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Edu-Rover: Application of Unmanned Vehicle Systems for Robotics and STEM Education in Nigeria

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Abstract

INTRODUCTION: Robotics needs to be made simple to understand in order to serve as a direct introduction to programming. In this paper, we propose the Edu-Rover (an unmanned vehicle system) for teaching robotics, and other science, technology, engineering, and mathematics (STEM) related subjects.
OBJECTIVES: The aim of this project is to expose students to the applications of the theoretical knowledge learned in STEM subjects.
METHODS: To determine the applicability of our apparatus, we conducted workshops in schools. These include the collection of questionnaire data from students and teachers to evaluate its pedagogical significance.
RESULTS: Results show that our Edu-Rover is useful for teaching STEM subjects and concepts in schools.
CONCLUSION: Thus, we hope that this would stimulate creativity and cognitive abilities among students, especially in developing countries like Nigeria, in robotics and other STEM related subjects.

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1. Introduction

Robotics is an interdisciplinary field of a broad-based education that cuts across different fields of science and engineering, and even non-technical fields like creative art and psychology. According to [1], robotics is primarily the technology and the underlying science that integrates Physics, Mathematics, Mechanical Engineering, Electrical Engineering, and Computer Science with the goal of re-engineering and automating some aspects of human functions, especially the mobility and manipulative functions of the animal. The replication of our biological locomotive features as transport machines has intrigued the imagination of many young minds; as a result, this art of bio-mimicry has inspired the flair of these people for Science, Technology, Engineering, and Mathematics (STEM). Based on this insight, many educational systems around the world are taking practical steps to reform their STEM education from early childhood to college-level studies, mainly through increased efforts to incorporate new technological and project-based learning activities [2]. According to [3], this approach could enhance the students' ability to grasping advanced technological concepts (such as mechatronics and programming) that are intrinsically part of robotics.

In the United States, policy makers and educators predict the shortage of workers in STEM fields and are concerned that this will have a negative impact on the economy [4]. For this reason, many American schools are introducing STEM-related subjects, study programs, and extracurricular hands-on activities into their educational system. A typical example of this initiative is the FIRST robotics competition (FRC); where 'FIRST' stands for "For Inspiration and Recognition of Science and Technology". The FRC is an international sport-oriented high school robotics

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competition founded by Dean Kamen and Woodie Flower in 1992. Every year, FRC sponsors teams of high school students, instructors, and mentors to work for a duration of six-week to develop game-playing robots [5]. Since its inception, FRC has contributed to defining America's path to space exploration [6]. This is evident in the success story of space robots and planetary rovers like the opportunity, spirit, and curiosity that has enabled scientists in NASA to probe extraterrestrial environments like the surface of the moon and planet Mars [7]. In Nigerian secondary education, the major STEM subjects include Basic Science, Basic Technology, Computer Studies, Mathematics, Physics, Technical Drawing, Auto-mechanics, Chemistry, and Biology. There is hardly a practicable didactic means of establishing a unifying relationship between these STEM subjects. The only subject that promises this kind of synergism is Robotics. This instructional constraint is also palpable in our universities and polytechnics, where the relevant faculties are struggling to modify science and engineering curricula to conform to world best practice, which is largely driven by advances in automation, robotics, and artificial intelligence (AI).

Unfortunately, several infrastructural factors are hindering the full introduction of robotics in Nigeria's educational system. These include the epileptic supply of electric power, shortage of indigenous robot makers, poorly equipped or total lack of robotics laboratory in secondary schools. This is very evident in the report of [8] on the opinion of stakeholders that Nigeria is not prepared for robotics education. However, some prominent Nigerians have expressed optimism on the capability of adopting and nurturing robotics education in Nigeria. A Nigerian former Education Minister, Dr. Obiageli Ezekwesili while calling for a radical change in the Nigerian education sector in Lagos [9] has charged the federal government of Nigeria to focus on key reforms that will bring about the introduction of novel technological contents like artificial intelligence, robotics, internet of things and machine learning into Nigerian schools' curricula. In recent times, some foreign agencies in collaboration with the Nigerian government and some indigenous entities are initiating practical steps toward establishing platforms that would support the infusion of robotics into all levels of Nigeria's education system. For instance, in October 2017 the United States Diplomatic Mission to Nigeria partnered with RoboRave International, a United States of America based robotics academy to train 460 Nigerian students, teachers, and scientists on hands-on robotics and donated a hundred robots to the participating school in a bid to inspire robotics education in Nigeria [10]. Also, it is worth mentioning that some local entities are not left out of this effort. The ACI computer education is one of them; here all they do is build robots. It was established by Olaoluwa Balogun, an undergraduate student of the Obafemi Awolowo University (OAU) in the year 2011 as a non-profit organization that trains young Nigerians on programming and robotics [11]. In the present paper, we propose our Edu-Rover (abbreviation for educational rover). This is a robotic unmanned vehicle for teaching STEM-related practical concepts in schools.

