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Towards Achieving Smart Healthcare Through the Adoption of Information Technology

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Abstract.
Purpose: The study focuses on the impact of Virtual Reality as a therapeutic technology in the context of Smart Healthcare on the rehabilitation of hand amputees and the ability of out-patients to gain computer access in a cost-effective manner.
Methods: A qualitative, descriptive bibliometric survey of the literature was undertaken, utilizing peer-reviewed literature relevant to the integration of virtual medical care (V-Med) with the IoT, EHR, and CDSS. The literature examined was categorized into two analytical domains - physical and clinical opportunities and technical challenges.
Results: The evidence suggests that cloud focused Virtual Reality (VR) helps people with Phantom limb pain and reduces the time required for amputees to achieve the adaptation to a prosthesis. The disadvantages of VR technology will only be realized when VR technology, EHR and the Internet of Everything (IoE) systems coalesce. This is where the central issue of technical feasibility lies.
Novelty: The presentation here outlines a shift in attitude towards Virtual Reality. Rather than isolating it from a continuum encompassing all virtualization in the cloud with amputee rehabilitation modalities, we embrace it. We propose a framework that integrates cloud-based IoT wearables, EHRs, and CDSS into a Smart Healthcare ecosystem, thus outlining a feasible, affordable scalable virtual rehabilitation path.

Keywords: Virtual Reality, Smart Healthcare, Electronic Health Records, Internet of Things, Amputee Rehabilitation

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INTRODUCTION

Limb amputation occurs as a result of trauma, such as traffic accidents, or chronic diseases. Limb amputation hinders the execution of daily functioning. The most notable of such disabilities occurs in the ability to perform digitized work, communicate, or engage in entertainment activities that someone who possesses two functional natural hands can perform. To engage in modern digital work, learning or education environments, the keyboard and mouse require two functional natural hands. Limbed amputations place numerous technological barriers in the domain of digital work and learning. The problem is how human-computer interaction can be restored even when the user cannot utilize conventional input devices.

The population of amputees presents as large and still growing. In the United States alone, approximately 185,000 amputations are performed each year. In 2050, the global amputation count is estimated to reach 3.6 million, a steep increase from 1.6 million in 2005 [1]. Conventional prosthetics and assistive input devices remain expensive, specialized, or limited in functioning. Current technology is unable to seamlessly assist amputees with digital interactions. The need for flexible technology that can be integrated into Smart Healthcare is pressing.

Earlier studies on virtual reality technology showed promise for treating phantom limb pain and increasing adaptation speed to an artificial limb. A number of studies [2]–[3] reported on the use of mirror-box therapy and immersive virtual reality rehabilitation for phantom limb pain. Hao et al. and Paillet et al.[4] and [5] provided systematic reviews on virtual reality rehabilitation aimed at amputees. Simulator devices that

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allow for a virtual hand phantasm controlled by the EMG signals of the residual muscles were reported on, demonstrating VR of myoelectric control [6]. Progress in low-cost sEMG hardware [7] and in the combination of electronic health records and telemedicine [8] aids in the construction of an infrastructure focused on Smart Healthcare. Integration of these components is also needed. In general, research so far shows that these components have mostly progressed independently and no system focused on providing virtual control for hand amputees was developed.

Unlike how IoT, EHRs, and CDSS have been developed independently, VR has also been treated as an independent research area, while the IoT, EHRs, and CDSS have progressed mostly in an independent manner. There is a lack of an integrated system that allows a hand amputee to operate a computer via a Smart Healthcare supported VR system Oculus. This paper proposes to integrate all the systems and components into a Virtual Reality Interaction System (VRIS) to work and provide computer access to hand amputees using a low-cost EMG Monitoring Socket, VR-based Virtual Keyboard and Mouse, and the IoT/EHR/CDSS.

Historical background of virtual reality

Since the start of the 1990s, virtual reality has gained popularity and has grown into various industries such as education, manufacturing, and healthcare, as the technology has improved [9] , [10]. The term "virtual reality" means that while the user is in the real world the headset can transport them to a computer generated scene. They are able to feel what it is like to be in that environment rather than what it is like to be a spectator to that scene while looking at a computer. VR shows the user visuals and/or sounds that respond to the user's movements and touch and replaces what is in the surrounding environment, give a feeling of actually being in a different reality rather than actually being there [11].

Virtual Reality was first formally introduced by Jaron Lanier, a computer scientist, in 1989. He described it as something imaginative, graphic, auditory, and interactive [12]. In 1982, Thomas Furness, an official in the Air Force Research and Development Center, developed a Visually Coupled Airborne Systems Simulator. In this system, the pilot wears a head-mounted display (HMD) that enhances the outside view from the window with pictures describing the targets and provides the pilot with information placed on the flight path [13]. In 1984, the Virtual Visual Environment Display (VIVED) was developed by NASA to allow a user to view digital 3D spaces as shown in Figure 1 [14].

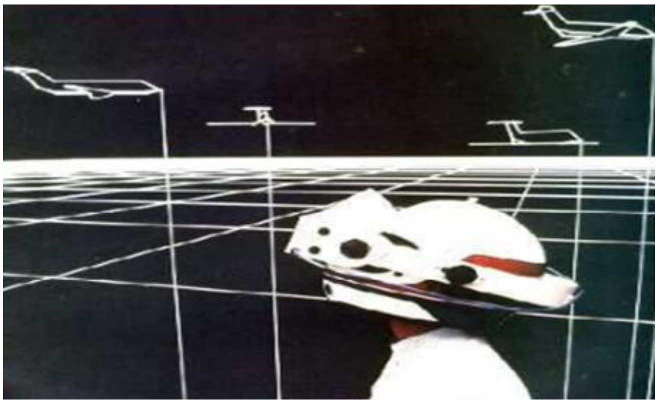

Figure 1. VIVED of NASA

The sensors read the hand's movements, and the computer interprets them as commands through software. The software then implements the commands into the virtual environment, making the interaction appear intuitive [15]. In 1989, the Binocular Omni-Orientation Monitor (BOOM), made by Fake Space Labs, improved the user experience. It increased the view of virtual environments by putting two CRT screens, connected by a mechanical arm, inside a compact, balanced box, by providing a mechanism for counterbalancing the user's head [16].

Unlike the BOOM, the CAVE (CAVE Automatic Virtual Environment), the virtual reality system introduced in 1992 which took a different approach from traditional VR systems and head-mounted displays, offered a better quality, wider field of view than head-mounted displays. This CAVE system projected images onto the walls of a room and required users to wear LCD shutter glasses. This system improved the quality of stereoscopic images [17]. Street View's 3-D and rotating, and more recently, CaseLaw (with its in-built, artificial intelligence), increased the quality of stereoscopic images and interactivity [18].

