	29/3/2021	Second draft addressing review comments submitted to HB	RJH/UNIVLEEDS
v0.4		Final draft addressing PC and PMB reviewers' comments	
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Glossary	
Abbr./ Acronym	**Meaning**
AAEON Up Board	A tiny computer for use in robotics and Internet of Things projects.
Ably	A realtime messaging service that allows messages to be sent between devices; able to act as a broker for MQTT communication.
Actuator	An actuator is a component of a machine that is responsible for moving and controlling a mechanism or system.
BLE Beacon	Bluetooth Low Energy Beacon – a beacon that broadcasts information using the Bluetooth Low Energy protocol. Using its identifier and signal strength, the proximity of such beacons to a device can be determined.
HIPI	Haptic intelligent personalized interface – the goal of SUITCEYES and built as a textile structure.
MQQT	Message Queuing Telemetry Transport: an open source, ISO standard protocol for communication between devices such as microcontrollers via a server computer known as a broker.
RGB-D Camera	A camera capturing both a conventional (RGB) image, and a depth map such that both 3D spatial information is available.
Raspberry Pi	A tiny computer made for teaching computer science. Widely used in development projects.
ROS	Robot Operating System. An operating system that provides methods for capturing and processing sensor information, and delivering instructions to actuators.

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Executive Summary

This report outlines the development of the prototype Haptic Intelligent Personalised Interface (HIPI), with the aim of enabling the sensors and visual analysis algorithms developed in the project to be run on a wearable prototype for testing purposes. The report describes three iterations of development, showing the refinement of the sensor system and hardware, and how this was then integrated with the textiles being developed in WP5.

The final prototype contains the ultrasonic sensors, depth camera and BLE Beacon detection of the version reported in D4.2, but now integrated into a single wearable garment with a vibrotactile belt for direction information and a 4x4 grid of vibration motors on the back to deliver more complex haptograms. It also provides online communication to the visual analysis and ontology components developed in WP3. The prototype has been validated by using to conduct an active object search test to verify that the sensors continue to provide correct outputs when worn. The system is now ready for testing the use of haptic signals to aid navigation tasks, to be tested in WP6.

Introduction

As described in T4.3: Integrate Sensor System with Smart Garment, Deliverable 4.3 (Prototype HIPI) is the final revision of the sensor system, such that the sensors are incorporated with the haptic interface developed in Work Package 5 and that signals are provided to trigger haptic feedback as required. Task 4.3 involves three main activities:

a) Refining the sensor array and processor so that it can be integrated with the haptic interface;

b) Integrating the sensor array with the haptic interface to form a combined prototype HIPI; and

c) Verifying that combined HIPI prototype provides correct outputs during movement.

The completion of these activities has been affected by lab closures during the 2020 COVID-19 pandemic, which are still ongoing at the time of writing. Activity a) has been completed; Activity b) has been partially completed and activity c) cannot be completed until the prototype has been finally interfaced. Accordingly, this report outlines the progress on the first two activities to date, and an updated report will be submitted once the activities are completed.

Refining the Sensor Array

This section describes the starting point of the Sensor Array at the beginning Task 4.3, and refinements made to develop the system ready for integration with the Work Package 5 garment.

First Iteration Prototype

The first iteration of the sensor system was submitted as Deliverable 4.1 and revised in Deliverable 4.2 into a system comprising:

- An RGB-Depth camera (the Intel RealSense R200) to capture images for visual analysis and depth data for collision avoidance;
- Three ultrasonic distance sensors for collision avoidance;
- An inertial measurement unit (IMU) to detect self motion and rotation;
- Bluetooth low energy (BLE) beacons for indoor proximity detection;
- An AEON Up board as the main processor;
- Arduino Nanos (for ultrasonic sensor data acquisition and vibration motors control). A simple bespoke tactile belt with 6 vibration motors and its driver circuit were developed for system testing.
- A belt of six vibration motors to provide basic vibrotactile feedback.

This initial system is illustrated in Figure 1, below.

