# Wearable Human Computer Interface for Control within Immersive VAMR Gaming Environments Using Data Glove and Hand Gestures

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***Abstract*—The continuous advances in the state-of-the-art in the Virtual, Augmented, and Mixed Reality (VAMR) technology are important in many application spaces, including gaming, entertainment, and media technologies. VAMR is part of the broader Human-Computer Interface (HCI) area focused on providing an unprecedentedly immersive way of interacting with computers. These new ways of interacting with computers can leverage the emerging user input devices. In this paper, we present a demonstrator system that shows how our wearable Virtual Reality (VR) Glove can be used with an off-the-shelf head-mounted VR device, the RealWear HMT-1™. We show how the smart data capture glove can be used as an effective input device to the HMT-1™ to control various devices, such as virtual controls, simply using hand gesture recognition algorithms. We describe our fully functional proof-of-concept prototype, along with the complete system architecture and its ability to scale by incorporating other devices.**

***Keywords—Virtual Reality, Augmented Reality, Mixed Reality, Human Computer Interface, VR Glove, RealWear HMT-1™, Hand Gesture Recognition, Control, Immersive Environment***

## I. INTRODUCTION

In the recent years, there have been significant advances in the Virtual, Augmented, and Mixed Reality (VAMR) technology. These developments are a major step forward in the way humans interact with computers. It is an enabling factor for many applications spaces involving immersive Human-Computer Interaction (HCI). This technology enables people to interact with computers using head-mounted displays/devices (HMD) [1], which can offer an immersive experience. The significance of these developments is recognized by large technology companies. Indeed, global companies, such as Google, Microsoft, Facebook, and others, are actively investing in this space through their own research and HMDs, or by means of acquisitions of smaller organizations. Some of the areas that experience an exceptional growth in interest include the leisure-focused traditional gaming, as well as serious gaming for training and education, and other simulation-based areas [2, 3].

The immersive HMDs play only a partial role in the VAMR technology. For a VAMR system to be complete, the users need to be able to interact with various objects, both real and virtual ones, through HCI. There exist various input devices that can serve this purpose including keyboards, mice, various controllers, including wearable ones. The HCI, however, is not limited to the input devices, but it also includes the ways, in which one interacts with computers using these devices. One of the ways that is appealing in the context of VAMR, are the hand gestures, which is something that people do naturally. Thus, it may be one of the most obvious approaches to consider when controlling objects within the VAMR. Much work exists in the literature looking at such HCI for control in immersive environments [4], including emerging vision sensors, called lens-less smart sensors, that can also be used in this context [5, 6]. Many possibilities exist regarding potential operations, which one can perform using hand gestures. One of the most apparent examples thereof can be the actuation virtual controls or actuators, i.e. they do not necessarily need to physically exist in the real word. Alternatively, these controls may physically exist, but they may be controlled from a distant location. If one can successfully perform this task using VR and hand gestures, then many other similar tasks could be also achievable.

For this to be possible, one must first be able to do a reliable hand motion tracking, before the gesture detection can be even considered. One of the instinctive approaches for hand tracking in this context could involve the visual tracking with camera systems. These methods, though effective in many use cases, are often impractical. In the context of VAMR, the use of inside-out-tracking, embedded in the HMD, tends to be the preferred method [7], as opposed to the outside-in-tracking, which involves external cameras. However, visual tracking suffers from many problems, mainly occlusion-related [8], which is one of the main disadvantages for this approach. From a practical point of view, visual-only tracking should be avoided in such use cases. Even the most advanced techniques,

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such as those that utilize state-of-the-art (SoA) convolutional neural networks with the RGB-D sensors, combining 2D colour with 3D depth images, consistently fail under conditions, which are typical for many VAMR applications [9]. Although some visual tracking methods prove to be promising [10], it is required that the tracked hand remains within the Field-of-View (FoV) of the camera. Moreover, uncontrolled lighting conditions can have a significant if not prohibitive impact on the performance of the visual tracking [11] and represent one additional challenge to visual tracking in this context, which is very difficult to overcome. . Therefore, alternative approaches should be considered.

The above-mentioned shortcomings could be overcome by using a hand glove fitted with Inertial Motion Unit (IMU) sensor systems as an input device [12]. Such an approach can eliminate the dependence on visual tracking. Recent advances in the SoA in this area show encouraging results, with several devices described in the literature. They include the VR Glove, which was developed in the Tyndall National Institute [13]. It is the result of a series of prototypes that laid the foundations for the latest iteration of the glove [14, 15], that can be used for hand gesture detection applications.