2. Related Works

To sustain the advancement of robotic technology, there is an apparent need to introduce robotics into all levels of the education system [12]. According to [13] and [14], robots could be used as effective apparatus for teaching different technical concepts in schools; also [15] suggests that robotics could be applied as conceptual tools for teaching Mathematics in schools. The impetuous need to prepare the younger generation for the coming age of automation, robotics, and Artificial Intelligence (A.I.) has prompted educational policymakers to contemplate the introduction of robotics into all level of the national educational system [16]; hence bringing about the need for a new regime of specialized teachers and teaching instruments. These have inspired many visionaries, roboticists, educational technologists, and instrument makers into the research and development of revolutionary teaching gadgets that would enhance the effectiveness of robotics education in schools. For example, [17] proposed a new methodology for teaching automotive mechatronics courses in the universities. From their study, they were able to show that the approach of handing out lecture materials beforehand and having the student learn by practicing in the laboratory can increase the interest and performance of students in STEM subjects rather than a purely theoretical approach as it is done in many universities. Also, [18] proposed an approach to increasing students' passion for computing and STEM related education by having them solve the logical problem in robot programming using the LEGO Mindstorms kits. According to them, this could enable students to discover their natural abilities and make the most appropriate career choice in STEM.

In another study, [19] developed an experimental platform of a quarter vehicle model to enhance the teaching-learning system of vehicle dynamics with a focus on the control of vehicle suspensions' dynamics. From their work, it was deduced that students can have a better understanding of STEM-related concepts by exploiting the experimental and research-based learning approach. Similarly, [20] developed a learning environment for middle and high school students that uses telerobotics as a mechanism to provide the students with the ability to remotely manipulate and control real robots and their environment through a Web-based interface to promote education in Physics, Computer Science and Mathematics at the middle school, high school and undergraduate levels. According to them, working with robotics environment can offer excitement to a wide population through the Internet, as an Internet of Things (IoT) application.

The above reviews are necessary because they reveal the importance of adopting the robotic apparatus for STEM education, which defines the purpose of our work. Based on the report of [21], we have identified the role of using vehicular models like the teleoperated drones and wheeled robots to teach STEM concepts. This is because vehicles are multi-technical systems which entails the synergy of Physics, Mechanical designs, electronics, and software applications. There is a whole lot of insight a student of STEM courses could gain from studying a vehicular system; little wonder the children, especially little boys, are very fascinated when they play with toy cars [22]. The ingenuity of many renowned automotive designers and navigational roboticists is traceable to their childhood experiences with technological transport toys, through which they learned the rudiments of Physics, mechanism, and control beforehand [23]. To enhance this approach to learning, we have developed the Edu-Rover – an IoT-based robotic vehicle system for teaching STEM concepts. These include the concept of machine design, remote control, servomechanism, and embedded programming as applied to navigational robotics, for all levels of STEM education.

