Human Machine Interface (HMI) - A Survey

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***Abstract*— Human-Machine Interface (HMI) has become a critical area of research, driven by the rapid advancements in embedded systems and the growing demand for seamless interaction between humans and machines. This survey provides a comprehensive overview of various HMI technologies, tracing their evolution and examining their applications in the development of assistive devices. The paper explores a wide range of interfacing techniques, including touch-based systems, voice recognition, gesture control, brain-computer interfaces, and haptic feedback, highlighting their unique advantages and limitations. While these technologies have significantly enhanced human-machine interaction, challenges such as usability, accessibility, and adaptability remain.**

***Keywords*— BCI, Embedded systems, HMII, Touch screen, PLC, Artificial Intelligence, Autonomous, VR, Hand Gesture Recognition, Deep Learning.**

I. INTRODUCTION

The advancement of Human-Machine Interface (HMI) technologies has been driven by advances in artificial intelligence (AI), sensor technology, and user-centric design principles. These advancements have not only improved the usability of devices but also expanded their accessibility, making technology more inclusive and intuitive for diverse user groups. HMI technologies have transformed the way users interact with embedded systems, moving from traditional input methods like keyboards and buttons to sophisticated multimodal interfaces like touchscreens, voice recognition, and haptic feedback. The transformational potential and inherent problems of modern technology by looking at things like brain-computer interfaces, gesture control, and AI-driven adaptive systems. Even though these developments have greatly enhanced human-machine interaction, there is still room for progress in areas like accuracy, latency, and user adaptability. Through this review, we have tried to reveal different types of human-machine interfacing techniques between humans and machines to exhibit the evolution of HMI technologies.

This review explores the contemporary groundbreaking technologies developed in this field and their advantages and limitations. An outline is drawn for forthcoming development in the field of human machine interface.

II. EVOLUTION OF HMI

Evolution of Human-Machine Interface (HMI) has significantly changed how we interact with technology, creating a seamless connection between digital systems and human understanding. Embedded systems, in particular, thrive in dynamic environments where HMI is essential for linking users to complex device functionalities. Over the years, HMI designs have progressed rapidly, fueled by advancements in computing, artificial intelligence, and connectivity.

1. Historical Evolution of HMI

The journey of HMI began with basic mechanical interfaces like buttons, knobs, and sliders, which were common in early industrial and computing systems. These interfaces allowed for direct, hands-on control over machines and were vital during the initial phases of automation and computing. The 1960s and 1970s marked the rise of command-line interfaces (CLI), where users communicated with computers through text-based commands. These early systems demanded considerable technical knowledge and were primarily used by specialized professionals.

A significant turning point occurred in the 1980s with the launch of graphical user interfaces (GUIs), which transformed human computer interaction by offering a visual and interactive way to control systems. The introduction of the mouse and keyboard, along with visual displays, enabled users to navigate digital environments more easily and efficiently. Operating systems like Windows and macOS popularized the GUI, making computers more accessible to a wider audience.

[14] The advent of mobile technology, especially the widespread use of smartphones, brought touchscreen interfaces to the forefront, making interactions more user-friendly. Touch-sensitive technology has since expanded beyond mobile devices to encompass

consumer electronics, industrial control systems, and medical devices. Gesture-based interfaces, such as those found in gaming consoles and virtual reality systems, have further broadened the scope of human-machine interaction. Recent developments in artificial intelligence (AI) and machine learning have led to the creation of more responsive and intelligent human-machine interfaces (HMIs). These interfaces now incorporate features like gesture recognition, voice control, and the ability to analyze user behavior patterns. Thanks to AI, these systems are becoming increasingly adaptive, learning from individual user habits and preferences to improve overall efficiency.