In this work, we used the VR Glove as an input device to a head-mounted VR device. The VR device of our choice was the off-the-shelf industrial-grade HMD HMT-1™ made by RealWear, Inc. [16], which may be considered an industrial VR headset used to interface with a virtual industrial control.

The main contributions of this publication include:

- A scalable architecture to accommodate multiple input-output devices (IO) for a VAMR system, described in Section II A (1);
- A robust gesture recognition technique using the VR Glove, presented in Section II A (2);
- A full implementation of a working proof-of-concept prototype, illustrated in detail in Section II B;
- Analysis of the developed system in terms of the advantages and shortcomings of an IMU-only motion tracking and gesture recognition is finally described in Section III.

## II. METHODOLOGY

The work described aims at designing and implementing a proof-of-concept prototype which demonstrates the capability of the VR Glove in the context of VAMR applications. The objective is to obtain a fully functional demonstrator system as a proof-of-concept lab-based demonstrator. Moreover, additional requirements consider the scalability of the system and the possibility to potentially incorporate future functionalities, such as various IO devices, which could be deployed in real-world scenarios.

The design and implementation of the work described is informed by three leading drivers. Firstly, the main objective is to evaluate and demonstrate the capability and versatility of the VR Glove, using an example of a specific application. Secondly, the selected application of interest involved the actuation of a virtual control using hand gestures. Finally, a suitable off-the-shelf VAMR HMD, the HMT-1™ was selected for integration with the current system. The resulting system design is illustrated in the next sections.

## III. SYSTEM DESIGN

### *A. System Architecture*

The overall system architecture was modelled on a design concept, which is commonly used in organising Wireless Sensor Networks (WSN) [17]. A grid-based data aggregation scheme was developed to maximise the functionality and future scalability, while limiting the complexity of the overall system. Instead of directly linking the smart data capture glove to the HMD, an intermediate step was introduced, i.e. the Data Aggregator, as shown in Fig. 1. This approach allows the use of various devices to be seamlessly integrated in the system, thus providing a variety of additional functionalities when required. Moreover, off-loading the peripheral device-related tasks to the data aggregator block can significantly decrease the risk of degrading the performance of the VR device. This is important because the users of VAMR systems can be equipped with a multitude of IO devices. These devices could use a range of telecommunications protocols, both wired and wireless, transferring data payloads at various rates and volumes. It could be expected that the system could also include ad-hoc peripheral devices, i.e. such devices that can join, or leave, the system at random. The use of such IO devices, in considerable numbers, would inevitably lead to temporal misalignment of the data exchanges. Temporal alignment must not be neglected in the context of the VR, particularly when it comes to data coming from motion tracking devices. If the HMD was used to handle all IO devices directly in real-time, the number and type of the IO devices would have to be limited. Otherwise, the latency and overall performance would quickly decrease to an intolerable level. The Data Aggregator can be used to effectively manage such situations and prevent such problems from occurring.

The dataflow in Fig. 1 gives an overall view of the system. The IO Device 0, i.e. the VR Glove, collects the sensor readings from the IMUs and transmits them to the Data

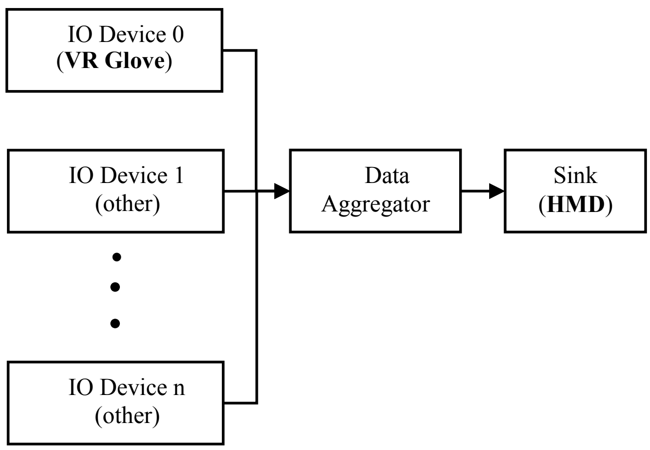



Fig. 1: Generalized System Architecture

Aggregator node. The Data Aggregator collects the readings, performs some specific data processing tasks on the incoming data, such as buffering and temporal alignment, and relays the results to the Sink (namely, the HMD in this case).

