Internet of Things-Based Remotely Simulated Educational Modular Robotics Trainer Utilizing ESP -NOW Protocol

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Abstract

This study explores the use of web-based education programs and the adoption of an IoT-based approach using the ESP-NOW protocol for affordable and effective robotics education. With technological advancements, distance learning has proven to be as successful as traditional face-to-face instruction when supported by proper methods and ICT platforms. While robotics education aligns with the growing needs of machine learning, the adoption of modular IoT-based approaches in STEAM education has been limited due to complexity and cost. This project addresses these challenges by utilizing both Wi-Fi technology and the ESP-NOW protocol for simulated wireless robotics educational learning, enabling secure communication between different robotic modules. The study aims to prepare and strengthen students' foundations in Engineering and Information Technology while ensuring affordability and effectiveness in robotics education.

Keywords: Internet of Things, ESP-NOW Protocol, STEAM Education, Modular Robotics Platform, Simulated Environment

1 Introduction

Web-based control and robotics distance education is a rapidly expanding field within engineering education, offering a wide range of educational materials and numerous teaching tools and platforms. Educational institutes across various locations are increasingly embracing distance education programs, even for courses that traditionally involve hands-on experimentation. However, the realm of web-based robotics education has witnessed some exceptions. As Kviesis et al. (2020) note, “The use of ESP-NOW protocol as a communication technology added an advantage of longer communication distance between measurement nodes in comparison to a previously used Wi-Fi based approach and faster data exchange.”.

In many Philippine schools, robotics laboratory classes are commonplace, where radio frequency (RF) technology is employed to control robotics devices. While some schools have explored the use of Bluetooth and Wi-Fi technologies, none have yet ventured into utilizing the ESP-Now protocol for controlling robots and their platforms.

Currently, there is a scarcity of Internet of Things-based modular robotics educational platforms available in the Philippine market. The few platforms that do exist often come at a high cost and imported from other countries, making robotics learning inaccessible to many. Additionally, some platforms are excessively complex, surpassing the level of expertise typically possessed by senior high school students. Furthermore, many existing platforms rely on radio-controlled Sumobots, line-following robots, and build-and-run construct kits, which lack wireless communication and protocol knowledge, training, and expertise. Moreover, many robotics education platforms lack internet-based control and manipulation capabilities.

This project aims to address the challenges by implementing and leveraging the ESP-NOW protocol to establish direct wireless access via Wi-Fi for each module within the robotics platform. By focusing on modular independent wireless connectivity, this study offers students in STEAM programs the opportunity to gain knowledge using a cost-effective educational robotics platform. Through the incorporation of internet protocols and modular networking, this project simplifies wireless modular programming for students aspiring to pursue careers in technology and engineering.

The proponents have chosen the ESP-NOW wireless protocol, enabling seamless communication among multiple devices utilizing together the protocol and Wi-Fi technology, thereby achieving the desired remote communication for the robotics modules. Similar to the low-power 2.4GHz wireless connectivity commonly found in wireless mouse devices, the ESP-NOW protocol facilitates secure peer-to-peer connections among modular parts within the platform, ensuring optimal functionality and versatility.

2 Literature Review

Related Literature and Studies

ESP-NOW Protocol Definition

ESP-NOW is a wireless protocol technology created by Espressif company that allows various devices to communicate with each other without relying on Wi-Fi. This protocol functions similarly to the low-power 2.4GHz wireless connectivity commonly utilized in wireless mouse devices. It is a secure and peer-to-peer connection with no handshake being required that the different robotic modules can communicate independently and dependently to other modules. This means that after pairing a device with each other, the connection is persistent. In other words, if suddenly one of your boards loses power or resets, when it restarts, it will automatically connect to its peer to continue the communication. It supports the following features:

- Encrypted and unencrypted unicast communication;
- Up to 250-byte payload can be carried;
- Sending callback function that can be set to inform the application layer of transmission success or failure.

ESP-NOW technology also has the following limitations:

- Limited encrypted peers, 10 encrypted peers at the most are supported in Station mode;

- 6 at the most in SoftAP or SoftAP + Station mode;
- Multiple unencrypted peers are supported, however, their total number should be less than 20, including encrypted peers;
- Payload is limited to 250 bytes.