Applications of virtual reality in healthcare

Medical training was among the earliest and continues to be one of the most notable areas to adopt virtual reality within healthcare. Medical students can perform surgical procedures and clinical decisions in a risk-free environment without the involvement of a real patient. 360-degree immersive simulations offer a safe practice environment for the medical training functions VR implements [19], [20] in healthcare. For patients with both physical and neurological impairments, therapeutic exercises can be performed within a guided virtual recovery environment. This is another field within VR where great strides have been realized [21].

Psychotherapy is likely to have significant benefits from VR as well. VR has been utilized for the treatment of anxiety, PTSD, and phobias, as it creates an environment for patients to face their internal fears and allowing therapists to have control over circumstances [22]. VR has also been used for pain management during dental procedures as it creates an immersive VR experience to make patients perceive less pain and describe less anxiety [23]. VR has recently started to be used more and more in Pediatric care, specifically for, pain and anxiety relief. It has been shown to reduce pain and anxiety levels in children during procedures as it creates an immersive distraction for patients [24]. VR has more recently started to be used for weight management as patients have an immersive connection to their health care routines, as it encourages multiple behaviors and motivates participation by providing more involvement within the weight management program [25].

Recent studies show how useful virtual reality can be in the field of medicine [26]. A surgeon can virtually practice conducting a procedure on a simulated patient (which helps improve the surgeon's skill and build confidence before the actual procedure). There is even the possibility of conducting a practice surgical procedure on a patient located in a different city through the use of VR and robotics (these are referred to as tele-surgeries). VR has the potential to be used in and outside a surgical theater as a diagnostics aid, to help patients with rehabilitation, to manage chronic pain, to aid in mental health, and to give more options to medical professionals for patients in a way that is proven to have results equal to or beyond that of standard practices [27].

Related works

A survey of previous studies related to the use of virtual reality technology for amputees shows that many research groups are actively working in this area. Many studies indicate the use of virtual reality in the rehabilitation of amputees and in training to better use prosthetic limbs [4], [5]. For example, Manjuladevi Kuttuva and colleagues used virtual reality technology to develop an interface that gives upper-limb amputees access to training with a virtual hand that can handle objects as shown in Figure 2. The interface receives signals from movements resulting from the remaining part of the limb and processes them into movements in the virtual hand. The system consists of sensors mounted on the arm, angles of the elbow and shoulder joint, and a virtual hand model with a 3D training environment [28].

Figure 2. Virtual hand that can handle objects

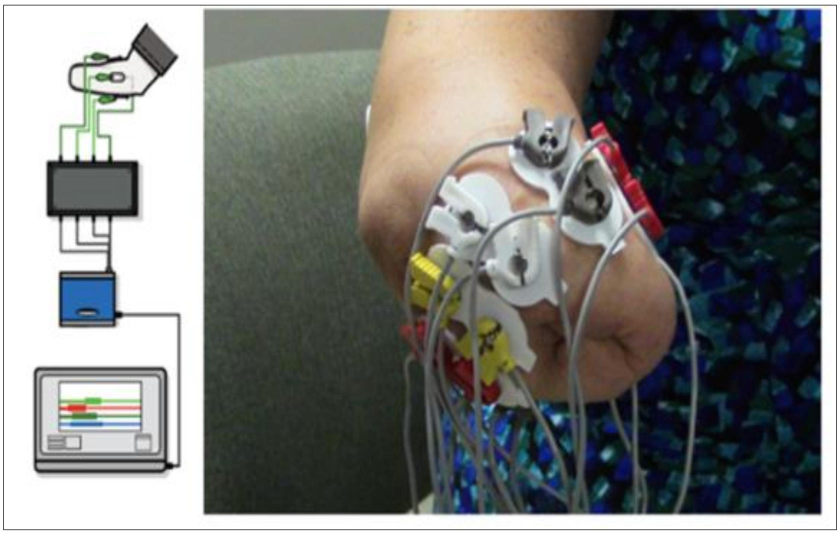

Figure 3. Virtual ıntegration environment system

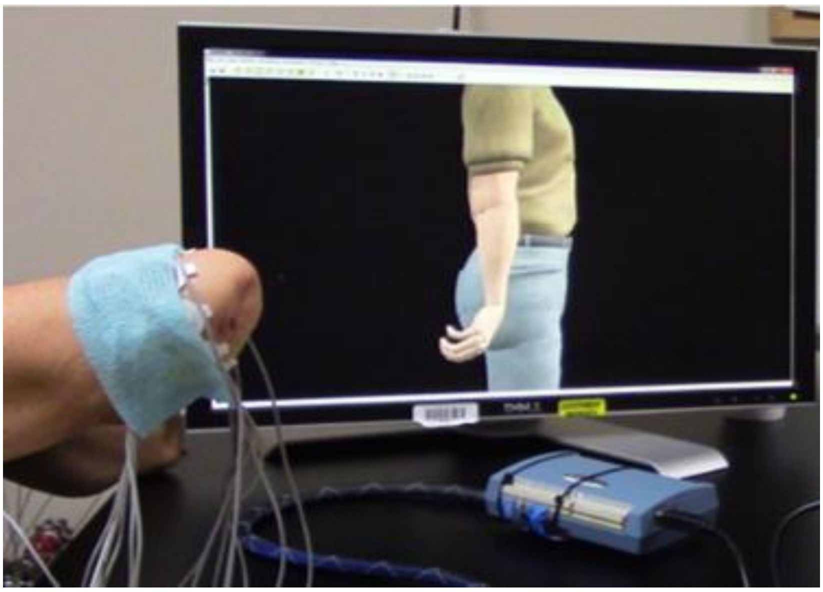

Figure 4. VIE training system with virtual limb

Briana N. Perry and colleagues developed a motor-training tool called the Virtual Integration Environment (VIE) for use with military personnel who have undergone upper-limb amputation as shown in Figure 3 and 4. Data obtained from residual muscle movement is collected and processed to recognize movement patterns via a machine-learning system, thus improving virtual limb control. Based on relevant studies, up to 95% accuracy can be achieved in determining movement patterns using electrical signal processing techniques [29].

Wake and colleagues used virtual reality to develop a system for the rehabilitation of phantom limb pain (PLP). The system architecture has input, software, and output components. For input, they used an accelerometer, Microsoft Kinect, electromyography sensors, and CyberGlove II. For the software, Unity game engine was used for VR development. For output, three devices with different sensors are used: head-mounted display (HMD) for visualization, headphones for auditory feedback, and a vibration motor for tactile sensing [2].