3. Materials and Methods

The Edu-rover robot is a software-driven system that comprises of several subsystems that synchronously work together to achieve the desired motion. The Figure 1 shows the generic model of the Edu-Rover system. This consists of a control system and an internal mechanism. These interact precisely with each other to drive the system. The Edu-Rover has a man-computer machine (MCM) interface that involves an ordinary radio frequency (RF), a wireless-fidelity (Wi-Fi) connection, or the combination of both. These ensemble constitutes the system's control network. In this network, the RF is used as the media for information exchange between the human operator and the vehicle's internal mechanism through the external control computer (ECC) within the line-of-sight (LoS), and also for the wireless relay of video feedbacks from the onboard video camera (i.e. CAM) to the personal computer (PC) to enhance visual observation of the vehicle's terrain. The Wi-Fi is used to establish an alternative or higher level medium for teleoperation via internet connection between the human operator and the ECC (while it is connected to the vehicle's internal

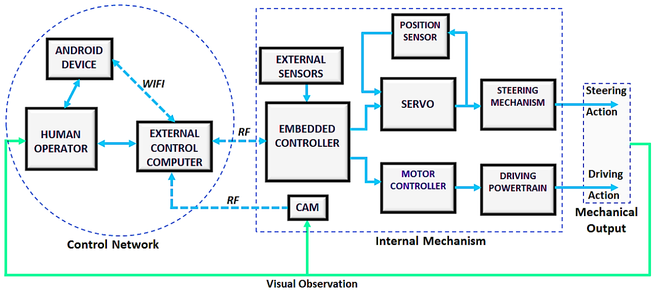

Figure 1. Block Diagram of the Edu-Rover System

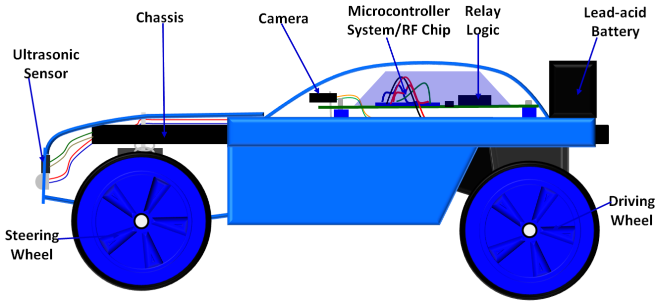

Figure 2. Model of the Edu-Rover system

mechanism) through a portable device like the Android system when the human operator is beyond LoS or in a very remote location. In this manner, the Edu-Rover system is essentially a cyber-physical system, which involves the flow of sensory data, control signals, and visual/video feedback between the human operator and the vehicle's internal mechanism over an IoT-integrated wireless control network.

3.1. Edu-Rover System: Design and Concepts

The Edu-Rover system is a simple rover design, which is remotely controllable with a desktop computer to demonstrate the "drive-by-wire" concept. The internal mechanism of Edu-Rover is made-up of some active components that include the driving mechanism, steering mechanism, sensors, and a controller. A control algorithm was formulated and used to integrate these components into a functional mechatronic system. The Figure 2 shows the 2D model of this system.

For navigation, Edu-Rover uses a high-torque drive system and a servo-mechanical steering system. The drive systems consist of a speed-reduction geared-motor that transmits equal power to the duo-rear wheels. The two rear driving wheels are attached to the load shaft to convert the rotary motion of the drive-train into the propelled linear motion of the robot, either to the forward or reverse direction, as dictated by the controller. Also, with the cushion effect of the rubber material used in lining the wheels and its large area in contact with the ground, enough traction is produced to propel our robotic vehicle system.

The steering mechanism of Edu-Rover is a servo-controlled Ackermann steering system – an improvement on the steering design of [24]. Its design layout and physical construction is shown in the Figure 3. Edu-Rover is steered whenever the rotation of the steering lever converts to the linear motion of the steering linkage. The servo can position the steering lever in three orientations on the horizontal plane i.e. 0°, 90°, and 180°. If the steering lever is oriented at angle 0°, the steered wheels turn left. At 90°, they align straight, while at 180° they turn right, according to the Ackermann steering geometry. The servo produces a stall torque, τ_{servo} of 1.0787 Nm at an angular velocity ω_{servo} of 6.5440 rad/s at 5V DC supply. The steering radius (i.e. length of the steering lever), r is 0.045 m.