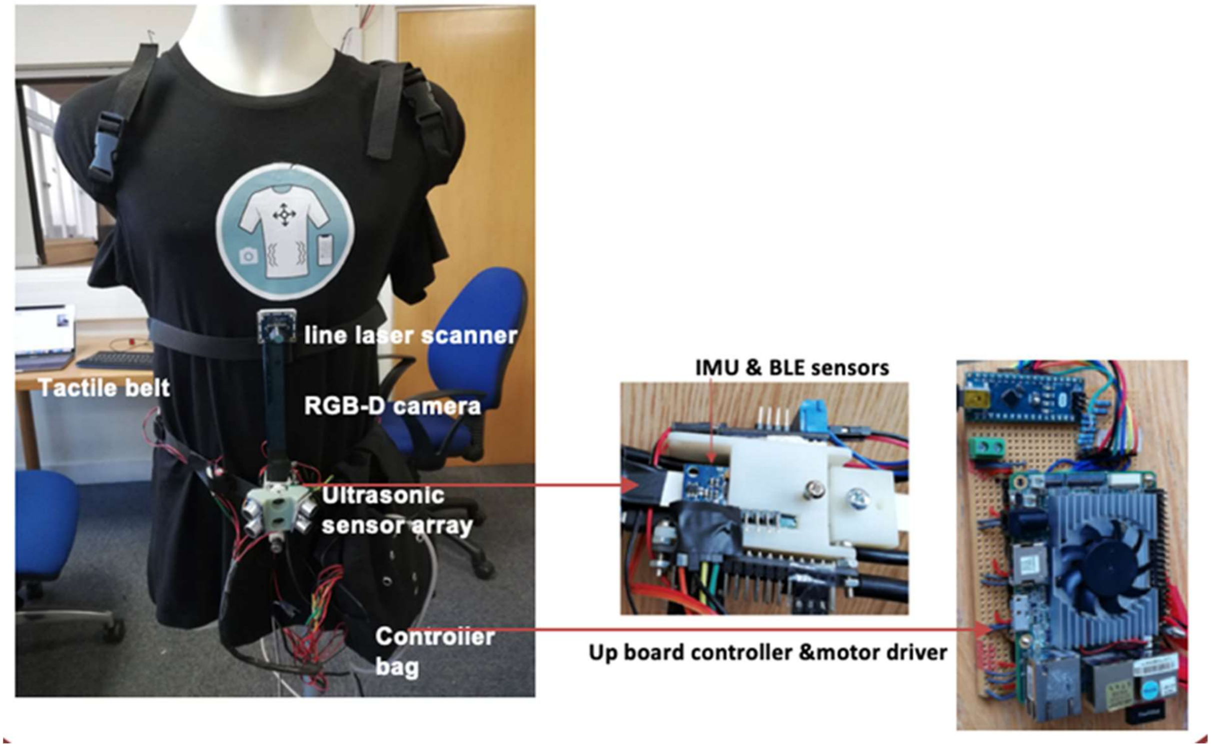

Figure 1: Sensor System at completion of D4.2

Second Iteration Prototype

There were three key goals in refining the sensor system was to ensure that it was ready for integration with the garment and haptic interface being developed in Work Package 5, by achieving three goals:

1) To finalise the location of sensors so that appropriate locations and wiring could be designed into the garment;
2) To finalise of the processors and battery so that they could be worn comfortably rather than all being carried at the waist;
3) To develop the interface between the processor and up to 24 vibration motors to be arranged around the body.

To address this, the second iteration introduced the following changes:

1) following feedback from the user studies in T4.2, two ultrasonic sensors have been added at shoulder height to detect high obstacles in front;
2) A sensor interface board for the IMU, Bluetooth and ultrasonic sensors to provide more reliable power supply to them;
3) A 24-channel motor driver board that mounts on top of an Arduino Mega to interface the system with vibration motors; and
4) A prototype embroidered circuit produced by HB to test the potential for using embroidered circuits in the final garment.

The second iteration prototype is shown in Figure 2, and the key changes described in more detail below.