Figure 5. IMU controllers mounted on the legs in VR system [30]

Elisabetta Ambron and colleagues used virtual reality technology to develop a low-cost treatment for phantom limb pain. According to the researchers, VR has shown good results in reducing phantom limb pain. A head-mounted screen is installed while playing dedicated games in which an amputee sees two virtual intact legs in real time. Movements of the virtual limbs are controlled by sensors attached to the real healthy limb and the remaining part of the amputated limb. The hardware used includes the Oculus Rift 2Dk for 3D graphical view. They designed virtual lower limbs as a robot with rotatable hip and knee joints controlled by four electromagnetic motion tracking instruments, as shown in Figure 5 [30].

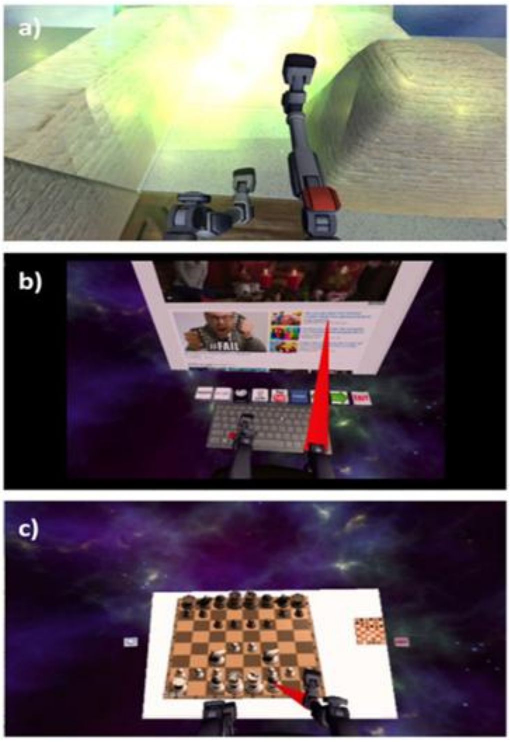

Figure 6. (a) Quest for Fire, (b) Web Browser, and (c) Chess games (the Checkers game looks very similar to chess) [30]

Data from the IMU controllers and an Arduino microcontroller are used to process the signals in a program written in Arduino. The Unity platform was used to design the virtual environments and filter readings from the IMUs. The user could control hip and knee flexion and extension for each leg and play four games: Quest for Fire, Web Browser, Chess, and Checkers, as shown in Figure 6 [30].

Immersive VR has also been explored as a modality for reducing phantom limb pain, building on the concept of mirror-box therapy. Such systems read muscle movements from the residual limb and display them on a virtual limb in an immersive environment. When the patient perceives the missing limb 'moving' again, the brain can experience reduced pain. Users wear a head-mounted display, and motion capture is achieved via data gloves and sensors placed on the elbow, wrist, knee, or ankle depending on the limb involved [3].

Lambrecht and colleagues developed a virtual reality simulator for electrical signals to test new control algorithms. The system collects EMG sensor signals from the remaining limb movement and integrates them with simulated technology in the virtual prosthesis, including force-based interactions with virtual objects. A default box and test block are displayed. The system is considered a promising tool for developing and evaluating control methods for amputees, as shown in Figure 7 [6].

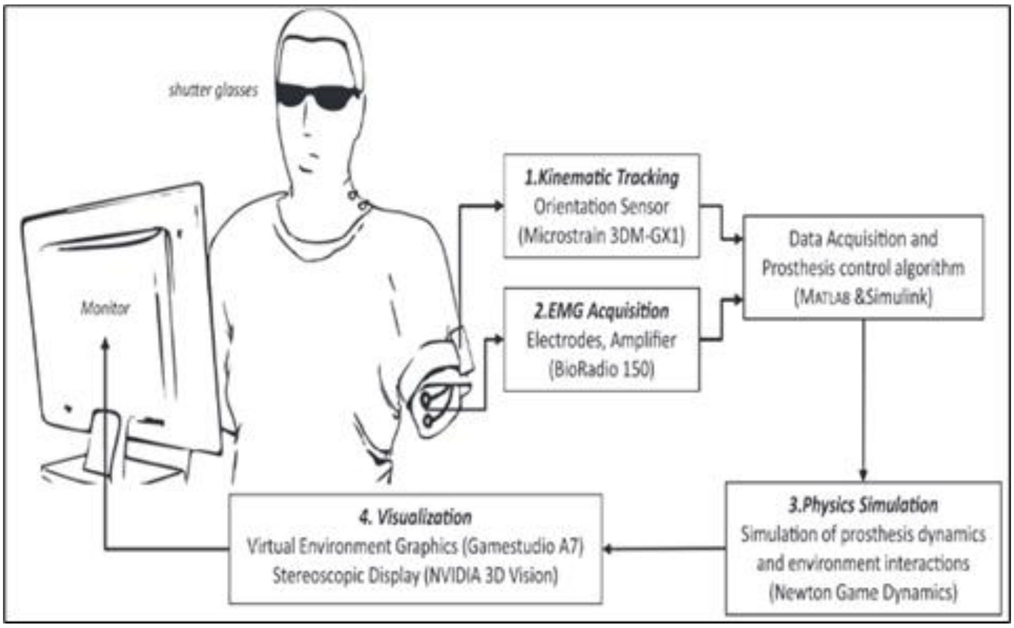

Figure 7. Virtual reality simulator system

Researchers such as Li and colleagues have explored extended reality (XR) for upper-limb myoelectric prostheses. MATLAB Simulink was used as the platform to build the virtual reality environment, and EMG electrodes placed on muscles of the residual limb captured electromyography signals to control a virtual arm [31].

Caicedo-Ortiz and colleagues developed a simple low-cost prosthetic hand. The hand is designed so that each finger operates separately. It is controlled using sEMG sensors placed on muscles near the amputation area, with a MyoWare microcontroller board and an Arduino Nano controller. The hand can perform various movements based on EMG signals and has shown reliable gripping and releasing performance across five tested positions [32].

Many amputees suffer from muscle weakness after amputation, resulting in weak signals from residual muscle movement. Researchers have used the MyoWare Muscle Sensor because of its ability to filter noise and amplify the signals; it is small, lightweight, and low cost.

Researchers have also developed a wearable bracelet that allows users to give presentations without needing their hand. Developers used EMG sensors, an Inertial Measurement Unit (IMU), and Bluetooth to collect and transmit signals wirelessly to a computer, as shown in Figure 8. The software interprets raw IMU and EMG signals and converts them into commands to control PDF, PowerPoint, and Word documents [33].