The tangential force generated by the steering lever is evaluated as

$$F_{\text{servo}} = \frac{\tau_{\text{servo}}}{r} = \frac{1.0787\text{Nm}}{0.045\text{m}} = 23.971\text{N}, \tag{1}$$

hence, the power of the steering system is in turn evaluated as

$$P_{\text{steering}} = \tau_{\text{servo}} \times \omega_{\text{servo}} = 7.0590\text{W}. \tag{2}$$

Further details concerning the mechanics of the Edu-Rover system is discussed in [25]. This analysis provides a basic understanding of robot locomotion and the underlying mechanics as a STEM concept. In effect, this could be applied to the primary and junior secondary education, within the context of introductory technology, to prepare young pupils for future career prospects in the field of vehicle design.

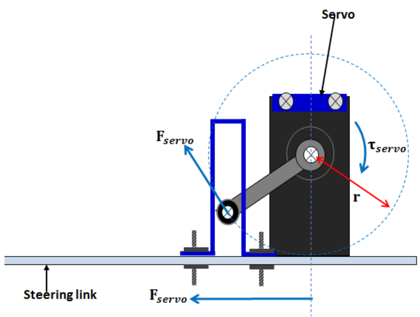

Figure 3. Depiction of the steering mechanism

3.2. Electrical Sub-system: Electronics and Sensors

The embedded controller of Edu-Rover is controlled and instructed using ATmega328P microcontroller. This is programmed as a semi-automatic controller. It monitors its serial communication port continuously in anticipation of radioed control signals from the human operator through the ECC. This embedded controller interacts wirelessly with the ECC in a master-and-slave architecture. Here, the embedded controller functions as the slave while the ECC functions as the Master. The peripherals of the embedded controller include the relay-logic motor controller, the steering servomotor, and four navigational sensors. The navigational sensors include an inertial measurement unit (IMU), ultrasonic sensors, a GPS sensor, and a compass sensor as shown in Figure 4. The relay-logic motor controller is electrically interfaced with the embedded controller. It contains two discrete relays that are wired together to form a two-channel relay H-bridge as shown in Figure 5. This can power the driving motor of Edu-Rover in either clockwise or counter-clockwise direction. The relay-logic powers the motor to spin clockwise if a logical HIGH is applied to the pin IN1 and a logical LOW to pin IN2 and, vice-versa for the driving motor to spin counter-clockwise. The relay-logic motor controller also functions as an electromagnetic isolator that protects the embedded controller which runs on 5 Volts from a 24 Volts source that powers the driving motor.

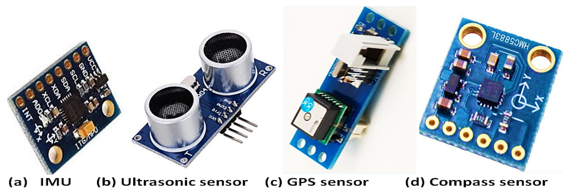

Figure 4. Navigational sensors of the Edu-Rover System

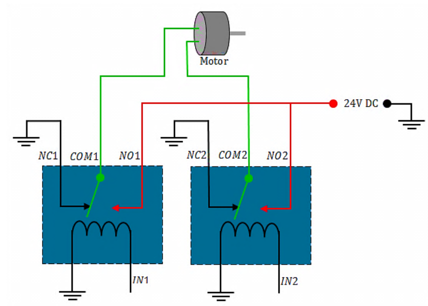

Figure 5. The Relay-Logic Motor Controller (contains two relays connected to form H-bridge circuit)

The MG995 Servo is used for the precision control of the angular position of the steering lever, which in turn, displaces the steering linkage to and fro, to steer the vehicle towards the desired direction. To control the steering system of Edu-Rover, the embedded controller sends electrical pulses of variable width to the steering servo, through its control wire, by a process known as pulse width modulation (PWM). The steering servo can only be controlled to rotate the steering lever by 90° in either direction for a total of 180° rotation angle. The PWM signal sent to the steering servo from the embedded controller determines the position of the steering lever at any instant. Based on the duration of the pulse sent to the steering servo via its control wire; the steering lever is rotated to the desired angular position. The steering servo continuously anticipates a pulse every 20 millisecond (ms) and the length of the pulse determines the angular position of the steering lever. A pulse of 1.5 ms will place the steering lever at the angular position of 90°. A pulse which is shorter than 1.5 ms (e.g. 1.0 ms) will rotate the steering lever in the counter-clockwise direction and place it at the angular position of 0°; while any pulse which is longer than 1.5 ms (e.g. 2.0 ms) will rotate the steering lever in a clockwise direction and place it at the angular position of 180°. The Figure 6 describes this process. The vehicle is aligned to drive in a straight line if the steering lever is placed at the angular position of 90°. If the steering lever is positioned at 0°, the vehicle is steered towards the right-hand side and the left-hand side, if the steering lever is positioned at 180°.

