Immersive Environments with Haptic Technology for the Control of an Industrial Robotic Arm

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***Abstract*— The technological advancement of Industry 4.0 and the Internet of Things has brought significant changes and benefits to the industry, allowing observation, control, and decision-making in industrial processes from anywhere in the world and in real-time. This article presents the power of a Mitsubishi RV-2AJ Industrial Robotic Arm using haptic technology "Senso Glove" and real-time 3D visualization, enabling users to interact and control the arm's movements. For the implementation, data is processed in Unity and sent to the "Firebase" cloud, where this data is requested by an embedded system to subsequently be converted into commands for arms control, specifically in the coordinates "X", "Y", "Z," and in the opening or closing of the gripper. The results demonstrated that the arm can be controlled from the gloves, opening various applications. Additionally, an accuracy of 87.8% was achieved in the conducted tests, with an average communication time of 815 milliseconds.**

Keywords*— *Senso Glove, Mitsubishi RV-2AJ Robotics Arm, Internet of Things, Unity.

I. INTRODUCTION

There is an overwhelming technological advancement and computational systems [1] that strengthen the Internet of Things, cloud computing, Big Data analytics, cybersecurity, simulation, digital transformation, and artificial intelligence, among others, which are integral to progress. These directly impact the final cost of our product [2]. Thus, Industry 4.0 aims for sustainability and improvement in production processes.

Robotic arms are also constantly evolving to provide their best services based on needs [3], handling hazardous tasks for operators such as managing radioactive elements [4], and ensuring precision and accuracy in certain processes, for example, in the pharmaceutical or automotive industry. In their basic form, they are composed of links, joints, and their end effector, the latter being a highly versatile tool that depends on the task the arm performs [5]. Motors in the joints allow the rotation or translation of the links. With the advancement of computing, they become more robust, acquiring diverse capabilities and designs, enabling the creation of complex geometries with high precision [6], and implementing advanced control techniques.

An example is the development of the modeling of the 5-axis Mitsubishi RV-2AJ robotic arm in SolidWorks by [7]. It stands out for not risking the actual robotic arm to conduct functional tests and make necessary corrections for its optimal operation. Another way to control the arm is remote, as implemented by [8], who, through the internet and an internal network within the laboratories, achieve manipulation of the RV-2AJ arm to conduct practical exercises for students. In real-time, students have a video feed and can observe the arm's manipulation based on parameters they input into the software externally. The human-robot communication interface has been increasingly developed [9]. They devised an interface where sensors can capture electromyographic signals from the human body's bioelectrical signals, allowing the generation of commands for robotic arm manipulation.

Wireless gloves (Senso Glove) enable the detection of every hand movement [10]. They contain sensors that transmit information about the current state of the fingers, palm, and wrist. These gloves are continually being updated, with the information sent via radio frequency to the computer to be extracted and simulated in a virtual environment.

Currently, the Internet of Things is booming, referring to the interconnection of intelligent devices to a global network that links the physical and digital worlds. There is a diversity of interconnected smart devices [11], leading to the emergence of smart homes. In these homes, appliances, sensors, and actuators are monitored and controlled remotely through the Internet [12].

Thus, the industrial RV-2AJ arm is controlled using wireless gloves (Senso Glove) and its respective simulation. The computer receives data wirelessly transmitted by the gloves, which is then processed in simulation software (Unity) and sent to the cloud (Firebase). Subsequently, the data is retrieved by an electronic card (ESP32) to determine the instruction to be sent to the RV-2AJ arm and execute the corresponding action. This action may involve movement along the vertical or horizontal axis or maintaining a stationary position. Simultaneously, the virtual arm is configured to replicate the same movements as the physical arm.

II. PREVIOUS CONCEPTS

A. Mitsubishi Melfa RV-2AJ Robotic Arm

It is of the angular or articulated type, small, compact, and powerful, featuring five joints, each with a specific range of motion [13]. The robotic arm is equipped with brushless AC servo motors, and its end effector is a pneumatic gripper designed to hold objects weighing up to 2 kg [14]. It finds applications in the medical field for sample handling and in education for tasks like palletizing or recreating a two-dimensional drawing, among others. There are three ways to control it [15]: through manual control using the R28TB, by executing a Melfa IV program in the arm's controller, or externally by sending commands through RS-232 serial communication.