### B. Gesture Recognition

Gesture recognition can be a challenging task to accomplish with an IMU-only approach. It can be particularly difficult to detect the given gestures if the user freely moves the hand to perform tasks that often involve complex motion patterns. Their hands may be used in all imaginable ways, including handling controllers, or other objects. Yet, the hand gesture detection routines would be expected to be robust enough to work reliably under most conditions. Therefore, a gesture needs to be both natural and unique enough to minimize the likelihood of causing ambiguity.

Given these requirements, there is a relatively limited amount of possible hand motion patterns that could be used for this purpose. In this work, we determined that one specific motion pattern that works better in the context of developing a demonstrator prototype system, which is the gesture depicted in Fig. 2. The gesture is detected if the angle between the palm and forearm crosses a threshold equal to α. The angle α is the angle of the Wrist Extension, as defined in [18]. This angle is considered as the threshold for a hysteresis region. The hysteresis region is defined as a range of wrist-to-forearm angles, within which the angle of the Wrist Extension may freely vary to accommodate any natural motion. The threshold angle α is set such that the probability of misdetections is minimized. Obviously, this threshold can be customised to best fit the needs of the particular user, or the application.

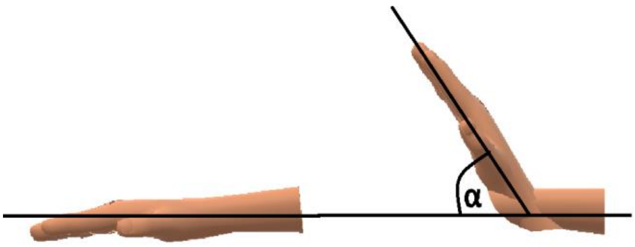



Fig. 2: Hand Gesture: Wrist Extension

## IV. SYSTEM IMPLEMENTATION

The prototype system was developed based on the diagram shown in Fig. 1. All major elements of the system fall into the three main blocks described there, i.e. the IO Device, the Data Aggregator and the Sink.

### A. IO Device 0 – VR Glove

The VR Glove, Fig. 3, played a key role in the system. It acted as the input device. Although it can provide multiple functionalities (such as, electric motor actuators to provide haptic feedback in VR environments, multiple IMU support for most of the hand segments, fast and efficient embedded processing and telecommunications capabilities, and even multiple Infrared LEDs, that can be used as markers by external camera systems. This work relies on only two IMUs to achieve its objectives. To detect the hand gestures, depicted in Fig. 2, the use of IMU sensor data on the Palm and Wrist was sufficient. These two sensor units could be used to calculate the angle of rotation between these two hand segments about the axis of rotation.

The embedded algorithms on the VR Glove were configured to output only the 3D orientation of the given IMU mathematically expressed as quaternions. The reference frame of these sensors was mapped to the directions of the Earth’s Gravity and Magnetic field lines. The IMU in the HMT-1™ also used the same reference frame. The VR Glove was programmed to output the two quaternions and transmit them over the Wi-Fi interface to ensure the maximum transmission speed. The embedded firmware was configured in such a way that the device operated as a Server in a standard peer-to-peer client-server networking architecture [19]. The data transfer began once the VR Glove (i.e., the Server), accepted the request from the Client (described in detail in the next section).

Fig. 3: Tyndall VR Glove

### B. Data Aggregator

This module is one of the most complex parts of the system, as it must provide both the ability to scale and a latency-free real-time performance. It also must be capable of aggregating data from various devices and relaying them to the HMD in real-time.

Given the requirements for this demonstrator system, one of several possible implementations was selected. A Linux Debian-based platform, a Raspberry Pi (RPi), was chosen due to the ease of use and versatility of operation. A generic off-the-shelf Wi-Fi router was also used to create a common network between the VR Glove and the RPi. The platform could also serve as an entry point for other IO devices in the system. The link between the RPi and the HMD used a Bluetooth connection using the HC-06 Bluetooth module. The HC-06 is a module based on the BC417 single-chip Enhanced-Data-Rate Bluetooth radio chip [20]. It proved to be the most robust device, also well supported by both the Unity3D programming environment and the Android OS.