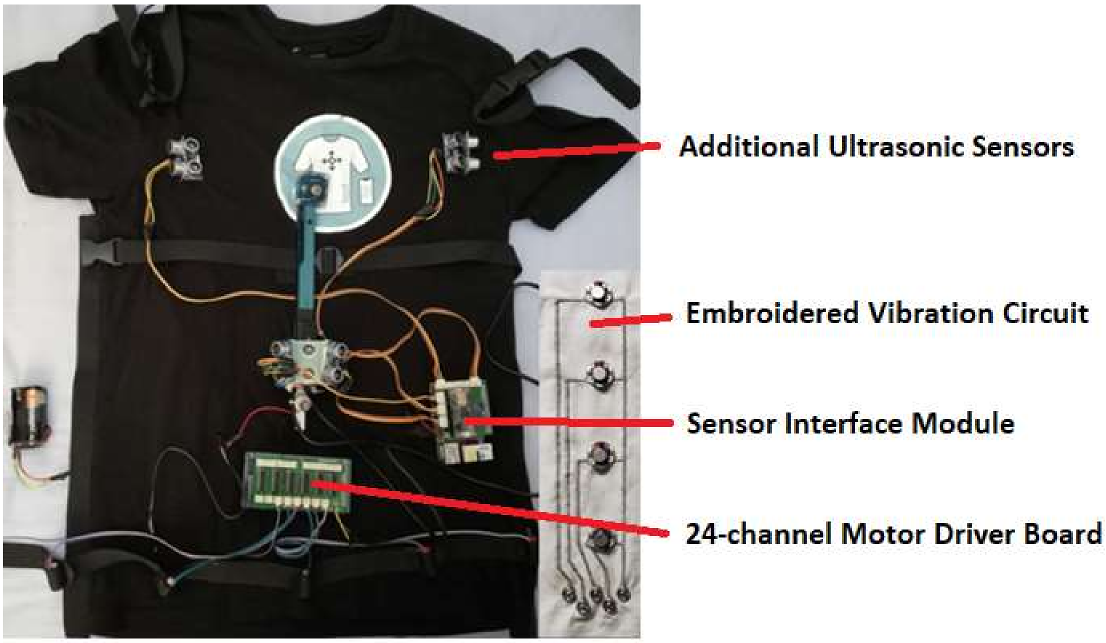

Figure 2: Second iteration prototype sensor system with key additions labelled

Sensor Interface Board

The first prototype required an Up Board in order to interface with the Intel RealSense Camera. However, unlike the Raspberry Pi 3B+, the Up Board does not have built in Wi Fi and Bluetooth Capabilities, so a combination of a Raspberry Pi 3B+ and an Up Board had to be used. To simplify this, a new sensor interface board was created that allowed Bluetooth, IMU and Ultrasonic sensors to be plugged into the UpBoard and powered from the battery to provide a more reliable source of power. This shown in Figure 3.

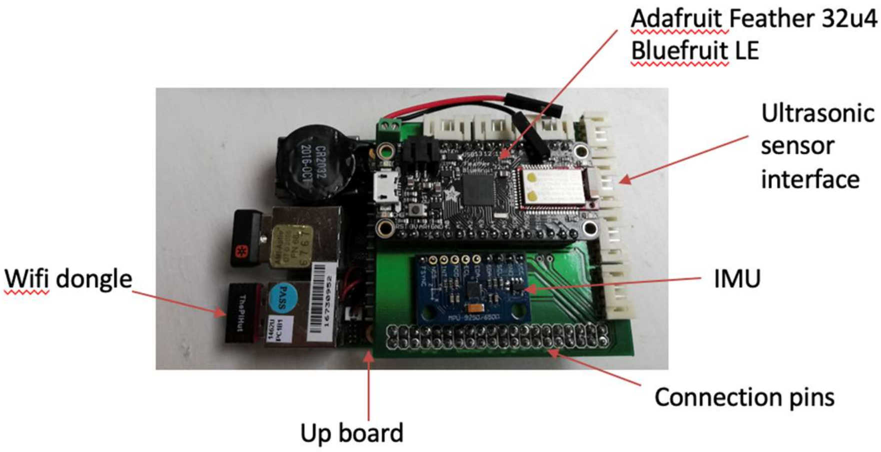

Figure 3: Sensor Shield Mounted on the Up Board

Motor Driver Board

To allow the running of 24 motors controlled by an Arduino Nano, a motor driver board that could be integrated with an Arduino mega controller directly was designed, as shown in Figure 4. It was based around an H bridge control circuit (L293DNE), each capable of provide four single direction motor driver channels, with a maximum current ~1A. This allowed the system to work with the motor driver developed in D5.4, running on an Arduino Mega. The Motor Drive Board is shown in Figure 4.

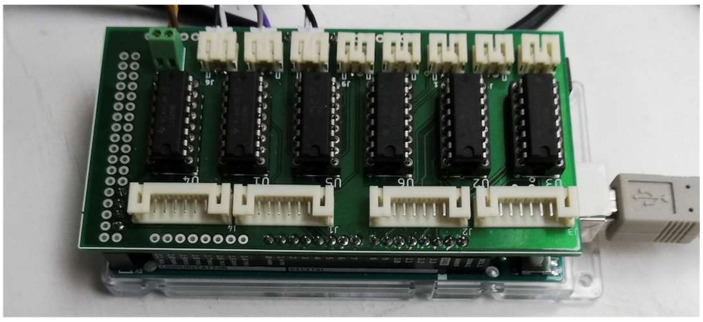

Figure 4: Motor Driver Board

Embroidered Circuits

Interaction with the prototypes developed in Deliverable 5.7 demonstrated that wire management is a significant issue, particularly when dealing with twenty-four vibration motors. One alternative would be to route power through the garment using conductive thread. Accordingly, a number of sample circuits were made at HB for testing at UNIVLEEDS. These explored the ability to power up to 4 pancake vibration motors in a column (1 column of the proposed 4 x 4 grid). However experimentation with embroidered circuits of different resistances found that cross-talk between channels was a significant problem (where activating one channel would cause a weak signal in an adjacent channel), and that when using resistances high enough to prevent this, significant power was lost from the circuit, weakening the vibrations in those motors with longer tracks. Accordingly, a decision was made to avoid embroidered circuits, and use conventional wires instead.