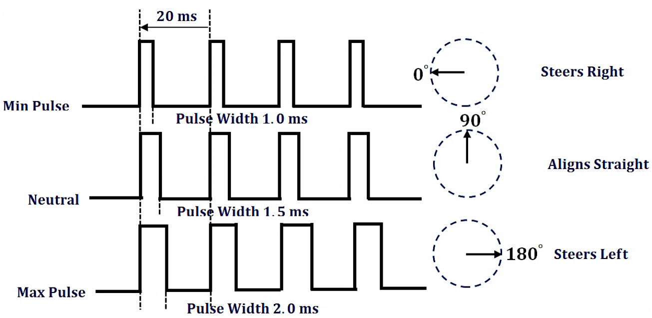

Figure 6. Different Pulse Widths and the corresponding Servo angular positions and steering action(s) of the vehicle

3.3. Software Subsystem: Control Logic and Algorithms

The software structure of Edu-Rover's control system comprises several embedded blocks of algorithms and logic, which controls its operation – navigation and perceptual responses. These include blocks of programs for remote-controlled driving, steering, anti-collision control, and sensory feedback. These were written in C++ programming language and compiled onto the embedded controller. The software structure of Edu-Rover is described in Figure 7. The algorithms of this software system are extensively discussed in Sub-subsection 3.3. This encapsulates conceptual techniques that could be used to teach object-oriented programming (OOP), as a STEM subject. Following the concepts in [26], some important subject-matters that can be learned from the software system of Edu-Rover include software organization, bit-wise programming, physical computing, and microcontroller-based OOP.

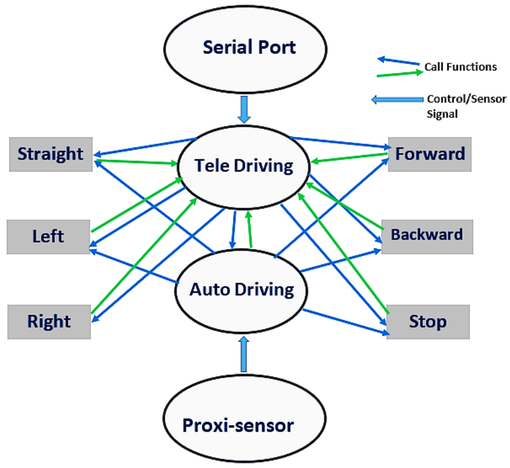

Figure 7. Software structure of the Edu-Rover system showing different blocks of embedded algorithms and logic

Tele-autonomous Control Algorithms. This comprises two blocks of algorithms – the tele-driving and auto-driving algorithm, for tele-operated and autonomous control respectively. The former describes a selection control structure that logically maps the command of the remote human operator to the target control function, at any instant of time. In this logic, the unique American standard code for information interchange (ASCII) characters are mapped to different preprogrammed motions of the Edu-Rover system. Here, the microcontroller continually observes its serial port for incoming signal(s) and compares it to its conditional constants, in order to execute the block of program whose conditional constant value matches that of the incoming signal. For instance, if a block of programs contains statements for actuating forward driving, the micro-controller causes Edu-Rover to move in the forward direction for a given duration of time. The logic of this function is described in Algorithm 1. In the absence of serial control signal(s) from the human operator, the robot automatically switches to the auto-driving algorithm (i.e. autonomous mode), through the activation of Algorithm 2, by means of function calls. Based on the definitions of [24] and [27], the inter-switch between Algorithm 1 and Algorithm 2 describes the implementation of a tele-autonomous system – a shared control between a human operator and the computer.