2. Role of Haptic Feedback in HMI

Haptic technology is essential for enhancing user experiences by mimicking touch sensations in digital settings. Studies on haptic communication and feedback have explored various methods for recreating tactile sensations, such as piezoresistive, piezoelectric, capacitive, and triboelectric sensors. These developments have improved the realism and immersion of human-machine interactions, especially in virtual and augmented reality applications. Haptic devices provide real-time feedback, enabling users to feel virtual objects and receive accurate force-based responses. This has significantly enhanced the effectiveness of remote operations in areas like telemedicine, robotic-assisted surgery, and remote industrial control. The integration of AI in haptic interfaces has further improved precision and adaptability, leading to advancements in fields such as rehabilitation and interactive training simulations. Nevertheless, issues related to latency, power consumption, and network reliability remain significant challenges for future research. Achieving high-fidelity haptic feedback remains a persistent challenge, particularly for applications that demand precision, such as medical simulations or high-precision robotic manipulation. Recent advancements in haptic interfaces include wearable haptic gloves, force feedback systems in gaming, and ultrasonic haptic displays that create mid-air touch sensations. The use of haptic technology in virtual reality (VR) and augmented reality (AR) environments is especially promising, as it enables users to engage with virtual objects in a more natural and intuitive way.

3. AI and Adaptive HMI Systems

The use of AI in human-machine interfaces (HMI) has revolutionized traditional interaction models by creating systems that are adaptive and aware of their environment. With AI-powered virtual assistants, predictive analytics, and real-time data processing, interactions have become more natural and efficient. Industries like automotive technology, healthcare, and consumer electronics have successfully adopted AI-driven HMIs. In autonomous electric vehicles, these AI-based HMIs improve situational awareness by offering multimodal feedback through visual, auditory, and haptic signals. This enhances the interaction between drivers and vehicles, making it safer and more intuitive while reducing cognitive load and aiding decision-making. Additionally, AI-driven HMIs are vital in security applications, utilizing biometric authentication and facial recognition to strengthen access control and user identification. Moreover, AI is increasingly important in creating more inclusive interfaces. Features like voice control, predictive text input, and real-time language translation have made digital interactions easier for users with disabilities. There is also ongoing exploration of AI-driven facial expression and emotion recognition technologies to foster emotionally intelligent interactions, enhancing human-computer communication in fields such as customer service, healthcare, and education.

4. Evolution of HMI in Embedded Systems and Industrial Applications

HMI has experienced significant changes within embedded systems, especially in areas like industrial automation, automotive interfaces, and home automation. The mid-20th century saw the introduction of 7-segment displays, LED indicators, and mechanical push-button controls, which set the stage for digital control systems. As microcontrollers and integrated circuits became more prevalent, HMIs advanced to include TV screens, touchpads, and basic graphical interfaces. By the early 2000s, capacitive touchscreens began to replace resistive touch interfaces, leading to better responsiveness and durability. The addition of voice command interfaces, LED displays, and AI-driven smart assistants has further improved the user experience. Today, embedded systems boast real-time processing capabilities, allowing HMIs to function seamlessly in automation, consumer electronics, and medical devices. In industrial environments, HMIs have evolved from simple control panels with mechanical switches to fully digital, interactive displays. Modern industrial touchscreen panels now support multi-touch gestures, real-time monitoring, and cloudbased analytics. The Internet of Things (IoT) has also enhanced HMI functionality by enabling remote monitoring and predictive maintenance, which helps reduce downtime and improve efficiency.

5. Recent Advances in Multimodal and Biometric HMIs

Recent advancements in multimodal HMI systems have made interactions more intuitive and seamless. These systems combine various input methods, such as touch, voice, eye-tracking, and gesture recognition, to create a more natural user experience. AI-powered voice assistants like Amazon Alexa, Apple Siri, and Google Assistant have raised the bar for voice interaction, enabling users to control smart devices with simple commands. Biometric-based HMIs, which include fingerprint scanners, facial recognition, and iris scanning, have improved security and accessibility. These technologies are now commonly found in smartphones, banking systems, and access control mechanisms, reducing the need for traditional passwords and PIN codes. However, biometric HMIs also present security challenges, including vulnerabilities to spoofing and concerns about data privacy. The use of haptic feedback in biometric systems is gaining popularity as well, enhancing authentication accuracy and providing users with tactile confirmation. Future developments are expected to further refine these technologies, addressing security and usability issues while improving overall interaction efficiency. This expanded summary provides a comprehensive overview of HMI evolution, emphasizing its historical development, technological advancements, industrial applications, and recent innovations. By exploring these elements, this review aims to enhance the understanding of human-machine interactions.