A dedicated Python script was developed for the RPi to implement the core functions, such as data collection, aggregation, and transmission to the HMD. The Python programming environment was selected due to its support of vast sets of library modules, allowing an effective system integration. For example, the Socket module provided a seamless access to the BSD socket interface [19]. Thus, it enabled the implementation of the data stream between the VR Glove and RPi.

It needs to be noted that the use of such a system architecture was a design choice adopted to facilitate the integration of future potential functionalities.

### *C. Sink – HMD and User Case*

This block corresponds to the HMT-1™. It is a high-specification Android OS based HMD, made by RealWear, Inc. This device has all the capabilities of a typical high-end Android phone, except for the touch screen interface. Its display has the dimensions of approximately 16 mm by 10 mm and is located just below the line of sight of the user, as shown in Fig. 4. The display's resolution is 854×480 pixels. It is viewable at various lighting conditions, including bright sunlight [16]. This device has one distinct feature that differentiates it from other such devices in the market, e.g. the six-axis adjustable arm holding the display, which can be easily adjusted to any user's preferences. The device itself is symmetrical, which allows the user to flip it over, so that it can be used with both eyes. The device can run some of the most resource-demanding applications, such as graphics intensive VR applications developed in Unity3D game development environment. These specifications proved to be sufficient to meet the requirements of this work.

Fig. 4: HMD: RealWear HMT-1™

A Unity3D program was developed for the HMT-1™ device to validate the proof-of-concept. The input packets that arrive from the Data Aggregator unit over the Bluetooth link are passed into the application on the HMD. The Unity3D program on the HMD runs several C# scripts. It collects the data packets, processes them, and performs the gesture recognition functions.

The application continuously tracks the orientation of the VR Glove's Palm and Wrist. A feedback is provided to the user on a dedicated user interface (UI), on the screen of the HMD. A screenshot of the application is shown in Fig. 7. A virtual hand is displayed on the screen. It is rotated to reflect the rotational motion of the VR Glove in real-time. A virtual gauge is also provided on the UI, to facilitate more than just a binary ON-OFF control operation. The gauge also included an indicator for the hysteresis region, i.e. the angle of $\alpha$, defined in previous section. The red needle indicator rotates, once the wrist-palm angle exceeds the preset threshold angle $\alpha$. A series of preliminary experiments helped to determine the optimal value of $\alpha$. The best results were obtained when $\alpha = \pm 30$ deg. To the left of the virtual gauge there is a visualization of the IMU sensor data from the Wrist and Palm, to give a better understanding of the state of the VR Glove in real-time.

Moreover, the orientation of user's head is also tracked. The Unity application accesses the rotation values from the IMU embedded in the HMD itself to determine the head orientation round the vector aligned with direction Earth's gravity. Head's rotation is shown by displaying the green cross below the virtual hand. Since both the HMD and VR Glove used the same global reference frame the relative orientation of the VR Glove and the head could be then easily visualized.

### *D. Complete System*

The complete system diagram showing the implementation details is depicted in Fig. 5. The main blocks map closely to the generalized system architecture shown in Fig. 1. It is organized to clearly show the dataflow through the system. The flow starts from the VR Glove and ends by reaching the HMD. The detailed interactions of the individual elements of the system are omitted for clarity reasons. Some of these interactions include the connection establishment and management, as well as the data exchanges via the Bluetooth and Wi-Fi interfaces. The specifics of the software implementation are also omitted. The details of the Data Aggregator block are generalized and simplified to put an emphasis only on the most important aspects and functions of this block.