Figure 8. Wearable presentation armband

Building on the VIE work described earlier, research groups at the Johns Hopkins Applied Physics Laboratory and partner institutions have continued to develop advanced VR-based training platforms for upper-limb prosthesis users. These platforms use a virtual version of the prosthetic arm that the amputee controls with the same myoelectric inputs as the physical device, so that skills learned in VR transfer directly to daily use. Myoelectric signals captured by the socket sensors are translated into movements of the virtual arm, enabling patients to practice before the real prosthesis is fitted [29].

Avinash Sharma and colleagues developed a mixed-reality programme combining virtual and augmented reality, where amputees can train, interact with objects, and receive tactile feedback. They collected information through sensors, and all was merged into the augmented reality environment displayed via Microsoft HoloLens. More than one MPU9250 was used as a 9-axis IMU controller for limb position calculation—one placed on the shoulder blades, the other on the biceps. Bluetooth modules were used for each IMU to transfer information to the computer [34].

Cosima Prahm and colleagues developed a clinically functional and enjoyable rehabilitation programme to increase patient motivation. They used EMG sensors placed on muscles to collect signals. They tested the system with two participants, each with two computers—one processing signals and displaying them, the other displaying the game. Ottobock Healthcare GmbH surface EMG sensors were placed over the residual muscles, as shown in Figure 9 [35].

Figure 9. Prosthesis interaction system with game

At the Vienna University of Technology, a master's thesis entitled 'A Virtual Reality Training Tool for Upper-Limb Prostheses' designed a virtual training environment that simulates a virtual hand. The ioTracker motion-tracking system developed at the Vienna University of Technology was used. Data is sent via a framework called Open Tracker to an application programmed in Unity3D [36].

Marek Kurzynski and colleagues built a computer-aided training system that generates visual and sensory stimuli. They designed a 3D virtual hand observable on a VR headset, with sensory feedback provided by mechanical vibration during interaction with virtual objects. The system demonstrated that mental training supported by visual and sensory stimuli leads to beneficial changes in brain activity, enhancing the sensation of an amputated upper limb. For 3D hand design, Blender and Maya were used; Gimp was used for textures [37]. Figure 10 presents (A) the hand skeleton, (B) the hand mesh, and (C) the textured hand model.

Looking at the earlier research, they all have the same broad aim of developing systems to help people who have been amputated, one way or another. Some work focuses on developing activities to help lessen phantom limb pain. Others try to help ease amputees into training with their prosthesis further ahead in time, making the adaptation a necessary hurdle in the process. Less numerous are those who take a playful approach to designing activities, such as games, that aid in preserving the spirits of the patient while making rehab activities less tedious. The tools and software platforms developed for or used in these studies differ quite a lot and are chosen in relation to the particular case that who is being treated and the guidelines of the research [37].

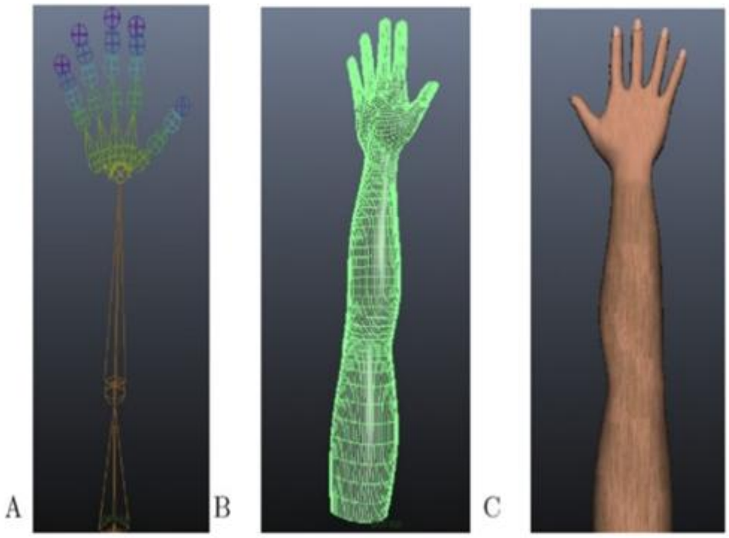

Figure 10. (A) Hand skeleton, (B) hand mesh, and (C) textured hand model

METHODS

This section outlines the method used for the current survey-based research, as well as the scheme for the proposed Virtual Reality-based Interaction System (VRIS). The research uses descriptive and qualitative examination combined with a conceptual system design, as opposed to an empirical study involving people.

Research design.

A structured literature survey was conducted to identify how Virtual Reality, Electromyography (EMG) sensing, Internet of Things (IoT) wearables, Electronic Health Records (EHR), and Clinical Decision Support Systems (CDSS) have been applied to amputee rehabilitation and Smart Healthcare. Peer-reviewed journal and conference sources were retrieved from scientific databases (including IEEE Xplore, Frontiers, MDPI, and Elsevier) and reviewed for relevance to hand-amputee computer interaction. The surveyed systems were then organized into two analytical categories: (i) physical/clinical opportunities, and (ii) technical challenges related to hardware, signal processing, and system integration.

Proposed system architecture.

On the basis of the survey findings, the VRIS architecture was designed around four coupled components: (a) a low-cost prosthetic socket (designed in a prosthesis workshop or via 3D printing) housing the sensing and processing hardware; (b) surface EMG sensors with a MyoWare processor unit to capture residual-muscle signals with integrated noise filtering; (c) an Arduino microcontroller for signal digitization and transfer to the host computer via USB or Bluetooth, with an MPU-9250 9-axis IMU enabling socket-based cursor control; and (d) a Virtual Environment implemented in Blender (3D modelling) and the Unity game engine (runtime), presenting a virtual hand, virtual keyboard, virtual mouse, and virtual desktop through a Head-Mounted Display. The system operates in two modes—hand mode for keyboard input and mouse mode for cursor control—switchable by amputee gestures captured via EMG.

Evaluation plan.
Because no prototype has yet been implemented, the present paper is a design-and-survey contribution; empirical evaluation with amputee participants, including signal-classification accuracy, task-completion time, and user-experience metrics, is planned as future work and discussed in the Results and Discussion section.

Information technology in smart healthcare
Integrating healthcare with information technology (IT) has been critical for the development of intelligent, integrated care systems. Health Information Systems (HIS) refers to the range of systems and tools that maintain, disseminate, and analyze patient information with the goal of enhancing safety, efficiency, and overall improvement of healthcare services [38]. The acceleration of digital health technology adoption has changed healthcare services; however, scoping reviews have documented inequity in access and health outcomes, which will need to be addressed in addition to the clinical benefits [39]. The use of healthcare systems and technology has been linked to positive outcomes in patient safety and staff satisfaction and overall effectiveness of healthcare services.