Third Iteration Prototype

The second iteration prototype describes the state of the system at the start of March 2020 when the COVID-19 pandemic led to lab closures and made further work on the prototype and garment impossible. By the time work resumed on integration in October 2020, there had been a number of significant developments in the rest of the project and relevant technologies:

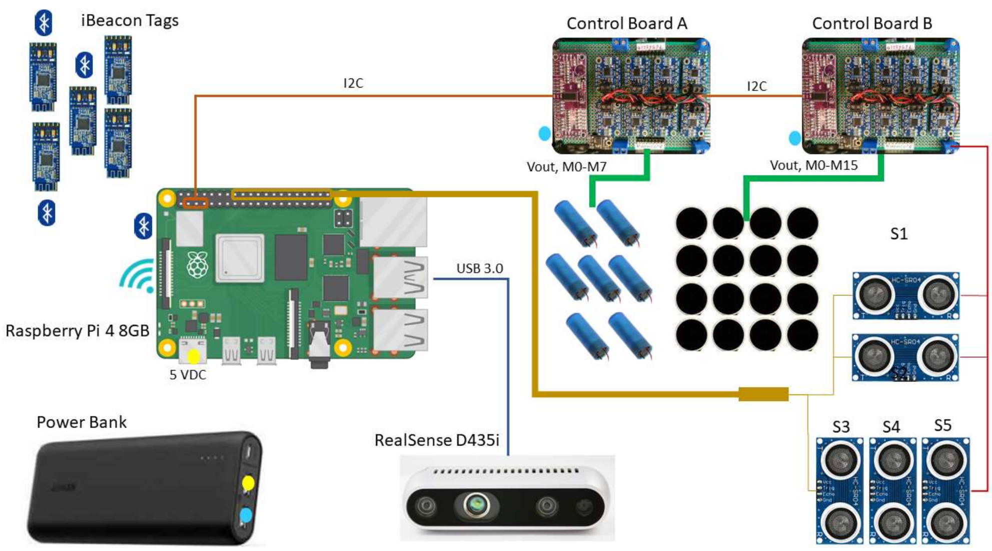

Figure 5: HIPI Hardware System

1) The Raspberry Pi 4 8GB model had been released offering the potential to replace the Up Board with a mini-computer that had built-in WiFi and Bluetooth connections and was able to interface with the low cost Raspberry PiCam; additionally the Raspberry Pi 4 formed the basis of experiments in WP3 and WP7. The updated system designed around RPi 4 as the central and only onboard computation module is shown in **Figure 5**.
2) Developments in WP3 and WP6 suggested that PWM control on all motors would be desirable, which led to replacing the Arduino Mega with a PCA9685 Servo Driver, requiring a new motor drive board to manage power. Two haptic motors control board are presented in **Figure 6.** Both boards are based on PCA9685 for variable vibration intensity control. The first prototype is utilizing DRV8833 motor driving chips. DRV8833 drivers are PWM controlled by the PCA outputs. The PCA is connected to the RPi4 and the second PCA over an I2C bus. Two PCA are connected in series to control the 16 disc motors on the back and 7 cylindrical motors around waist and on shoulders. A more compact control board is designed with USB power interface and an additional power protection layer.
3) As the RealSense R200 was no longer fully supported by the most up-to-date RealSense SDK, it was replaced with the more recent RealSense D435i camera. Additionally, the D435i is equipped with an improved depth sensor, faster serial data transmission, and embedded 6-axis Inertial Measurement Unit (IMU).
4) The RealTime Framework, which forms a core part of interaction between the HIPI and functions such as visual processing and ontology, the tactile interface developed at HSO, and the one-to-many communication being developed at Tu/E, ceased operating. Accordingly, the communication protocol was updated and the current prototype uses another data exchange protocol; MQTT via the Ably Broker.

These features formed the basis of the efforts to integrate the sensor system with the textile elements developed at HB.