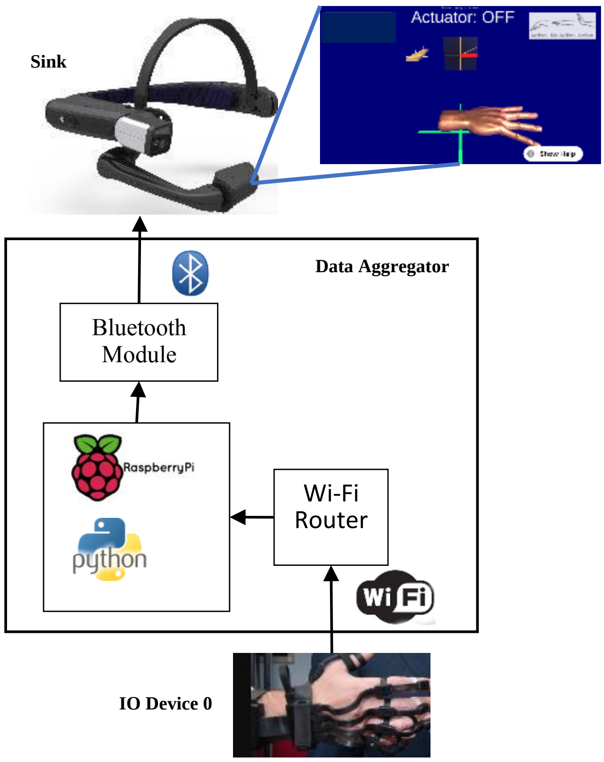



Fig. 5: System Implementation Diagram

## V. EVALUATION AND RESULTS

The complete system was validated by carrying out a series of practical experiments. The user was fitted with the HMD, i.e. the HMT-1™, and the VR Glove, as shown in Fig. 6. Subsequently, the user was instructed to carry out several basic tasks. These tasks included simulating work at an office workspace, and carrying out typical tasks, such as: using a keyboard, a mouse, turning pages of a paper document, hand-writing, reaching for objects, etc. All activities were carried out with the right hand, i.e. the one wearing the VR Glove. At the same time, the developed test application was run on the HMD. The VR Glove tracked the motion of the user's right hand, and continuously communicated the readings with the HMD. The user was able to execute the tasks, as instructed, while simultaneously monitoring the state of the VR Glove on the HMD's screen. One of the additional instructions for the user was to occasionally perform the tracked gestures, i.e. the Wrist Extension. The user was instructed to perform these tasks as naturally as possible.

Fig. 6: System Implementation: User with HMD and VR Glove

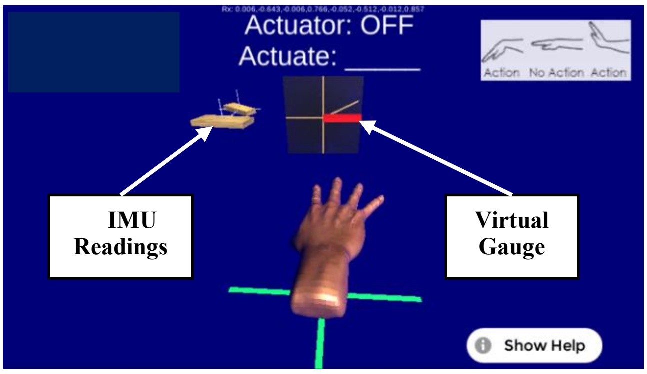
The output of the system, i.e. the UI, is shown in Fig. 7. Two screenshots of the application are presented. Fig. 7 (a) shows the UI during the normal operation, i.e. with no gesture detected. Fig. 7 (b) captures the moment when the hand gesture was detected. It can be observed, that the red needle indicator had moved in response to the gesture. The value of rotation of this indicator was equal to approximately 45 deg. It corresponded to the angle of the Wrist Extension measured by the two IMU sensors in the VR Glove.

Moreover, when the IMU visualisation segments, on the left-hand-side of the virtual gauge are closely examined, by comparing the two states from Fig. 7 (a) and Fig. 7 (b), it can be observed that the hand was also rotated to the right. These two visualisation segments clearly show the relative orientations of the wrist and palm, and how the wrist-to-palm angle was determined.

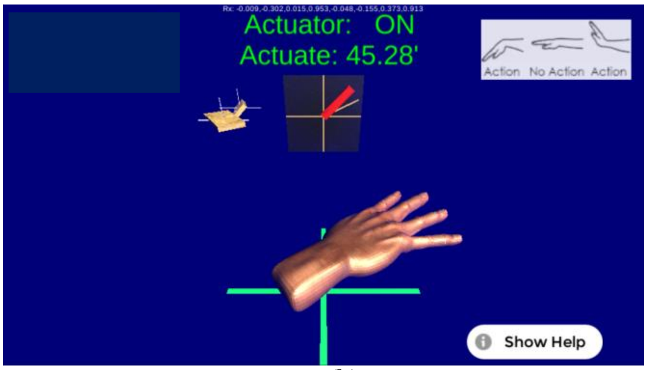
The experiments showed that the proposed system achieved a near real-time performance, as the perceived latency was hardly noticeable to the user. The time delay between hand movement and the response on the HMD's display was low. The system was easy to use, as there were no obstructions to the user. When in operation, the system looked just as shown in Fig. 6. The user did not have to adapt to the system. Although, the VR Glove was worn on the hand, it was possible to type on a computer keyboard, and handle the computer mouse without difficulties. The user was able to handle objects, such as water bottles or mugs with ease. Even hand-writing, using a regular ball pen and a sheet of paper, turned out to be relatively easy. Indeed, the VR Glove did not pose significant difficulties in performing this task. It was tested on a small group of users within our research group who were asked to carry out their normal routines and occasionally perform the gesture. Afterwards, we conducted an informal survey with the users on their experiences. Our findings were consistent with those of M. A. Conn, et al. [21]. Although, our results were only preliminary, these findings were encouraging.