Core to this digital framework are Electronic Health Records (EHRs), which are a complete digital representation of a patient's medical record. EHRs contain a patient's diagnosis, treatment, lab tests, and clinical notes and are continuously updated so that all practitioners have access to the same information about a patient at any step of the treatment process [40]. EHRs have led to improvements in healthcare services by providing information to practitioners, which results in the ability to supervise care and reduce adverse drug events and gaps in care [41].

Integrating EHRs with telemedicine means clinicians can access all sections of a patient's medical history during a virtual consultation, enabling better critical thinking on the clinical decision support system's (CDSS) function, data analysis, and individualized and accurate patient care [42].

CDSS is designed to improve the clinical decision-making capabilities of the clinician, and is a data approach to decision support within the intelligent entities of the evidence and data generated from the patient, current literature and studies, recommended practices, and health-related data from the analysis [43]. Furthermore, CDSS can also use predictive analytics to determine the likelihood of particular events occurring and patient data and use health-related analytics on data to identify new health problems and recommend the best practices to reduce it [44]. The CDSS interventions also support the standards for clinical practice to eliminate the risk of clinical and health-related errors [45].

The traditional healthcare system has been transformed through the implementation of IoT and health monitoring devices that allow safety, real-time remote care monitoring with the system that enhances the quality of life by assuring the safety of patients [46]. IoT wearable devices collect and transmit a multitude of metrics and provide multiple health statistics continuously to health care clinicians [47]. While patients can wear devices to record several metrics including the continuous monitoring of SpO2, blood pressure, temperature, ECG, heart, and respiratory rates [48].

Moreover, the Internet of Wearable Things (IoWT) can impact the healthcare market positively, through the development of automated telehealth workflows, aimed to track and update the concerned parties, the patients' status and emergent situations, at the right time, to either the patients' physicians or their family members [49]. Telemedicine has also undergone significant transformations. The communication line between the physicians and their patients has evolved into a seamless service that employs technology to integrate and optimize the activities of physicians, nurses, patients, and even clinical research personnel

[50]. Telemedicine and EHR systems are complementary. System integrations mean better quality of care with more manageable daily operations of the clinical personnel [51]. Over 80% of healthcare providers have attested to the fact that, with the use of integrated services, telehealth has substantially improved the speed and the timeliness with which patients are attended to [8]. The development of Smart Healthcare is influenced by a vast array of other innovative technologies. All these other technologies are of considerable importance to the virtual reality interaction system for patients with amputation that has been developed in this research.

Problem definition and proposed solution

Computers are integrated into work and play. Losing one or both hands can isolate a person from computer based activities. This creates a major obstacle for computer technology. Microsoft attempts to overcome this problem by allowing hand amputees to type on a physical keyboard while inside a VR environment, suggesting hand tracking technology. The OptiTrack Flex 13 tracked hands with an Oculus Rift DK2 used as a head mounted display. Figures 11 and 12 illustrate the hand tracking and typing representation [52].

The key query is straightforward: what is the outcome for a user who has lost a hand to amputation? That question is the starting point of the present study.

People with hand amputations often find it difficult to interact with computers because they cannot use the keyboard or mouse in the normal way. To help them, different solutions have been introduced over the years. Some solutions are based on voice recognition, where the user gives spoken commands. Others use cameras to follow the hand or body gestures. More recently, researchers have developed systems that allow control of the mouse cursor with the tongue, with facial expressions, or just with eye movements, opening new possibilities for people with limited hand mobility [53], [54], [55].

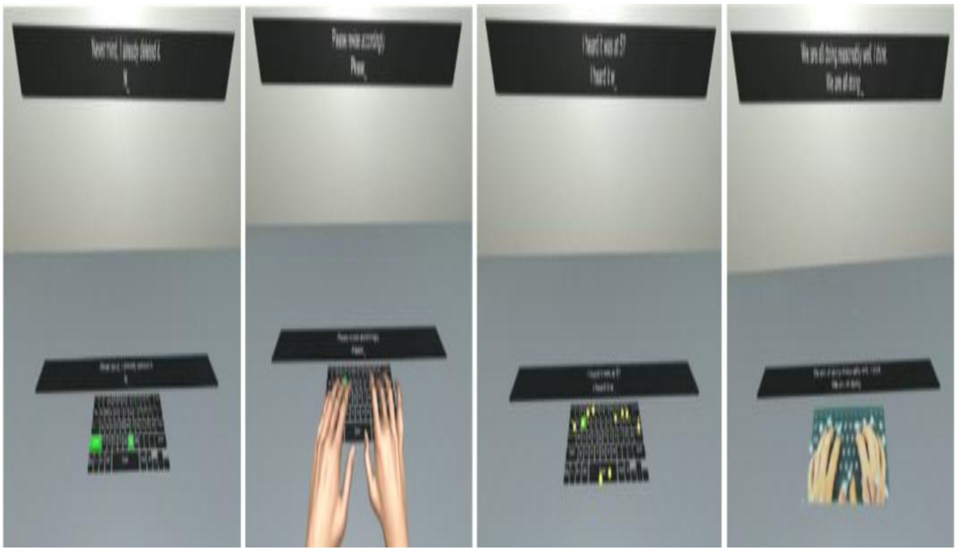

Figure 11. Representation of typing in VR

Figure 12. Microsoft hand tracking system

The proposed solution aims to develop an easy-to-use and low-cost VR-based interaction system that can replace lost hand functions for computer use by people with hand amputation. The Virtual Reality-based Interaction System (VRIS) consists of several components: Virtual Environment, Physical Parts, Electronic Parts, and Hardware Part.

Virtual environment

The basis of the VRIS concept is a virtual environment containing a virtual hand, virtual keyboard, virtual mouse, and virtual desktop screen displaying the computer system. For 3D modelling, Blender (open-source 3D computer graphics software) is used to design the virtual environment and 3D hand model. Unity is used as the gaming platform to programme the system. Figure 13 shows the default design of the virtual reality side of the system.

Figure 13. VRIS virtual hand, keyboard, and desktop

Physical parts

A low-cost prosthetic socket is designed in a prosthesis workshop or by using a 3D printer. The socket replaces the remaining part of the amputated hand and contains EMG sensors that capture signals from muscles, along with microprocessor units that prepare signals for transmission to the computer for processing.