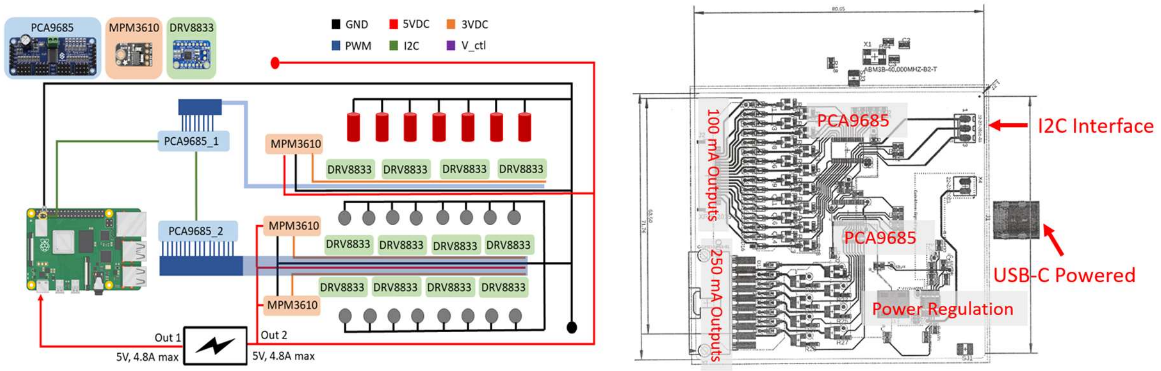

Figure 6: Motor Control Hardware Interface, left: Circuit using off-the-shelf components, right: Custom designed haptic motor control board.

Garment Integration

The garment as it stands is designed to be modular, so that it can work with either the Raspberry Pi or the Up Board (or any computation board with similar or close footprint and interfaces such as the Nvidia Jetson); and so that the low cost Pi Cam or more expensive cameras (such as the RealSense D435i) can be affixed. This allows the potential for different implementations (a cost effective, acceptable performance version; or a more expensive high-performance version) as well as the potential to update the hardware components for future projects without the need to change the textile infrastructure.

The garment is shown in Figure 7. The garment is side-entry, so that it can be put on and off without disturbing the centrally mounted camera and computer, and so that wires can run around the non-opening side.

Figure 7: Prototype Garment showing front pockets for power pack (lower) and Raspberry Pi (upper); back pocket for motor driver boards; and side opening zip.

The prototype described here is design for a medium build, but elastic panels and adjustable straps mean that some variation in size can be accommodated. In practice, however, it is impossible to make a garment that is one-size fits all, so ultimately different sizes of garment would need to be made to accommodate different body sizes.

The inner section of the garment is shown in Figure 8. An inner lining is included to shield the wires from the user: this can be unzipped to gain access to the wires.

Figure 8: Inner section of the garment showing (upper) wires ready for connection to the Raspberry Pi and sensors and actuator matrix; and (lower) the wires covered by internal lining.

The 4x4 actuator grid is created as a separate module, illustrated in Figure 9 that can be plugged into the main garment.

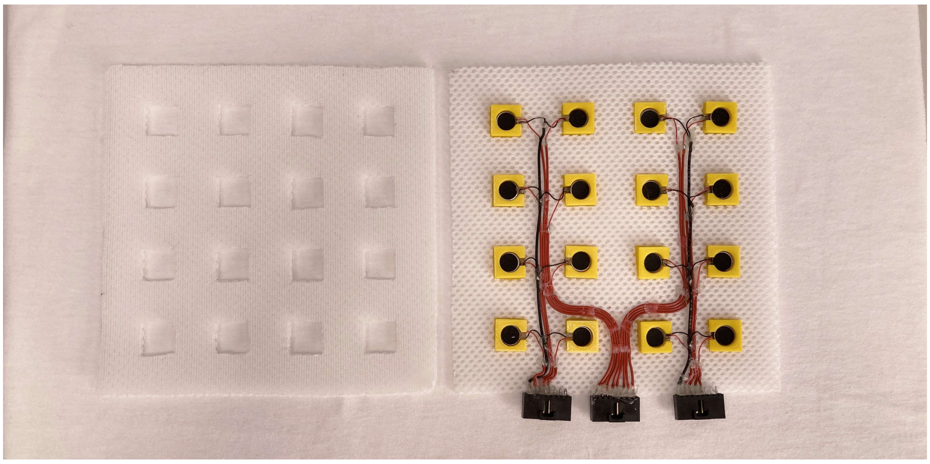

Figure 9: The 4x4 actuator grid, and protective cover.

Additionally, 3D-printed housings have been designed and produced for the ultrasonic sensors (shown in Figures 10 and 11).