III. RECENT DEVELOPMENTS IN HUMAN-MACHINE INTERFACE (HMI)

A. Speaker Identification, Differentiation and Verification Us- ing Deep Learning for Human Machine Interface

Differentiating speakers is crucial for security and criminal justice firms, modern systems now use transformer-based architectures and self-supervised models, like Wav2Vec 2.0, to extract detailed speaker features even under difficult acoustic conditions. These approaches enable accurate matching of voice samples against large databases and robust confirmation of a speaker's identity by analyzing unique vocal traits. Additionally, improved segmentation techniques allow these systems to efficiently partition continuous audio streams into distinct speaker segments, thereby improving the overall reliability of real-time applications. Recent advances in deep learning have significantly transformed human-machine interfaces, especially in the areas of speaker identification, verification, and differentiation.

In addition to these improvements, the integration of multimodal biometric strategies has further improved system security. [7] By combining voice recognition with complementar -y modalities like facial recognition and behavioral biometrics, recent developments offer a more comprehensive approach to authentication and forensic analysis. Techniques such as advanced data augmentation and adversarial training have been implemented to combat background noise and spoofing attempts, ensuring that these systems remain resilient in diverse operational environments. Collectively, these innovations pave the way for more secure, accurate, and scalable human-machine interactions across a variety of industries.

B. Hospital Management Information System

The security of hospitals' data assets must be given top priority because it is essential to maintaining business continuity. Regular security audits are now necessary to protect hospital management information systems (HMIS). Using the ISO 25023 standard, this study evaluated the software quality of the HMIS at X Hospital with an emphasis on the security features of the pharmacy unit and outpatient service module. Confidentiality, integrity, non-repudiation, accountability, and authenticity are the five main qualities that ISO 25023 uses to define security. Security scores, with values ranging from 0 to 1, were calculated as part of the review process. A threshold of 0.80 was established to determine standard compliance.

[2] According to the assessment results, Internal Data Corruption Prevention received a score of 0.75, which is below the allowed limit, even if the majority of security features met the necessary threshold. The study suggested database replication as a mitigation technique to lessen the chance of data corruption in order to address this problem. In spite of this, the HMIS's overall security performance was deemed adequate, with an average score over the cutoff, indicating that X Hospital's HMIS complies with ISO 25023 requirements. To preserve and improve data

security going forward, ongoing monitoring and system improvements will be required.

C. Virtual Reality for Human-Vehicle Interactions in the con text of Autonomous Driving

New developments in autonomous driving technology are revolutionizing the driving experience overall in addition to improving road safety and easing traffic congestion. It is becoming more and more important to comprehend how self-driving cars interact with pedestrians as their use grows. A recent study used virtual reality (VR) environments to mimic interactions between digital cars and actual pedestrians. Through the integration of human activities into a simulated environment, these immersive virtual reality interfaces showed how virtual human-machine interfaces (HMIs) might affect user perception and behavior. An autonomous car was controlled by a digital model of a pedestrian crossing.

[6] Regardless of different braking techniques, surveys showed that pedestrians felt more secure when the HMI was in operation, according to the study. Additionally, objective data demonstrated that earlier pedestrian crossings were promoted by both HMI activation and softer brake cues. Building on these discoveries, further developments in technology have made it possible to simulate human-vehicle interactions even more realistically by introducing more adaptable VR systems and better sensor integrations. These developments are opening the door for improved pedestrian-autonomous vehicle communication protocols, which will ultimately lead to safer and more effective urban mobility solutions.