Electronic parts

The starting point of the system is electromyography (EMG) technology that senses electrical signals resulting from movement of the remaining muscles in the amputated limb. Based on [7], EMG sensors combined with the MyoWare processing unit are the best option for this proposed solution for two reasons: first, they are inexpensive compared to medical-grade EMG devices; second, the MyoWare board has built-in filters that clean the raw EMG signal from noise, so the output is ready to be processed by the microcontroller without extra filtering circuits. Arduino serves as the open-source electronic processing unit for the signals. For data transfer, the Arduino board can be connected via USB cable to a PC, or a Bluetooth board can be integrated with Arduino for wireless data transfer. Since the amputee lacks a hand, a standard mouse cannot be used; therefore, the socket can function as a mouse using a nine-axis MPU-9250 module (gyroscope, accelerometer, and magnetometer) integrated with Arduino, converting amputated-limb movement to cursor motion. Specific gestures from the amputated limb can also substitute for left- and right-click tasks.

Hardware part

The user wears a Virtual Reality Head-Mounted Display (HMD) for presentation of the virtual world. Through the HMD, the user sees the virtual desktop screen, virtual hand, virtual keyboard, and virtual mouse. The system operates in two modes: hand mode for typing on the virtual keyboard, and mouse mode for cursor control. Mode switching is performed via EMG-captured gestures. Briefly, the socket is custom-fitted for the amputated hand; the EMG sensors and other electronic parts (Arduino and control units) are placed within the socket wall. The socket converts muscle movements into electrical signals processed by the MyoWare and transferred to Arduino, then to the computer. This arrangement allows the amputated user to use the computer through a virtual environment with a virtual keyboard and a socket-integrated virtual mouse. The virtual environment can be customised by adjusting room appearance and colour themes to suit the user's preferences. Figure 14 shows the default diagram of the VRIS system.

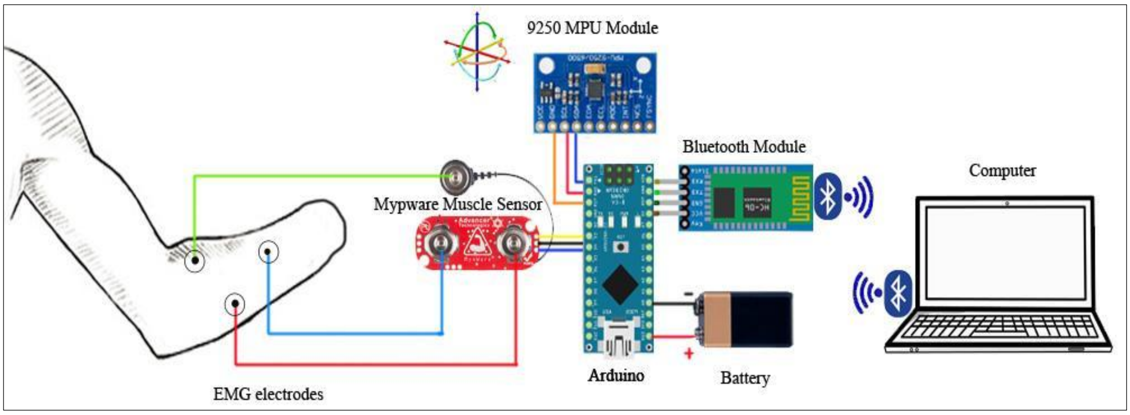

Figure 14. Default diagram of VRIS system

RESULTS AND DISCUSSION

In all areas of research and development, researchers face difficulties and challenges during their work, with the scale depending on project size and complexity. One challenge expected in the proposed solution is that the socket used for the amputated hand cannot be adjustable to fit all amputee users; this is because the fit depends on the type of amputation and the remaining muscle structure. Additionally, the location where the EMG sensors are placed is important to obtain good and clear signals from the muscles. The socket design must be performed and adjusted by a prosthesis workshop technician.

Although many studies have confirmed the benefits of virtual reality for rehabilitation and for reducing phantom limb pain in amputees [30], some researchers have also pointed out that when a user wears a prosthesis without physical feedback such as touch or impact, the muscles of the residual limb can lose effectiveness over time, because the brain does not receive normal sensory input [2]. Incorporating small vibration units into prosthesis sockets has been suggested by some designers as a way of enabling the user to feel a sense of touch through the virtual limb when it collides with an object [36]. While still some way off, a fundamental shift towards numerous more intelligent systems of EMG will be needed, moving towards systems that will be able to classify the specific muscle signals associated with the movement and determine which part of the limb of the prosthesis, or which part of a single joint or finger, to communicate that command to, instead of simply commanding the whole hand to act [56].

Earlier researchers anticipated that future VR-based prosthetic training could begin very early, right after amputation and even before socket fitting, since most VR training does not require the user to actually wear a real prosthesis. The idea is that by practising with the virtual prosthesis first, the user becomes more comfortable and efficient with controls before using the real device. Recent progress in modern EMG pattern-recognition systems and smart prosthetic designs indicates that these early visions are becoming reality [57].

Another future possibility is further development of the socket and system so that they are compatible with various similar devices. The user could then control home devices such as smart TVs and personal devices such as mobile phones and tablets. With the addition of a small screen inside the socket, the user could control and change device settings by moving their muscles with gestures from the amputated hand. Specialists in electronic board development can also work on miniaturizing electronic components (Arduino and related parts) into a single compact, energy-efficient device.

CONCLUSION

The conclusions obtained through research are important because they represent the focal point for completing the path in post-research development. A key finding from this survey is that the problem of amputees is not limited to the inability to complete tasks and activities; many amputees also suffer from psychological, moral, and social challenges, because hands are the means through which a person touches, works, and communicates. For an individual whose hand was amputated after working directly on a computer, the impact is substantial; the individual becomes unable to return to previous activities without assistive technology. This paper presents a proposed solution to this problem. The aim of this study was to design a Virtual Reality-based Interaction System (VRIS) that would let hand amputees continue using computers. The approach combines EMG-driven input, a virtual keyboard and mouse, and a prosthetic socket housing the electronic components, all situated within a Smart Healthcare framework made up of IoT wearables, EHRs, and CDSS. The reviewed literature makes two things clear: VR-based rehabilitation consistently helps reduce phantom limb pain and shortens the time needed to adapt to a prosthesis, and low-cost sEMG and Arduino-based platforms already on the market are technically capable of supporting the proposed architecture. At the same time, the review confirms that VR only delivers its full value when paired with interoperable IoT devices and EHR systems, and this integration remains the main technical challenge going forward. On that basis, future work should focus on four directions: (i) redesigning the socket so that it can be adjusted across different amputation types, (ii) developing smarter EMG classification that can resolve intent at the level of individual fingers and joints, (iii) incorporating haptic feedback to preserve muscle effectiveness over time, and (iv) building and empirically evaluating the VRIS prototype with amputee participants, so that the framework proposed here can be validated in practice.