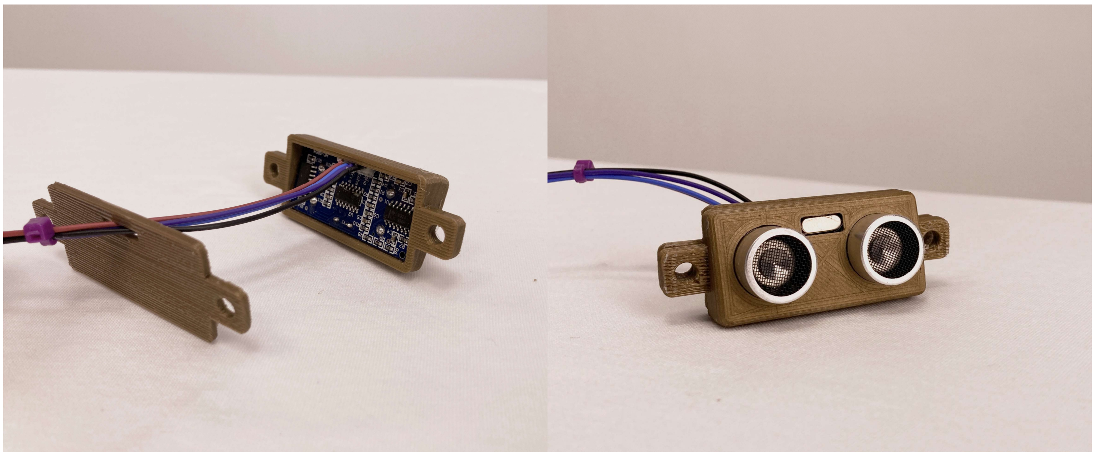

Figure 10: Mount Design for Shoulder Ultrasonic Sensors.

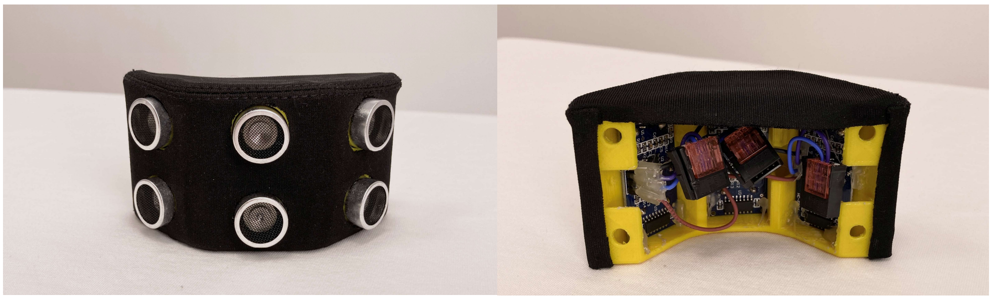

Figure 11: Mount Design for central Ultrasonic Sensors.

The haptic motor control and sensor power interface board is shown in figure 12. The board consists of two stacked PCBs, each can control up to 16 vibrating motors. Multiple power outputs are available to power the rest of the sensors in the system. The board is powered via a USB cable connected directly to the HIPI's power bank. The board connects to the Raspberry Pi 4 via the I2C pins on the Pi's GPIO header as shown in figure 5.

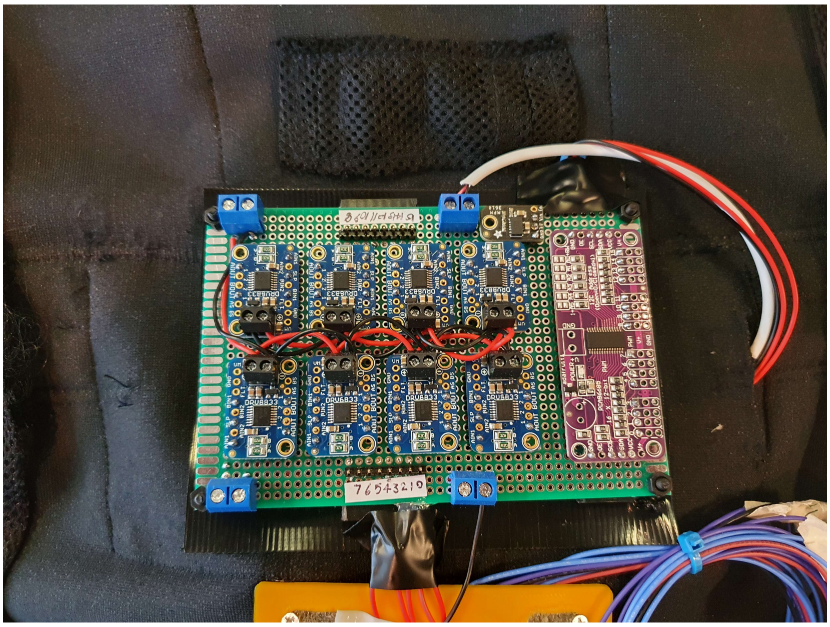

Figure 12: Haptic Motor Control Board.