In simple words, ESP-NOW is a fast communication protocol that can be used to exchange small messages (up to 250 bytes) between internet capable microcontroller module boards. ESP-NOW is very versatile and you can have one-way or two-way communication in different setups.

Virtual Robot Arm Control Model

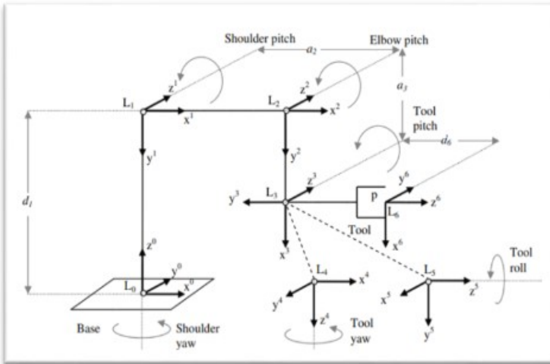
In the study of Kottege and Sonnadara, 2016, a Six-axis Virtual Robot arm (SVR) was designed with adjustable kinematic parameters to mimic a 6-axis articulate robotic manipulator with revolute joints having 6 degrees of freedom. Their interface screen based interface was complemented by a custom designed external controller which was connected through the parallel port of the PC. The interface and the main mathematical engine that deals with rigid body transformations has been implemented with Borland Delphi 6, while the external controller was based on the 10-bit A/D channels of the PIC18F458 microcontroller, programmed using the MPASM assembler by Microchip Inc.

Their study achieved that the SVR can be manipulated using direct kinematics to change the spatial orientation of virtual objects in 3 dimensions. Picking and placing of virtual objects can be done by using the virtual proximity sensors and virtual touch sensors incorporated in to the jaw design of the SVR. Furthermore, it can be trained to perform a sequence of movements repeatedly, to simulate the function of a real industrial robotic manipulator.

Figure 1. Link coordinate model diagram for the Six-degree Virtual Robot Arm (SVR) with horizontal tool (Kottege and Sonnadara, 2016)

The iCub Humanoid Robot Simulator

In this study of Tikhanoff, V et al, 2015, the authors present the prototype of a new computer simulator for the humanoid robot iCub. The iCub is a new open-source humanoid robot developed as a result of the RobotCub project [1], a collaborative European project aiming at developing a new open-source cognitive robotics platform. The iCub simulator has been developed as part of a joint effort with the European project iTalk



on the integration and transfer of action and language knowledge in cognitive robots. This is available open-source to all researchers interested in cognitive robotics experiments the iCub humanoid platform.

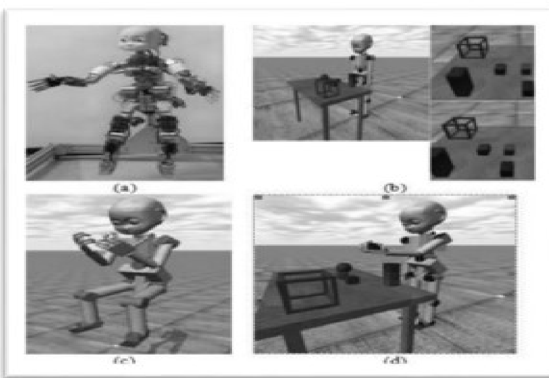


Figure 2. Software simulated of real iCub (a), of simulated iCub and the binocular view (b) The simulated iCub moving all four limbs as part of a demo (c) and the simulated iCub looking at and manipulating an object in its environment (d), (Tikhanoff, V et al, 2015)

Master-Slave Robot Arm

This study of Gupta, 2017, details the design and development of designing and control an anthropomorphic robotic arm using a bilateral master–slave control methodology. The project focused on the master robot which was fitted to a human arm with a 6 revolute joints for smooth and unblocked motion of the human arm. Two cabins will be designed for the robots one for the master and one for the slave to control the synchronization of them using 2 PLC integrated with servo motor drivers and twin Xbee modules for wireless communications.

The Slave robot is an high strength iron robotic arm with the same 6 revolute joints in the master arm, this robot is fixed to an iron column which can be fixed in the future on an another mobile robot, this slave will work with 6 powerful servo motors attached to the joints to copy the motion of the master robot. An advanced option will be fitted to the robot after finishing it which is the force feedback from the slave to the master.