B. Senso Glove

It is a hardware device (wireless glove) that enables human-robot interaction by capturing hand movements [10]. Utilizing inertial measurement unit sensors, it features eight sensors communicating at a speed of 400 Hz, with a latency of 15 ms. Additionally, it includes a controller for virtual reality or augmented reality and vibration motors for user feedback [16]. The sensors incorporate a gyroscope, allowing the measurement of orientation in three dimensions, including the pitch, roll, and yaw angles for each finger, palm, and wrist. Moreover, they provide information about the speed at which our fingers or the entire hand is moving.

C. Firebase

It is one of Google's cloud-related products that provides services such as [17] storage, hosting, instant messaging, user self-identification, and real-time NoSQL database. In the case of the NoSQL database functionality, it synchronizes all clients in real time, providing each with an instance to automatically receive updates. It is used in multiple applications, including web services, mobile applications, and sensor data, implementing data encryption security [18]. This involves the use of a digital certificate that authenticates identity, enabling a secure connection.

D. Internet Of Things

Technological advancement is overwhelming, being in the fourth industrial revolution [19], defined as the connection of sensors and actuators to the internet, sending real-time information to assess changes and control objects or phenomena in both physical and digital processes. Additionally, objects interact with each other, and their information is collected and evaluated. To achieve this, high-speed internet, data storage, and computing power are essential [20], leading to the use of cloud computing technology. Its applications are diverse, ranging from video security in communications, automobile navigation systems, telemedicine, production systems, home automation [21], and more. It is a comprehensive multidisciplinary system, ensuring the security and reliability of data transmission. While the initial implementation cost is high, it provides accessibility from anywhere in the world.

III. METHODOLOGY

A. Developed Proposal

Perform control of the Mitsubishi RV-2AJ arm through the Senso Glove (Figure 1). The wireless glove operates in the 868 MHz ISM band. The information it sends to Unity (version 2021.3.19f) is processed based on the arm's movements and sent to the cloud using one of the Firebase Realtime Database services that utilizes the WebSocket protocol. At the moment it is sent, it is also processed for the digital arm, which depends on this data for its movement. Subsequently, the sent information will be read by the ESP32 electronic card, which interprets and sends commands serially for the movement or activation of the gripper of the RV-2AJ arm. Below is a detailed breakdown of each configuration segment to achieve the proposed objectives.

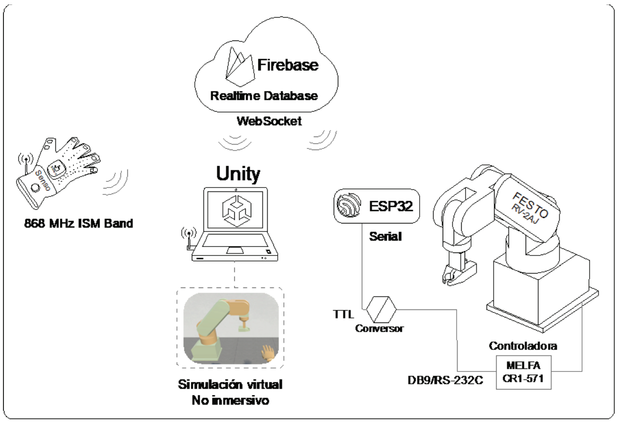

Fig. 1. Design of control and simulation using the Senso Glove for the Mitsubishi RV-2AJ arm.

B. Virtual Design

In this case, a 3D CAD design software is used to create a virtual arm that replicates the key features of the physical arm, including its base, links, and end effector, while adhering to its dimensions to ensure similarity.