Figure 13: Current prototype of the HIPI system with all components mounted.

Testing and Validation

To test the functionality of the HIPI, we designed a sample demo to illustrate the operations of various system's components. Before running the test, we run some calibration steps to make sure the fit is comfortable, and the user can physically distinguish different vibrating patterns. Figure 13 shows the HIPI on the user who reports comfortable fit of the HIPI even after extended testing hours that extended to 4-5 hours in some of the testing days. Heat buildup can be a problem especially in long sessions, suggesting that it may be desirable to provide more insulation between the user and the electronics where possible. The fabric flexibility and the belts on the side greatly contribute to adjusting the fit for the user comfort so it is not too tight or too relaxed.

Figure 14: Comfortable fit of the HIPI on the user during the experiment.

The experiment was designed with our collaborators in CERTH who is developing computer vision algorithms for objects and scene detection and classification. The user testing the HIPI is steered toward a desired object inside the room starting from outside the room door.

The testing setup in figure 15 consists of the following elements:

A. HIPI: all sensors and actuators are connected to the Raspberry Pi directly or through the control board. The onboard communication chip supports WiFi and Bluetooth. The WiFi antenna connects the system to a wireless router for local diagnostics and internet link. The Bluetooth antenna is used to scan and read the iBeacon tags data for proximity estimation. The Raspberry Pi runs 3 software modules:
   1. Communication: responsible for encoding, decoding, and exchange data over the internet. It also handles hardware interfaces and necessary data filtering.
   2. Control: it receives the processed data from the ontology and other local sensors and generate the high-level control commands to guide the user throughout the navigation mission, e.g. move forward, turn left, turn right, arrived, search, …, etc.
   3. Haptic Interface: translates the control signals to vibration patterns. The user is trained to identify different vibration patterns and their meanings.

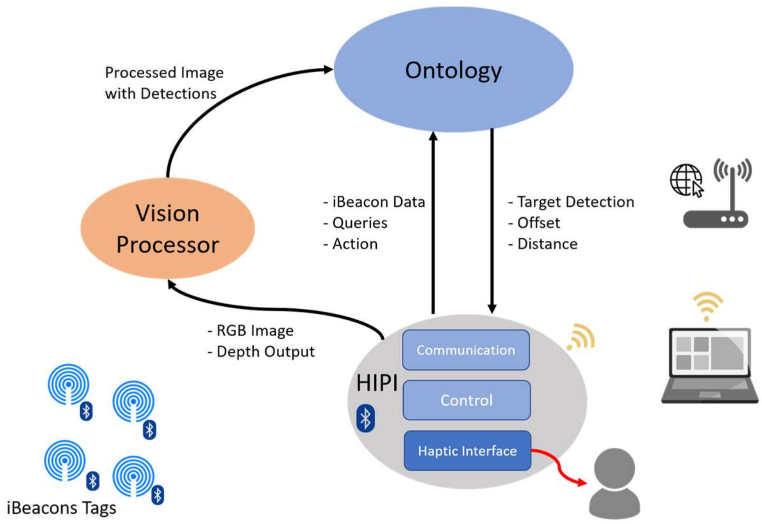

Figure 15: HIPI Testing Setup.

B. Vision Processor: the RealSense camera image and depth data are streamed over the internet to the computer vision server and sensor data is communicated via MQTT using the Ably broker. The vision data is processed, and the results are sent to the ontology.

C. Ontology: receives the processed sensor and image data in addition to a requested query specifying an object to find (currently sent from a laptop computer) and sends back information to the HIPI including whether the requested object is identified, how far and the relative direction. The HIPI communication interface receives this data over the internet via an MQTT incoming message. The feedback data is fused with the local sensors readings and processed to generate the control action and the associated Haptic feedback that is sent to the user.

D. iBeacons tags: attached to object of interests (hotspots) inside the room to provide a sense of proximity to the user. These tags are scanned by the Raspberry Pi on the HIPI and their RSSI is filtered and used to estimate the relative distance.

E. Networking and Monitoring: the room is equipped with a wireless router that enables the HIPI to connect to the internet and to connect to other devices available locally that can be other HIPIs or monitoring devices. In this experiment, a laptop running Ubuntu OS is used to debug and monitor the data transmission and the flow of the operation.