The study is similar to the researcher's project wherein it employs simulated robot arm, but unlikely, the current research was more on the IOT-based remote communication control and manipulation.

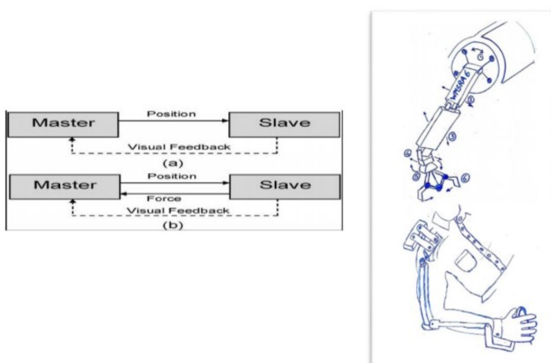


Figure 3 – The concept of Gupta's Master-slave robotic arm simulation. (Gupta, 2017)

Design of a Modular Arm Robot System based on Flexible Fluidic Drive Elements

In the works of Kargov, A., et al., 2015, they have designed, constructed, and demonstrated the technical characteristics, functionality and control scheme of a new modular hand-arm robot system. Their system is designed for applications in robotic and rehabilitation medicine. They have developed a novel, compact modules based on flexible fluidic actuators which are equipped with measurement and control elements for a robust control and, hence, precise positioning of the modules. They focused their work in modules with pneumatic flexible driving elements which were characterized by a mechanical modularity that allows for various types of robot kinematics and in particular for lightweight and low-cost concepts. The study used modules, to medium-sized enterprises that rapidly and reliably adapted their system to various working environments and tasks and developed innovative robot systems for new and existing markets.

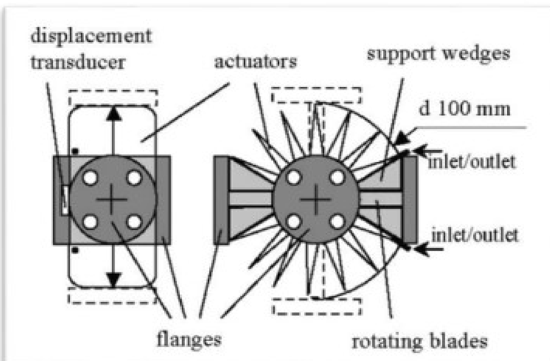


Figure 4 – A modular approach in connecting robotics modules, Kargov, A., et al., 2015, IEEE

3 Materials and Methods

Design and Methodology of the Study

The researcher used the experimental, descriptive, and developmental research method to efficiently gather data and establish a systematic way of developing an Internet of things-based remotely simulated educational modular robotics trainer utilizing ESP-NOW protocol.

A. Robotic Arm Trainer Configuration

In order to determine the system parameters, modules were designed and utilized the ESP- NOW protocol and integrate the protocol into each software modules inside the microcontrollers' flash memory. Two configurations were employed in controlling the individual hardware: the Master-slave and Master-master configurations.

In the master-slave configuration, the master microcontroller hardware serves as the base station of the robotics trainer that control the other module using the Internet based IDE while master-master configuration function each modules independently to each others.

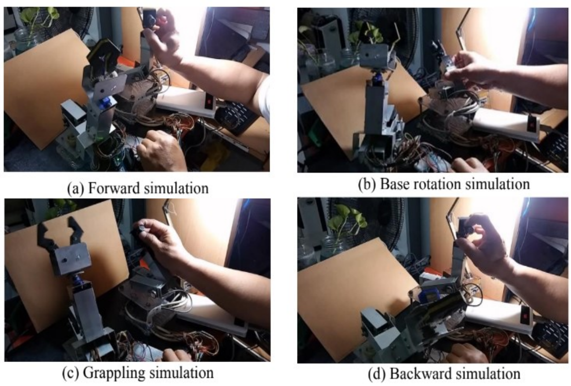


Figure 5. Different position and axis simulation of the robotics platform. (a) Forward simulation, (b) Base rotation simulation, (c) Grappling simulation, (d) Backward simulation

The ESP-NOW protocol is the heart of the software IDE that determines the individual communication configuration of each microcontroller modules. With ESP-NOW, each modular board is capable of sending and receiving at the same time in order to establish a two-way communication between boards.