Upon importing it into the Unity scene, it will be scaled using the Transform scale function: 0.05 for proper visualization. It is important to note that to emulate the movement of the physical arm, it must be constructed in a way that allows its joints to be programmatically controlled. For this purpose, the SolidWorks program was used, which enables the design of each movable piece individually and then assembling them. This assembly is saved in STL format to be imported into Blender software, version 3.1.2, and subsequently exported as an FBX file without any modifications.

Finally, the virtual arm is integrated into the glove scene, creating a scenario for the simulation of both at the same time, as shown in Figure 2

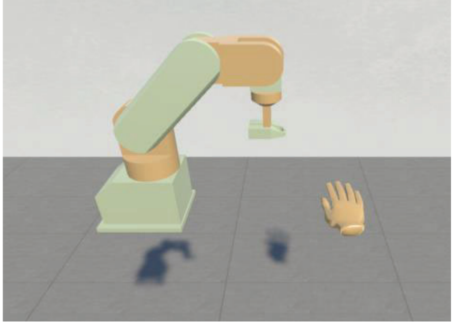

Fig. 2. Virtual integration of the RV-2AJ Arm and the Senso Glove hand, initial positions.

C. Glove Calibration

Firstly, to acquire data, communication is established between the glove and the computer through the Senso_DK3_GUI software. The calibrated glove and its connection, receiving real-time sensor data, can be observed. This communication occurs via radio frequency in the 868 MHz band. Upon initiating the software, it allows the user to calibrate the glove in case it is misconfigured, ensuring that hand movements align coherently with the received data through an animated visualization.

D. Communication

In the following Figure 3, the information flow is identified, starting from the gloves that have wireless communication with the PC. The data is processed within the Unity program through its C# scripts, structured for interpretation, and then sent to the Firebase Realtime Database. Subsequently, the electronic board will constantly evaluate the changes in the database and process them into corresponding commands for the RV-2AJ arm. It is worth noting that there is electronic hardware to accommodate the communication voltage levels between the ESP32 (0 to 3.3 V) and the Melfa CR1-571 arm controller (-15 to 15 V). This results in an action on the arm, whether it is to move, stop, or open and close the gripper.

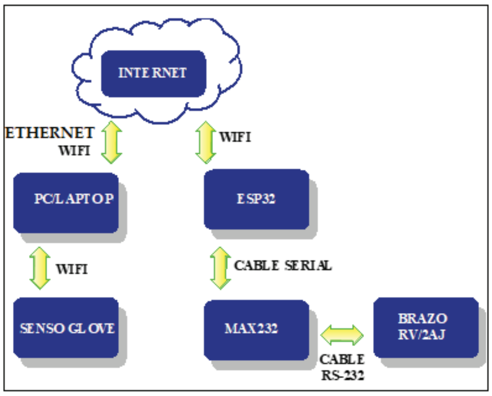

Fig. 3. Communication Diagram for RV-2AJ Arm Control.

E. Programming

In the Unity software, using the C# language, classes, methods, and variables from the freely accessible Senso gloves package (SensoHandSDK.unitypackage) are interpreted. These elements help obtain information sent by the gloves, allowing for the creation of new scripts based on specific needs. In this case, the scripts are developed to control both the physical RV-2AJ arm and its digital counterpart. The obtained ranges are associated with movements in two axes and the actions of the end effector. These relationships also guide the movements of the digital arm, such as moving from left to right, from top to bottom, or vice versa, and opening or closing the end effector.

In the following (see Figure 4), the MoveXY class diagram illustrates the analysis of data obtained from the SensoHandExample class, specifically data related to the palm and middle finger. The acquired information is segmented to conceptualize it according to our requirements, which, in this case, determines an action in the RV-2AJ arm. This allows for control of movements along the "Y" and "Z" coordinate axes and the opening and closing of the end effector gripper.

Additionally, the corresponding data is sent to the Firebase database to be read as needed. For the MoveArm class, control was implemented for the digital arm, which mimics the movement of the physical arm. Necessary calculations are performed to utilize Euler functions, ensuring the normal development of joint and link movements. Unity's nesting object property is also emphasized during this process.