The proposed gesture recognition technique could be considered an effective approach in certain applications. Despite the fact that this work involved only preliminary experiments, the results showed that such an approach may work. The user was able to repeatedly successfully perform the gesture, and the system captured it. The unintentional gesture detection was infrequent and could be further decreased by adjusting the threshold α to ensure it was beyond the non-gesture range of wrist extension.

Several additional experiments were carried out to evaluate the impact of strong magnetic field on the VR Glove. Since the IMUs incorporate magnetic field sensors, their




(a)




(b)

Fig. 7: System Implementation: Screenshots from the HMD: (a) No Gesture Detected: Actuator OFF, (b) Gesture Detected: Wrist Extension angle α = 45.28 degrees, i.e. Actuator ON, and actuate by α

performance can be affected in the presence of strong magnetic fields that distort, or override, the Earth's magnetic field. The user tested the system by performing the same activities in the vicinity of large steel construction elements. The experiments resulted in the expected degradation of the performance of IMUs embedded inside the VR Glove. The distortions to the magnetic fields made the gesture detection more challenging. It was more difficult to accurately trigger the hand gesture under these circumstances. However, these disturbances proved not to be prohibitive. In spite of that, it was possible to detect the Wrist Extension gesture after re-adjusting the threshold angle α. Large steel construction materials tended to cause transient difficulties, which could be overcome with a sensor calibration algorithm.

These results show that, although the VR Glove is a very versatile device with many functionalities able to provide very powerful VR experiences, it can also be used in applications that require much less complex interactions. The experiments showed that the proposed approach to hand gesture recognition, based on detecting and measuring the Wrist Extension, can be both effective and sufficient for applications that need limited interactions. Many VAMR applications fall into this category. The VR Glove, with as few as two of its IMU sensors, can be used to successfully detect such hand gestures.

## VI. LIMITATIONS OF THIS STUDY

The main limitation of this study is the lack of quantitative results of the system performance. The quantitative data would enable an objective, data-driven, analysis of this system. Secondly, the informal survey was not sufficient to conclusively assess the user feedback. A formal, structured, survey, carried out on a large sample of users would help to obtain reliable and statistically significant results. These results could help to better understand the strengths and shortcomings of this system.

## VII. CONCLUSIONS

The work described in this paper demonstrated how the VR Glove could be used in VAMR applications. It showed that the VR Glove is a versatile device which can be used effectively in various applications, such as the control of virtual objects using hand gesture recognition. Furthermore, it could be considered a multi-purpose IO VR device, whose functionalities could be used selectively to appropriately fit given application's requirements. For example, a user could wear it at all times, and use it in different ways for different purposes. The VR Glove's behaviour could adapt to the changing context of its use.

This paper also demonstrated a proof-of-concept prototype showing a scalable architecture. It could be used to aggregate multiple peripheral IO devices and provide a unified interface with a VAMR HMD. This architecture allows the HMD to off-load the process of handling excessive amounts of real-time tasks to an external unit. A VAMR user is likely to be equipped with multiple wearable devices performing different functions at various speeds, and use various, both wired and wireless, telecommunications protocols. This is an important consideration, because any HMD must be able to provide a responsive and fluid UI to the user. In this context, virtually any additional device providing input (or output) in real-time, especially if the communication channel is bi-directional, can degrade the performance of the HMD. Thus, the proposed architecture could be viewed as a viable consideration to prevent such problems.

The preliminary experiments of our proof-of-concept system yielded encouraging results. They proved that the VR Glove, and the proposed system architecture, form a feasible option in the context of VAMR. An extended research work is needed to establish the exact capabilities and limitations of the system. More detailed experimental work, along with the quantitative analysis of the results, could give a better insight into what the system can achieve. These data could then help determine what other applications spaces this system may be suitable for.

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