Figure 6. Master-master and Master-slave configuration of the ESP-NOW protocol

B. Modular Design of Individual Parts

Aside from wireless connectivity, integration of base station and modular units were designed in a plug and play, mechanical modules. Connectivity in a connected mode was achieved via a four pin connector common to all the modules. The pins were configurations are positive five (5) volts, negative or the ground, positive signal and negative signal pins.

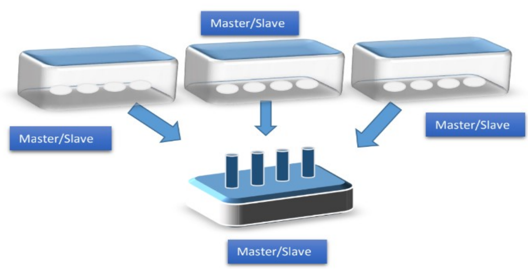


Figure 7. Modular connectivity of the individual modules

C. Internet of Things Configuration

The system can be controlled via cloud internet or direct Wi-Fi connection. All microcontroller modules are IP-based and have each individual IP addresses and can be controlled via internet or direct Wi-Fi access station. Each module can communicate remotely to other target modules as desired individually via the internet based IDE. Each module's functions can be controlled directly via any smart devices or stations as long it is capable of connecting to the internet or network. The modules can be configured as master-master or master to slave connection with common base module that controls the other modules. Below is a block diagram of the IOT configurations:

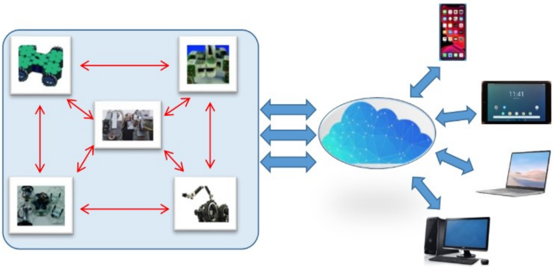


Figure 8. Modules can be masters or slaves and can be controlled via any browser with the web-based IDE.

D. Method and Techniques

The developed project was backed-up with a well-defined survey, proper planning, implementation, design, and management. Basically, crucial consideration of DEPED's STEAM program, educational robotic resources, and technical surveys have carried out and considered at the initial stage of the project conception. The main concerns of the implementation of the project are as below:

1. Knowing the wireless technology to be provided in the trainer;
2. Output Based Education survey and analysis with respect on the target curriculum subjects;
3. Programming language to be used;
4. Programming mindset and scientific inquiry skills;
5. Cost-comparison with the existing educational robotics trainer;
6. Determining the different functions of the modules;

7. Identifying the level and industry standards of building the educational robotic trainer;
8. Maintenance process and project testing;
9. Engineering project standard confinement (in case of any modification)

Respondents of the Study

The respondents included in the study were the heads and members of the Faculty of Electronics, Information Technology, and High School Principals of different Bulacan Private Schools that offers STEAM programs. Hobbyist and Engineers were also selected especially of those with circuit design capabilities. As shown in Table 1, the researcher involved 100respondents to have a valid investigation. Bulacan State University, Living Angels College, Grace Christian Academy of Baliuag, and Baliuag University, each has five member respondents. St. Mary High School of Baliuag, Collegio De Sto. Niño of Bustos, Holy Child Academy, and Notre Christi Academy have individually had four member respondents.

Teachers/Faculty/Engineers	Population	Samples	Percent
1. BulSU	5	5	100
2. St. Mary HS of Baliuag	4	4	100
3. Collegio De Sto. Niño	4	4	100
4. Living Angels College	5	5	100
5. Baliuag University	5	5	100
6. Holy Child Academy	4	5	100
7. Notre Christi Academy	4	4	100
8. Grace Christian Academy	5	5	100
TOTAL	36	36	100

Instrument of the Study

A locally constructed questionnaire used in the project. Before its construction, the researcher made intensive readings of electronic books, hardware and software magazines, educational robotics manufacturers, robotics web forums and related studies to come up with a useful instrument. CHED's STEM and VOC-TECH modules were also considered to cater its learning outcome requirement. The first draft of the instrument presented to three experts and highly qualified engineers in the academe. Their valuable comments and suggestions are useful in improving the draft.