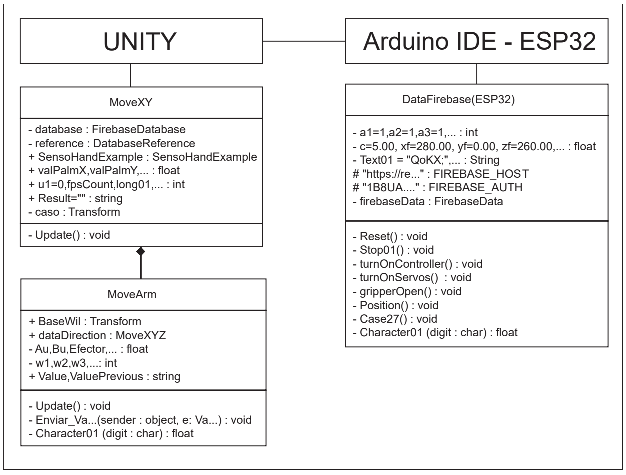

Fig. 4. Control System, Classes for Sending Information of the Digital and Physical Arm.

The real-time location of the physical arm can be requested, and this information is sent by the arm in a character string containing the corresponding values of its current location. The respective functions are used to obtain these values, making them usable locally or externally.

IV. RESULTS

A. Data Presentation

In Table I, two segments of 30 samples each are summarized, one when communication is optimal and the other when there is an initial delay in the received signal intensity. These data were extracted from the Senso_DK3_processing Windows console, which is activated when the gloves communicate with the computer.

TABLE I. QUALITY OF RECEIVED SIGNAL INTENSITY

Sample	FPS	rssi	Delay	Wi-Fi RSSI
1ra.	67/68	-63	2,013	Very Good
2da.	48/68	-79	4,420	Good

Next, with the information obtained in the Unity software from the inertial IMU sensors includes the interpretation of movement concerning the coordinate axes "X," "Y," and "Z" of the rotation angles Pitch, Roll, and Yaw, respectively.

B. Communication Times

In Figure 5, option a) shows the gripping actuation sampling time from the moment the signal is sent from the Senso Glove, with an average of 850 ms. The data is transmitted from the gloves, processed in Unity, sent to the Firebase cloud, and then read by the ESP32, which finally encodes it to open or close the gripper. For option b), the box-and-whisker plot illustrates the median with a value of 800 ms.

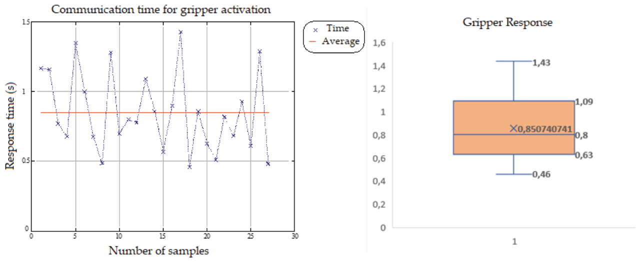

Fig. 5. Gripper Response from the Data Processing by Unity.

For option a) in Figure 6, the time it takes to react to movement along the "Y" or "Z" axes is shown, with an average of 780 ms. Similarly, the data is sent to the Firebase cloud to be later read by the ESP32 and transformed into the respective command for movement. For option b) in Figure 6, the median is observed with a value of 760 ms.

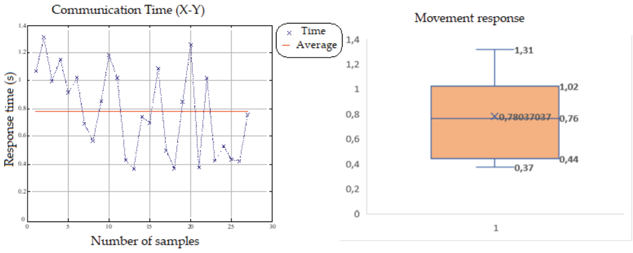

Fig. 6. Response of the Arm Movement when the Data is Processed from Unity.