D. AI-Powered Human-Machine Interfaces

The evolution of human-machine interfaces (HMIs) has been significantly influenced by advancements in artificial intelligence (AI). Modern HMIs leverage generative AI to create more sophisticated, contextually aware, and user-centric virtual assistants. These systems can understand and respond to user inputs in real time, making interactions more natural and intuitive. The advancement of artificial intelligence (AI) has revolutionized human-machine interfaces (HMIs), enabling more intuitive and intelligent interactions. Modern HMIs leverage generative AI to enhance user experience by making systems more responsive, adaptive, and context-aware. These interfaces are now capable of understanding and processing user inputs in real time, facilitating smoother and more natural interactions.

A key component of AI-driven HMIs is natural language processing (NLP), which enables machines to comprehend and generate human language with high accuracy. Leading AI frameworks from organizations such as OpenAI and Hugging Face have significantly improved the efficiency of virtual assistants by allowing them to interpret text, recognize speech, and generate contextually relevant responses. Additionally, interactive tools such as Gradio enhance user engagement by simplifying the development of AI-powered applications, while real-time audio feedback tools like Play.ht contribute to a more immersive experience.

[14] One of the major strengths of AI-powered HMIs is their ability to learn continuously from user interactions. By employing advanced machine learning techniques, these systems refine their responses over time, improving accuracy and personalization. This adaptability ensures that HMIs remain effective across various domains, from customer service to industrial automation.

However, ethical considerations must be addressed when implementing AI in HMIs. Issues such as data privacy, bias mitigation, and responsible AI deployment are critical to ensuring fair and secure user interactions. As AI technology continues to evolve, maintaining transparency and user trust will be essential.

The integration of generative AI into HMIs marks a significant technological leap, making human-machine interactions more efficient and user-friendly. Future developments will further expand the capabilities of AI-driven interfaces, shaping a more intelligent and connected digital ecosystem.

E. Advancing Human-Machine Interaction Through Brain-Controlled Interface

Brain-Machine Interfaces (BMI), also referred to as Brain-Computer Interfaces (BCI), are transforming human-machine interactions by enabling direct communication between the brain and external systems. Unlike traditional methods that rely on neuromuscular pathways, BMI allows users to control devices through brain activity alone. These interfaces play a crucial role in rehabilitation, assistive technologies, and motor function restoration for individuals with mobility impairments. BMI technology primarily relies on electroencephalography (EEG) and electromyography (EMG) signals to interpret user intent and convert it into actionable commands. EEG-based systems record brain activity from the scalp to detect motor imagery (MI), event-related desynchronization (ERD), and event-related synchronization (ERS). EMG signals, which capture muscle activity, serve as an additional input to enhance system accuracy and reliability. The combination of EEG and EMG, known as multimodal BMI, improves precision in human-machine control applications.

One of the most promising uses of BMI is in lower-limb exoskeletons designed for rehabilitation and mobility support. Conventional exoskeletons often require manual operation through buttons or joysticks, limiting their effectiveness in mimicking natural movement. In contrast, BMI-powered exoskeletons interpret motor intentions directly from the brain, enabling smoother and more intuitive control. Research suggests that these advanced systems can promote neuroplasticity, aiding in faster recovery for individuals with neurological disorders. With ongoing advancements in AI and neural signal processing, BMI is expected to further enhance human-machine interaction, offering greater autonomy and improved quality of life for individuals with mobility challenges. The continuous development of brain-powered control systems holds the potential to revolutionize assistive technology and rehabilitation in the coming years.

F. Empowering Humans, Enhancing Machines: The Future of Intelligent HMI

The field of Human-Machine Interaction (HMI) has advanced significantly with the integration of surface electromyography (sEMG) signals, deep learning (DL), and edge AI. These technologies enable the development of real-time, wearable, and energy-efficient HMI systems for a variety of applications. One of the most impactful areas is assistive robotics and prosthetics, where AI-driven robotic arms and intelligent prosthetics help individuals regain mobility. By utilizing sEMG signals, these systems enable precise gesture recognition and motion control, while machine learning (ML) techniques enhance the accuracy of muscle activity interpretation. Another significant application of HMI technology is in industrial automation, where robotic systems assist in manufacturing and assembly processes. [9] AI-powered wearable sensors allow workers to control machines more naturally, improving both productivity and workplace safety. This reduces human effort in hazardous environments, making operations more efficient and secure.