Linear-motion and Steering Algorithm. To perform drive-by-wire motions in 2D planes, the Edu-Rover software system incorporates two motion control algorithms. These are linear-motion algorithm (i.e. Algorithm 3) and steering algorithm (i.e. Algorithm 4). During the operation of the Edu-Rover system, Algorithms 3 and 4 responds to function calls (in the form of "go to" statements) from either Algorithm 1 or 2 to perform

Algorithm 1 Tele-driving Algorithms

```
Require: serialPort
function teleDriving
    while serialPort > 0 do            ▷ ASCII code is on the serial port
        controlSignal ← serialPort
        if controlSignal = 'F' then
            goto forward
            continue for 1 seconds
            goto stop
        else if controlSignal = 'B' then
            goto backward
            continue for 1 seconds
            goto stop
        else if controlSignal = 'S' then
            goto stop
        else if controlSignal = 'G' then
            goto straight
        else if controlSignal = 'Q' then
            goto left
            continue for 1.5 seconds
            goto straight
        else if controlSignal = 'P' then
            goto right
            continue for 1.5 seconds
            goto straight
        end if
    end while
    while serialPort ≤ 0 do            ▷ No ASCII code on the serial port
        call autoDriving
    end while
end function
```

Algorithm 2 Auto-driving Algorithms

```
Require: proximitySensor
Require: serialPort
function autoDriving
    while serialPort ≤ 0 do            ▷ No ASCII code on the serial port
        distance ← proximitySensor
        if distance ≤ 30cm then
            goto stop
            goto backward
            continue for 1.5 seconds
            goto stop
            goto left
            goto forward
            continue for 1.5 seconds
            call autoDriving
        else if 30cm < distance ≤ 60cm then
            goto stop
            goto backward
            continue for 1 seconds
            goto stop
            goto right
            goto forward
            continue for 1 seconds
            call autoDriving
        else if distance ≥ 90cm then
            goto forward
        end if
    end while
    while serialPort > 0 do            ▷ ASCII code on the serial port
        call teleDriving
    end while
end function
```

the electrical and logical operations in Subsection 3.2. Algorithm 3 describes a switching control structure, whose basic function is to switch the logical states of the 2-channel relay as shown in Figure 5 and as so, rotates the driving motor either in the clockwise or counter clockwise direction. The syntax of the embedded software statements for executing linear-motion control is given in Listing 1. This particular statements cause the Edu-Rover system to move in the forward direction. For the reverse motion and brake, the logical states in Listing 1 are varied according to Algorithm 3.

Listing 1: Forward-motion Control source codes

```
/*Object for forward driving*/
 forward:
{
    digitalWrite (relay_1, HIGH);
    digitalWrite (relay_2, LOW);
    teleDriving ();
}
```

To control the steering system of Edu-Rover, the branches in Algorithm 4 are consecutively called by Algorithm 1 or Algorithm 2 to execute the motion schedule. This involves the variation of the steering angle according to Figure 6. The syntax of embedded software statements for executing steering control are given in Listing 2. This particular statements cause the Edu-Rover system to steer towards the left. To drive straight or steer towards the right side, the steering angle in Listing 2 is varied according to Algorithm 4.

Analogous to the conventional computer system, the input-processing-output characteristics of the Edu-Rover software system describes how electrical signals (i.e. inputs) from the keyboard and sensors are used to control the motion (i.e. output) of a mechanical system, through the computer (i.e. processor). Thus, providing an intuitive understanding of how the computer system works.

Listing 2: Steering control source codes

```
/* Object for steering to the left*/
left:
{
   steering.write(180);
   teleDriving ();
}
```

Algorithm 3 Linear-motion Algorithm

Input: $goto \Rightarrow forward, backward, stop$
Output: $Logical\_States$
Output: $call \Rightarrow teleDriving$

```
procedure RELAY SWITCHING ▷ Controls drive motor
    forward:
    Relay_1 ← 1
    Relay_2 ← 0
    call teleDriving.

    backward:
    Relay_1 ← 0
    Relay_2 ← 1
    call teleDriving.

    stop:
    Relay_1 ← 0
    Relay_2 ← 0
    call teleDriving
end procedure
```