Table 2 shows the gripper opening with an effectiveness of 92%, based on a sample of 25 consecutive repetitions. Likewise, for the respective movements along both axes, there is an average of 83% effectiveness between them.

TABLE II. EFFECTIVENESS IN THE MOVEMENT AND GRIPPER OPENING BASED ON 25 REPETITIONS.

Position	Up	Down	Left	Right	Gripper
Number of times obtained.	22	21	20	20	23
Effectiveness.	88%	84%	80%	80%	92%

C. Results

In Figure 7, the non-immersive virtual environment of the arm and glove with their corresponding physical parts can be observed. In this case, the arm is moving to the right, both physically and digitally, due to the interaction of the Senso Glove, which is in the right position from its initial point.

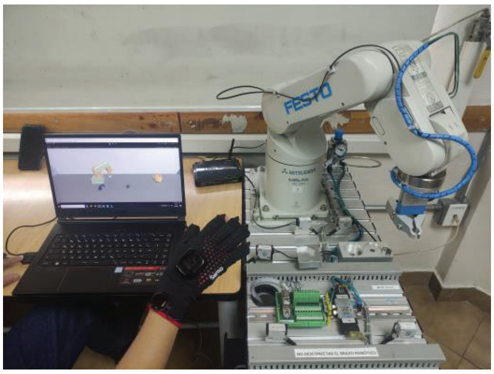

Fig. 7. Overall Visualization of the Physical and Virtual Environment.

Figure 8 displays the physical and virtual environment of the robotic arm for different positions. The end effector, with its digital and physical gripper opening, is observed. It is controlled from the glove, enabling the operator to perform arm movements based on hand motion.

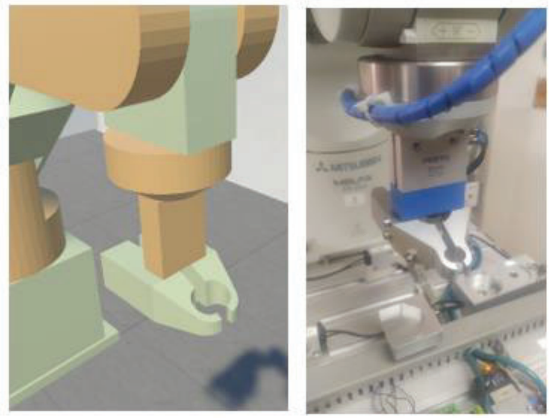

Fig. 8. Initial Position of the RV-2AJ Arm and Gripper Opening.

V. DISCUSSION

In this study, control of an industrial robotic arm was achieved through Haptic technology, cloud communication, and visualization in a virtual environment. It was observed that the use of Haptic technology provides a more user-friendly control, and the system exhibits high precision in various movement tests. It was observed that the calibration process of the Senso Glove is crucial to determine the working environment and thus ensure the proper functioning of the arm, which can then be visualized in the virtual environment.

The results indicated that there is a variability of 70 ms in the response times for both movement and gripper, with the averages in both cases. The medians are below the averages, indicating asymmetric box plots. This time depends on the processor of the machine running the programs. The focus of this research is on the Internet of Things (IoT) with outcomes for non-critical processes, leading to a considerable latency based on the obtained results.

VI. CONCLUSIONS

Controlling a robotic arm through haptic technology and visualizing its digital representation in real-time is achievable through the integration of various technologies such as IoT, 3D simulation, haptic technology, and communication protocols. There is a delay in the data flow from Unity to ESP32 due to the transmission or reception to the Firebase cloud and the repetition loops in both Unity and ESP32, resulting in an average of 850 ms for gripper actuation and 780 ms for response to movement on its axes. It should be noted that the time is directly related to the processing power of the machine and can be improved by using a PC with better specifications.

In the control system, specifically in opening or closing the gripper, there is an average effectiveness of 87.8%, with higher values obtained in samples of 15 or 20 consecutive repetitions. This value depends on the movements given to the arm because interaction involves multiple axes, and the response times of the arm are slower than those of the hand due to its manufacturing characteristics and degrees of freedom.

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