The user wearing the HIPI starts outside the room, enters the room and searches for a target object. In the specific sample scenario in figure 16, the target object is the water bottle on top of the chest of drawers. A software query is sent from a separate computer to the ontology that triggers a search for the target object. When the object is not in the camera scene, the ontology returns a message indicating this, and the HIPI sends a haptic signal sent to the user to put him in **Search Mode** where the user needs to move around and explore the room until the object is detected. The iBeacon proximity estimates will contribute to inform the user haptically if he/she is getting closer or further from the target.

When the target object is detected, the ontology alerts the HIPI, which then sends a haptic signal to notify the user to enter the **Guided Mode** where the vibrators on the waist are used to convey the relative direction and distance from the target. Once the user is in proximity of the target (where the object is within hand reach), the user is haptically notified with an arrival signal that triggers fine movement adjustments for the subsequent guiding signals. This is the **Final Approach Mode** where the user needs to also utilize his/her touch sense in addition to the vibrating signals to finally grab the target object.

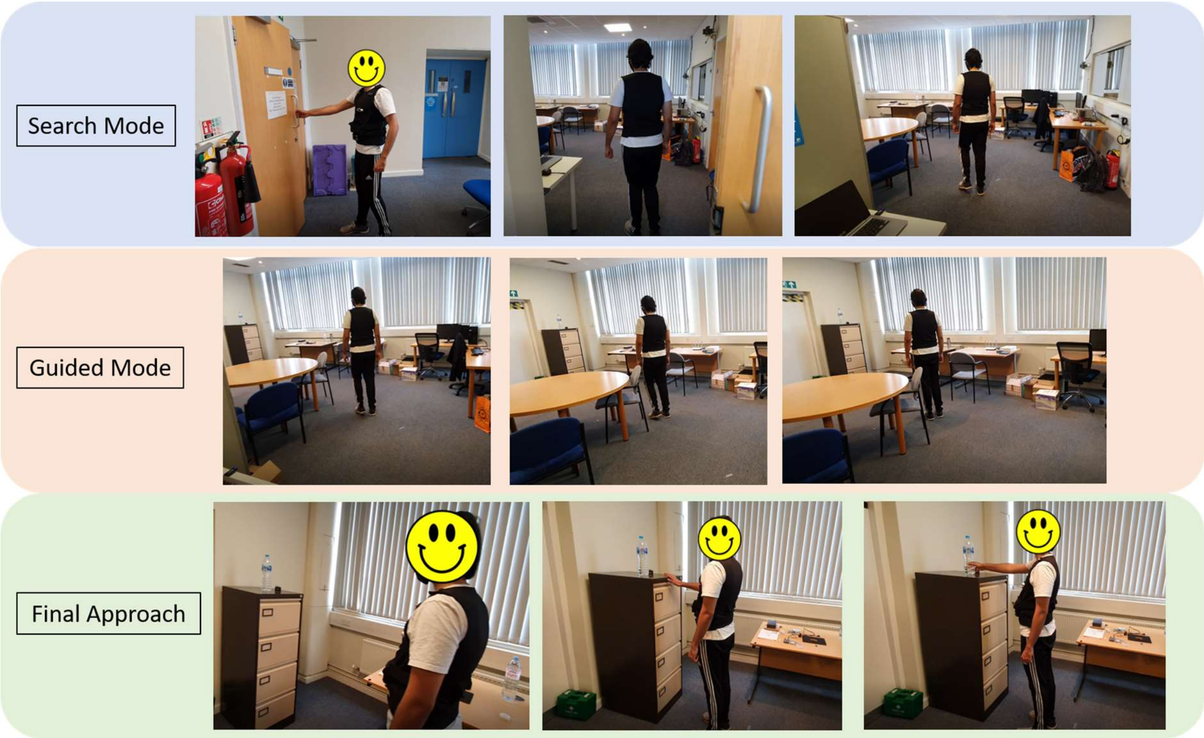

Figure 15: A Sample Navigation Mission Using the HIPI Haptic Feedback.

Summary

This report describes the development of the initial prototype HIPI, bringing together work from Work Packages 3, 4 and 5 into a single device ready for the navigation studies in Work Package 6. Three iterations of prototype development have been described, leading up to the first completed prototype that has been tested using a sample navigation mission. There are still areas for development in future iterations of the HIPI, particularly in terms of comfort and integrating the ability to send pre-defined queries from the HIPI to the ontology, rather than using a separate computer to issue queries. This prototype represents a basis for the next stage of testing, and retains the modular philosophy developed throughout the project so that it can form a platform for future research as well.