REFERENCES

[1] M. Maciver, D. Dixon, and D. Powell, “Quality of life in young people with limb loss: a systematic review,” Disabil. Rehabil., vol. 46, no. 19, pp. 4323–4334, 2024.

[2] N. Wake, Y. Sano, R. Oya, M. Sumitani, S. Kumagaya, and Y. Kuniyoshi, “Multimodal virtual reality platform for the rehabilitation of phantom limb pain,” in 2015 7th International IEEE/EMBS Conference on Neural Engineering (NER), IEEE, 2015, pp. 787–790.

[3] A. S. Eldaly et al., “Virtual and augmented reality in management of phantom limb pain: a systematic review,” Hand, vol. 19, no. 4, pp. 545–554, 2024.

[4] J. Hao, Z. Chen, A. Remis, and Z. He, “Virtual Reality–Based Rehabilitation to Restore Motor Function in People With Amputation: A Systematic Literature Review,” Am. J. Phys. Med. Rehabil., vol. 102, no. 5, pp. 468–474, 2023.

[5] J. Paillet et al., “The Effects of Virtual Reality Interventions on Motor Function Rehabilitation in Lower-Limb Amputees: A Systematic Review and Metanalysis,” Bioengineering, vol. 12, no. 11, p. 1170, 2025.

[6] J. M. Lambrecht, C. L. Pulliam, and R. F. Kirsch, “Virtual reality environment for simulating tasks with a myoelectric prosthesis: an assessment and training tool,” JPO J. Prosthetics Orthot., vol. 23, no. 2, pp. 89–94, 2011.

[7] M. Garouche and O. Thamsuwan, “Development of a low-cost portable EMG for measuring the muscular activity of workers in the field,” Sensors, vol. 23, no. 18, p. 7873, 2023.

[8] Elation Health, "Telehealth and EHR integrations: Improving patient care," Elation Health Resources, 2025. [Online]. Available: https://www.elationhealth.com/resources/blogs/telehealth-and-ehr-integrations.

[9] J. Radianti, T. A. Majchrzak, J. Fromm, and I. Wohlgenannt, “A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda,” Comput. Educ., vol. 147, p. 103778, 2020.

[10] J. Luo and C. K. Y. Chan, “Qualitative methods to assess intercultural competence in higher education research: A systematic review with practical implications,” Educ. Res. Rev., vol. 37, p. 100476, 2022.

[11] M. M. T. E. Kouijzer, H. Kip, Y. H. A. Bouman, and S. M. Kelders, “Implementation of virtual reality in healthcare: a scoping review on the implementation process of virtual reality in various healthcare settings,” Implement. Sci. Commun., vol. 4, no. 1, p. 67, 2023.

[12] M. V. Carbonell and S. S. Arcón, “Virtual Reality and Its Main Characteristics: A Beginner’s Guide,” OnBoard Knowl. J., pp. 1–10, 2025.

[13] L. Mertz, “Virtual reality pioneer tom Furness on the past, present, and future of VR in health care,” IEEE Pulse, vol. 10, no. 3, pp. 9–11, 2019.

[14] S. S. Fisher, M. McGreevy, J. Humphries, and W. Robinett, “Virtual environment display system,” Proc. 1986 Work. Interact. 3D Graph. I3D 1986, vol. 1987-January, pp. 77–87, 1987, doi: 10.1145/319120.319127.

[15] W. Felger, M. Göbel, D. Reiners, and G. Zachmann, “VR Research at Fraunhofer IGD, Darmstadt, Germany,” arXiv Prepr. arXiv2403.01629, 2024.

[16] Draftings, "Everything you need to know about virtual reality," Draftings, 2024. [Online]. Available: https://draftings.com.au/virtual-reality.

[17] M. Helbich, M. Danish, S. M. Labib, and B. Ricker, “To use or not to use proprietary street view images in (health and place) research? That is the question,” Health Place, vol. 87, p. 103244, 2024.

[18] M. Silva, C. Allis, and C. De Silva, “Potential of virtual reality (VR) technology for safety training and accident prevention in construction,” in Proceedings The 12th World Construction Symposium| August, 2024, p. 840.

[19] T. Tene, D. F. Vique López, P. E. Valverde Aguirre, L. M. Orna Puente, and C. Vacacela Gomez, “Virtual reality and augmented reality in medical education: an umbrella review,” Front. Digit. Heal., vol. 6, p. 1365345, 2024.

[20] T. Tursø-Finnich, R. O. Jensen, L. X. Jensen, L. Konge, and E. Thinggaard, “Virtual reality head-mounted displays in medical education: a systematic review,” Simul. Healthc., vol. 18, no. 1, pp. 42–50, 2023.

[21] E. Chaplin, C. Karatzios, and C. Benaim, “Clinical applications of virtual reality in musculoskeletal rehabilitation: A scoping review,” in Healthcare, MDPI, 2023, p. 3178.

[22] D. Freeman et al., “Automated virtual reality therapy to treat agoraphobic avoidance and distress in patients with psychosis (gameChange): a multicentre, parallel-group, single-blind, randomised, controlled trial in England with mediation and moderation analyses,” The Lancet Psychiatry, vol. 9, no. 5, pp. 375–388, 2022.

[23] L. Fan et al., “Virtual reality in managing dental pain and anxiety: a comprehensive review,” Front. Med., vol. 10, p. 1285142, 2023.

[24] S. Addab, R. Hamdy, K. Thorstad, S. Le May, and A. Tsimicalis, “Use of virtual reality in managing paediatric procedural pain and anxiety: An integrative literature review,” J. Clin. Nurs., vol. 31, no. 21–22, pp. 3032–3059, 2022.

[25] M. Lytras et al., “Virtual reality in the treatment of patients with overweight and obesity: a systematic review,” 2022.

[26] M. Mergen, N. Graf, and M. Meyerheim, “Reviewing the current state of virtual reality integration in medical education-a scoping review,” BMC Med. Educ., vol. 24, no. 1, p. 788, 2024.

[27] D. Mistry, C. A. Brock, and T. Lindsey, "The present and future of virtual reality in medical education: a narrative review," Cureus, vol. 15, no. 12, p. e51124, 2023.

[28] M. Kuttuva, G. Burdea, J. Flint, and W. Craelius, "Manipulation practice for upper-limb amputees using virtual reality," Presence Teleoperators Virtual Environ., vol. 14, no. 2, pp. 175–182, 2005.