In healthcare and rehabilitation, HMI plays a crucial role in assisting patients recovering from conditions such as stroke and neuromuscular disorders. sEMG-based devices monitor muscle activity and provide adaptive control for physical therapy, ensuring effective recovery. The integration of edge AI enables real-time processing, making these systems portable, cost-effective, and responsive to patient needs. Beyond robotics and healthcare, HMI is transforming augmented and virtual reality (AR/VR) by enabling gesture-based control in digital environments. This enhances gaming, training simulations, and remote collaboration, providing users with more immersive and interactive experiences.

Despite these advancements, challenges such as signal noise, variability in muscle activity, and real-time processing limitations still need to be addressed. However, innovations in low-power AI accelerators, FPGA-based processing, and improved deep learning models are overcoming these hurdles, making HMI systems more reliable and efficient. The continuous evolution of HMI is set to redefine accessibility, efficiency, and user experience across multiple industries, shaping the future of human-machine collaboration.

G. Human-Computer Interaction Through Voice Commands Recognition

The The study's objective is to enhance human-machine interaction by automating and efficiently executing tasks through the use of speech recognition technologies. The ability of a machine or piece of software to identify natural language speech or sentences and convert them into computer-understandable instructions is known as Automatic Speech Recognition (ASR) [5]. The audio signal, operating system, product extraction procedure, classifiers, and information database are just a few of the many variables that frequently affect how these systems are developed. Deep Convolutional Neural Network Development (DCNN) architecture [5] has made significant strides in natural language processing and speech recognition, enabling humans to process words with robots in the form of straightforward queries and responses . To help with human-machine interaction (HMI), this article introduces a novel interface design. First, spoken words are detected, recognized, and transformed into commands by the framework. Additionally, voice control is converted into operating commands that are intended to simplify daily tasks. The design model was validated and positive outcomes were reached through analytical examination of English literature

H. Human-Machine Interaction Sensing Technology Based on Hand Gesture Recognition – A Review

The paper provides a comprehensive overview of hand gesture recognition (HGR) technologies, highlighting various sensing methods and their applications in human-machine interaction, driver assistance, prosthesis control, and sign language identification, among other fields. Radar sensors, surface electromyography (SEMG), ultrasound, vision, and other sensor-based technologies are among the sensing technologies discussed. This article [8] discusses the difficulties faced while examining potential directions for future study in the area of human-machine technology. The cost, accuracy, applicability, and application of glove materials, visual guiding, SEMG, and ultrasonic signals are all compared in this article. Additionally, covered are the benefits and drawbacks of different technologies for HGR systems. Additionally, it examines how HGR technology may enhance human-machine interaction, streamline daily operations, simplify technology control, analyze signals, and help avert conflict. Future HGR technology [8] will need to integrate many sensors, explore new features, and create challenging algorithms in order to increase recognition accuracy and performance. By addressing the possible drawbacks of HGR technology, this study adds to ongoing research targeted at creating a variety of useful applications of gesture recognition.

IV. CONCLUSION

Increased sophistication, smooth integration, and improved user experiences are all hallmarks of the exciting future of human-machine interfaces, or HMIs. Future HMIs have the ability to completely transform how humans interact with machines by utilizing advancements in artificial intelligence, robotics, biometrics, and immersive technologies. This might lead to new levels of efficiency, creativity, and human-machine collaboration. A vital link between people and technology, the Human-Machine Interface (HMI) allows for smooth contact and communication. Its development from basic switches and levers to sophisticated brain interfaces and user-friendly touchscreens has completely changed the way humans interact with machines, increasing accessibility, safety, and efficiency in a variety of fields. In order to fully utilize HMIs to improve our lives and move us closer to a future in which humans and machines work together harmoniously, it will be crucial to prioritize user experience and ensure user-centric design as we continue to push the boundaries of technology.

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