Algorithm 4 Steering-control Algorithm

Input: $goto \Rightarrow straight, left, right$
Output: $pulseWidth \Rightarrow steeringAngle$
Output: $call \Rightarrow teleDriving$

```
procedure SERVO SIGNALING ▷ Turns steering angle
    straight:
    SteeringAngle ← 90°
    call teleDriving.

    left:
    SteeringAngle ← 180°
    call teleDriving.

    right:
    SteeringAngle ← 0°
    call teleDriving.
end procedure
```

3.4. Control Architecture

For the operation of Edu-Rover as an IoT device, we provided the control model in Figure 8. This allows it to integrate an internet-enabled ECC for both LoS and beyond LoS control. The later control channel involves an internet connection between ECC and third-party hardware (e.g. an Android device). This becomes useful whenever the human operator needs to drive Edu-Rover from a remote location. Thus, we can reconfigure the Edu-Rover system to have two inter-system communication interfaces. The first interface is the wireless communication between Edu-Rover's internal mechanism and the ECC, while the second one is between the ECC and the human operator (which alternatively involves the Internet as earlier mentioned). In this configuration, the ECC only acts as a gateway between the vehicle's internal mechanism and the outside world.

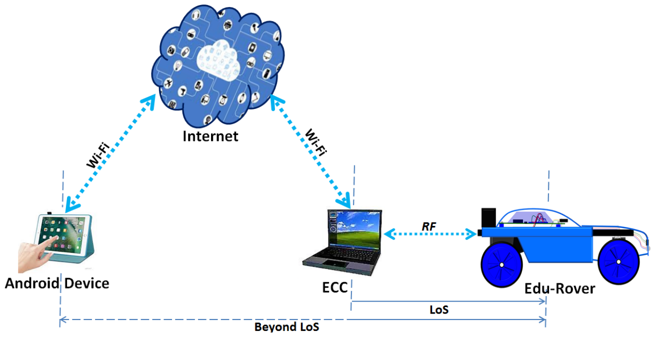

Figure 8. Edu-Rover Control Architecture

4. Results, Application, and Discussion

Using the available materials and technology in the Nigerian environment, we prototyped Edu-Rover as an unmanned vehicle system and demonstrated it before different groups of students in several workshops to ascertain its applicability as an instructional apparatus. During the demonstration of Edu-Rover, the students performed test procedures with Edu-Rover. We also examined their knowledge of its working principles to ascertain the pedagogical significance of Edu-Rover. The Edu-Rover vehicle was assembled and demonstrated to the students as shown in Figure 9. We issued questionnaires to two sets of 105 participating students at the completion of their hands-on exercises to rate on a scale of zero to ten how Edu-Rover system improved their STEM knowledge. This questionnaire was restricted to their knowledge of Physics, Mathematics, and Computing, which underlies our Edu-Rover system. The bar chart in Figures 10 and 11 are the graphical representations of the results. Also, a survey was carried out to determine the interest of participant teachers in the application of Edu-Rover to their subjects of specialization. The result of this study is shown in Figure 12.

From the Figures 10 and 11, it is palpable that a larger proportion of the students preferred the

(a) The developed system (b) STEM-based teaching (c) Technical demonstration

Figure 9. Live Exhibition of Edu-Rover to the students in a robotics experimentation session