[29] B. N. Perry et al., "Virtual integration environment as an advanced prosthetic limb training platform," Front. Neurol., vol. 9, p. 785, 2018.

[30] E. Ambron, A. Miller, K. J. Kuchenbecker, L. J. Buxbaum, and H. B. Coslett, "Immersive low-cost virtual reality treatment for phantom limb pain: evidence from two cases," Front. Neurol., vol. 9, p. 67, 2018.

[31] W. Li, P. Shi, S. Li, and H. Yu, "Current status and clinical perspectives of extended reality for myoelectric prostheses," Front. Bioeng. Biotechnol., vol. 11, p. 1334771, 2024.

[32] J. Caicedo-Ortiz et al., "Validation of a Low-Cost Myoelectric Prosthesis Prototype Developed with Arduino and 3D Printing," in New Challenges in Software Engineering: Volume 1, Springer, 2025, pp. 351–365.

[33] J. E. E. Goh, M. L. I. Goh, J. S. Estrada, N. C. Lindog, J. C. M. Tabulog, and N. E. C. Talavera, "Presentation-aid Armband with IMU, EMG sensor and bluetooth for free-hand writing and hand gesture recognition," Int. J. Comput. Sci. Res., vol. 1, no. 3, pp. 65–77, 2018.

[34] A. Sharma et al., "A mixed-reality training environment for upper limb prosthesis control," in 2018 IEEE Biomedical Circuits and Systems Conference (BioCAS), IEEE, 2018, pp. 1–4.

[35] C. Prahm, F. Kayali, I. Vujaklija, A. Sturma, and O. Aszmann, "Increasing motivation, effort and performance through game-based rehabilitation for upper limb myoelectric prosthesis control," in 2017 International Conference on Virtual Rehabilitation (ICVR), IEEE, 2017, pp. 1–6.

[36] L. El Raghibi et al., "Virtual reality can mediate the learning phase of upper limb prostheses supporting a better-informed selection process," J. Multimodal User Interfaces, vol. 17, no. 1, pp. 33–46, 2023.

[37] M. Kurzynski et al., "Computer-aided training sensorimotor cortex functions in humans before the upper limb transplantation using virtual reality and sensory feedback," Comput. Biol. Med., vol. 87, pp. 311–321, 2017.

[38] A. Epizitone, S. P. Moyane, and I. E. Agbehadji, "A systematic literature review of health information systems for healthcare," in Healthcare, MDPI, 2023, p. 959.

[39] R. Yao, W. Zhang, R. Evans, G. Cao, T. Rui, and L. Shen, "Inequities in health care services caused by the adoption of digital health technologies: scoping review," J. Med. Internet Res., vol. 24, no. 3, p. e34144, 2022.

[40] B. Chimbo and L. Motsi, "The effects of electronic health records on medical error reduction: extension of the DeLone and McLean information system success model," JMIR Med. Informatics, vol. 12, p. e54572, 2024.

[41] M. Cahill, B. J. Cleary, and S. Cullinan, "The influence of electronic health record design on usability and medication safety: systematic review," BMC Health Serv. Res., vol. 25, no. 1, p. 31, 2025.

[42] S. Murthi, N. Martini, N. Falconer, and S. Scahill, "Evaluating EHR-integrated digital technologies for medication-related outcomes and health equity in hospitalised adults: a scoping review," J. Med. Syst., vol. 48, no. 1, p. 79, 2024.

[43] Z. Chen et al., "Harnessing the power of clinical decision support systems: challenges and opportunities," Open Hear., vol. 10, no. 2, 2023.

[44] M. Elhaddad and S. Hamam, "AI-driven clinical decision support systems: an ongoing pursuit of potential," Cureus, vol. 16, no. 4, p. e57728, 2024.

[45] H. M. Tun, H. A. Rahman, L. Naing, and O. A. Malik, "Trust in artificial intelligence–based clinical decision support systems among health care workers: systematic review," J. Med. Internet Res., vol. 27, p. e69678, 2025.

[46] S. Abdulmalek et al., "IoT-based healthcare-monitoring system towards improving quality of life: A review," in Healthcare, MDPI, 2022, p. 1993.

[47] J. Baiense, E. Zdravevski, P. Coelho, I. M. Pires, and F. J. Velez, “Driving Healthcare Monitoring with IoT and Wearable Devices: A Systematic Review,” ACM Comput. Surv., vol. 57, no. 11, pp. 1–38, 2025.

[48] Q. Chen and N. Sheng, “A novel health monitoring system for vital signs using IoT,” Sci. Rep., vol. 14, no. 1, p. 19189, 2024.

[49] H. Xie, L. Yang, B. Jiang, Z. Huang, and Y. Lin, “State-of-the-art wearable sensors for cardiovascular health: a review,” npj Cardiovasc. Heal., vol. 2, no. 1, p. 53, 2025.

[50] M. Stoltzfus, A. Kaur, A. Chawla, V. Gupta, F. N. U. Anamika, and R. Jain, “The role of telemedicine in healthcare: an overview and update,” Egypt. J. Intern. Med., vol. 35, no. 1, pp. 1–5, 2023.

[51] X. Zhang and R. Saltman, “Impact of electronic health record interoperability on telehealth service outcomes,” JMIR Med. Informatics, vol. 10, no. 1, p. e31837, 2022.

[52] J. Grubert, L. Witzani, E. Ofek, M. Pahud, M. Kranz, and P. O. Kristensson, “Effects of hand representations for typing in virtual reality,” in 2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), IEEE, 2018, pp. 151–158.

[53] A. Fischer-Janzen, T. M. Wendt, and K. Van Laerhoven, “A scoping review of gaze and eye tracking-based control methods for assistive robotic arms,” Front. Robot. AI, vol. 11, p. 1326670, 2024.

[54] F. Karimli, H. Yu, S. Jain, E. S. Akosah, M. Betke, and W. Feng, “Demonstration of CameraMouseAI: A Head-Based Mouse-Control System for People with Severe Motor Disabilities,” in Proceedings of the 26th International ACM SIGACCESS Conference on Computers and Accessibility, 2024, pp. 1–6.

[55] N. Mohamed, “Eye-gesture control of computer systems via artificial intelligence,” F1000Research, vol. 13, p. 109, 2025.

[56] X. Liu et al., “A review on the usability, flexibility, affinity, and affordability of virtual technology for rehabilitation training of upper limb amputees,” Bioengineering, vol. 10, no. 11, p. 1301, 2023.

[57] N. Parajuli et al., “Real-time EMG based pattern recognition control for hand prostheses: A review on existing methods, challenges and future implementation,” Sensors, vol. 19, no. 20, p. 4596, 2019.