Data Gathering Procedures

Letters requesting the permission to conduct the survey via online was given to the principals and administrators of different High Schools in Bustos and Baliuag. Because of the pandemic, questionnaires of the survey instrument were filled-up via Google form. Video of the robotics trainer were shown to the respondents and provided them ample time to accomplish the questionnaires. Close supervision was extended by the researcher in the retrieval of the instruments to obtain one hundred percent return of the questionnaire.

Data Analysis and Statistical Treatment

Collected data were tallied, tabulated, and organized according to the following headings:

a.) Internet of Things Technology Acceptability
b.) Microcontroller Specifications;
c.) ESP-NOW Functionality;
d.) Remote communication and control;
e.) Compatibility with OBE and STEAM Syllabus of DepEd;
f.) Availability of Spare Parts;
g.) Sensors Inclusion;
h.) Accessories;
i.) Modular assembly and programming features;
j.) Price Range and comparison;
k.) Audience Target;
l.) Software Category

In the survey questionnaires variables, valuable factors were categorized according to the data above. The questions below are part in the design of IOT-based simulated educational robotic arm trainer:

1. What category of characteristics do they want in an educational robotics trainer? (Industrial robot kits, Mobile robot, biologically inspired robots, social interaction, competition based robot kits).
2. Is it DepEd recommended? Yes or No
3. Is it IOT or web-based?
4. Is it easy to be assembled even by STEAM students?
5. Do the spare parts is abundantly ready and available in the local market?

6. Are the robotic trainer's modules can be extended its application through the sensors? (Sensors adaptability and modular compatibility to real world)
7. What is the price compare to overall capability of the trainer? (Economy vs. Functionality)
8. Does it fits the required student's learning outcomes, and able to expand beyond that learning?
9. Do the hardware and software are supported by large technical and engineering pool?(Software and Hardware Open Systems).
10. What is the target programming age of the software and hardware? (Audience Range)

Results and Data Analysis

Most of the respondents accept, agreed and recommended the project due to the major edge of factors in the above survey. As shown in Table 1 the respondents agreed that the first thing they require in a trainer is its ability to support the Outcome Based Education especially in the STEAM and VOC-Tech strand. Learning modules of the trainer system can be supplied in accordance to the lectures required in the syllabus. The wireless functionality and modularity of the robotic trainer do not limit to robot arm only but can be expanded to any microcontroller based applications using the different modules with built-in sensors. The system design was compliant to Quality Assurance Standards (ISO 9126-1), an international standard that governs the software and hardware system design of a product especially of robotics.

4 Conclusions and Recommendations

Because of the lack of readily available IOT-based remotely simulated educational modular robotics trainer in the Philippine market, an increasing population of the STEAM students can be benefitted in this project, and also recommended to be of significance to the following:

STEAM, BulSU CIT, Engineering and IT Students. The educational robotic trainer is significant to the industrial technology, engineering and IT students since the system will provide a low-cost, flexible, and explorable IOT-based robotic trainer platform in the applications of robotics and automation.

Academic Institution. The project will be significant to the Bulacan State University and other schools offering STEAM programs in bringing about the strengths and weaknesses of the technical status of the existing curriculum. This will produce changes, innovation, and inventions of more applications in the field of wireless robotics and automation. They can also incorporate the trainer in their respective subjects that concern the input/output data manipulations.

Researcher. The researcher would also benefit in this project because this will enhance the skills in the area of technical research applications and work performance while inheriting knowledge throughout the development of the system. Some applications of concerns are Sensor Networking, Internet of things, Animatronics, Environment Monitoring and Control Systems, Embedded Systems, Automated Pick and Place Systems, Mini PLC-like functions, etcetera.

Future Researcher. The system will serve as an inspiration to those who wanted to develop and improve the existing system. The system also aids as a first step in developing different educational robotics and automation systems using various approach. They can also use this research as a reference for whatever study they will be venturing in the area of educational robotics. Further revision of this proposal to improve the system will be promoted for the betterment of the BulSU and academic community.

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