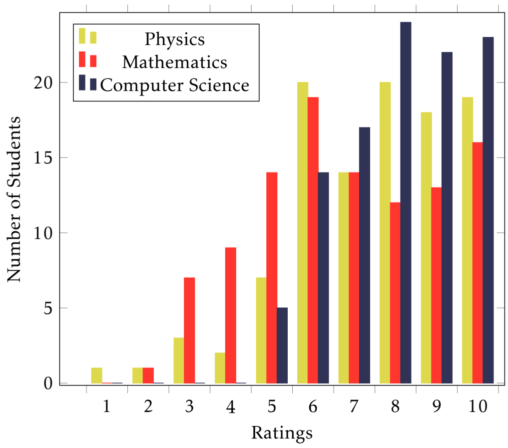

Figure 10. Sample-1: Students Course Assimilation Ratings using Edu-Rover

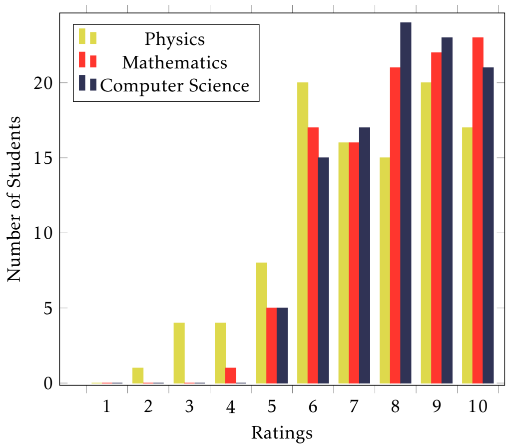

Figure 11. Sample-2: Students Course Assimilation Ratings using Edu-Rover

adoption of Edu-Rover as an instructional apparatus for STEM education, with Computer Science at the leading edge. This they say, could help them to visualize and physically experience the science and engineering theories they have been learning. The implementation of this project by each team helped to recall and enhance their knowledge in the Mathematics of the system, Physics of the mechanism, and Computer Science underlying the control algorithms. From Figure 12, it can be deduced that the application of Edu-Rover for STEM education would have higher impact on Computer Science and Engineering in relation to other STEM subjects; which unsurprisingly, are the two major disciplines upon which future advances in robotics and automation would apply. Also, some participant teachers suggested that our Edu-Rover is useful and applicable for teaching and demonstrating the rudiments of automotive technology in schools, which could significantly prepare talented pupils for a future career in the emerging field of autonomous vehicle systems.

5. Conclusion

In this paper, we discussed the need for practice-oriented STEM education in schools, with a focus on the observed inadequacy of hands-on learning technology in Nigerian schools. Based on our current development, we hereby propose and advocate a step towards the improvement of STEM education; through the introduction of hands-on robotics to school curricula. We implemented an unmanned robot-vehicle prototype to this effect. This involved the physical implementation of Edu-Rover and a mock adoption of the system for teaching STEM concepts. Here, we made use of the materials that are easily accessible in the Nigerian environment to show that the schools can actually start the introduction of robotics education on a low budget phase. Questionnaire data were collected from the participating students, to ascertain how the Edu-Rover influences their conceptualization of Physics,

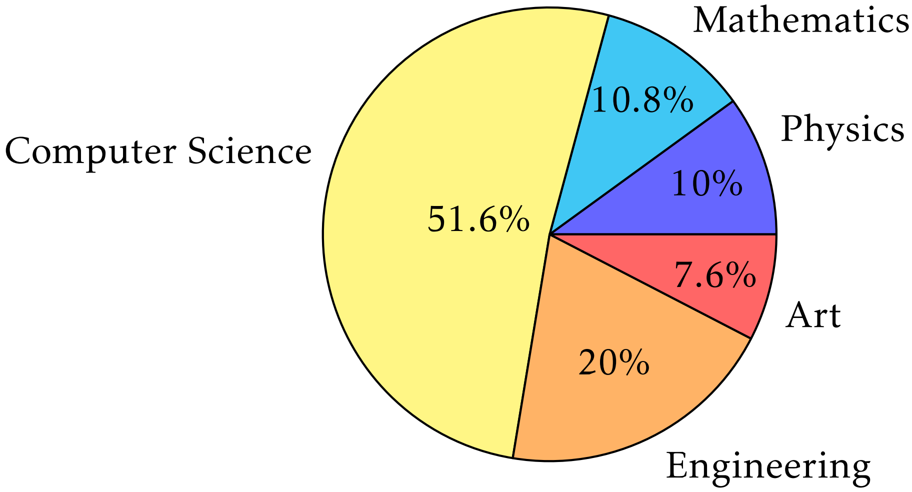

Figure 12. Classification of teachers' interests according to subjects of specialization

Mathematics, and Computer Science subjects. From the results, we observed that the Edu-Rover system and the associated didatics excited their enthusiasm in the application-oriented field of robotics, and as such, can be inculcated into STEM education in schools. Also, our initiative has motivated the students' enthusiasm to delve into the fields of Computing and Robotics. We therefore recommend that further research in this area be focused on the development of robotics curriculum and standard laboratory robots for teaching and learning purposes, especially in Nigerian schools. With this, we could envisage that Nigeria in no time, would join the league of technologically advanced countries of the world.

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