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An Evaluation of Hand Trajectory Gesture Controlled Vehicular Robot

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***Abstract*—Vehicular robotics (VRs) is an emerging field in Mechatronics application that offers numerous benefits to assisted living systems, exploits in unsafe terrains, agricultural harvesting, and manufacturing automation, among others. The absence of gesture angular displacement to speed relationship remains unresolved in literature. Existing systems controlled by hand gesture uses Radio Frequency (RF) module as a medium of wireless communication. In this paper, a re-engineered VR controlled by five palm gestures is implemented and evaluated. An accelerometer-powered transmitter circuitry for the palm glove is realized while integrating Bluetooth spectrum at the VR receiver for wireless signalling. C+ constructs are introduced for end-to-end control between the transmitter and receiver. Performance assessment carried out on actual speed, response time and a blind spot in both autonomous and semi-autonomous modes provided satisfactory insights. It is observed that in semi-autonomous mode (gesture mode), under tilting palm angle ranged 0-40 degrees, a minimum speed of 0.55m/s was observed. A medium speed of 0.63m/s and a maximum speed of 0.91m/s are obtained at 40 to 60 degrees and 70 to 90 degrees respectively. Furthermore, the autonomous mode offered a speed of 0.97m/s.**

Keywords— Mechatronics, Industry 4.0, Robotic vehicles, Automation, Embedded Systems

I. INTRODUCTION

Hand gesture recognition has drawn significant attention among robotics researchers in recent times. This is the result of complexities and inflexibilities found in deployment contexts. Unmanned vehicles used in unsafe terrains as well as various intelligent human-robot interactions make use of hand trajectory gestures for autonomous motions [1]. How such a vehicle is controlled has become an interesting research area. This is because the conventional use of joystick for remote control has been replaced by more flexible control mechanisms especially in an autonomous car [2]. Autonomous vehicles are applied in various facets of life such as in military activities where non-human intervention may be needed. Unaided mobility of disabled people all over the world who may not need to have driving skills is another. In agriculture, robotic vehicles can be used to harvest ripen fruits. Similarly, Industry 4.0 depicted in manufacturing operations supports the seamless movement of things around the production floor in a precise and efficient manner [3-5]. It can also serve as a huge entertainment (in form of toys) for kids. Interestingly, a hand gesture-controlled robotic vehicle can be used in all these capacities. The major concern in most application contexts is the absence of performance analysis on autonomous robotic systems.

This paper presents performance-driven hand gesture-controlled VR comprising a glove transmitter and a robotic vehicle (receiver). Experimental trials were conducted to understand responses to two stimulus types that depict steps towards real-time hand gestures control of VRs.

II. LITERATURE REVIEW

Advancement in robotics has fast-tracked growth in autonomous vehicles. Indeed, hand gestures have been used to control robotic systems and vehicles from close and distant ranges. These ranges can be seen as close as in the case of control of multimedia devices in cars [6],[7]. Hand automation in a parallel network hand detection and body pose estimation was studied in [8]. Currently, a dynamic deep learning network for hand gesture recognition has been investigated while other specific works in hand gesture-based schemes have been highlighted in [9-19].

The use of hand gesture control feels more natural as a means of control as against buttons or joysticks which are usually located on the mobile vehicle or remote control. While Kang in his study supports the natural use as against control buttons especially on wheelchairs [20], Sanders et al, in their virtual comparison of a traditional joystick and Leap Motion Control (LMC) fear that the accuracy of the joystick is being sacrificed for normal and easy gesture control [21].

Obviously, the control of robots (for both vehicles, wheelchairs, Unmanned Aerial Vehicles (UAVs), or robotic arms) share similar characteristics. It is envisaged that UAVs would evolve and tend towards easier means of

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control. In this regard, hand gesture provides flexible control. A categorized hand gesture control as a secondary control has been classified based on 1. Its applications, 2. Hand gesture system design techniques, 3. Hand Gesture Interface (Human to Computer Interface) and 4. Hand gesture system technologies. For instance, in [23], efforts were made to finish a novel human-machine interface. Two leap Motion (LM) controllers and coil were attached to a Cartesian platform to provide contactless electromagnetic force feedback. This for enhancing the accuracy and efficiency of human-robot manipulation. In [24], the dynamic modelling and impedance control for multi-arm free-flying space robotic design that captures non-cooperative target is presented. In [25], the authors discussed the advantages of torque-vectoring in an autonomous electric vehicle. In [26], efforts were made in designing a collaborative framework for integrating human driver distraction monitoring in V2V communications, and autonomous vehicles (AV) velocity control. This was done by constructing the smart velocity control of AVs. Path planning for path planning of autonomous vehicles was discussed in [27]. The work in [28] reported their work on an autonomous system for docking a vertical take-off and landing (VTOL) -unmanned aerial vehicles (UAVs) with a mobile manipulator. In [29], a deep neural network (DNN) based concrete inspection system with a quadrotor flying robot mounted on a smart camera is presented. It uses a visual-inertial fusion scheme to achieve camera and robot positioning and structural 3D metric reconstruction. In [30], the authors formulated a robotic motion planning problem within the context of optimizing two merging pedestrian flows that move via bottleneck exit. The robotic movement motion planner is trained end-to-end with a deep reinforcement learning algorithm, for the avoidance of hand-crafted feature detection and extraction.

In [31], the authors employed deep reinforcement learning (DRL) based multi-robot binding controller needed for autonomous aerial human motion capture (MoCap). The aim is to estimate the trajectory of body pose, and shape of a single moving person using multiple micro aerial vehicles [31]. The authors [32] looked at the issue of autonomous servoing control in unmanned aerial manipulator which has the potential of grasping target objects with computer vision.

Various studies in VR have little contribution especially in performance analysis of the interfaces. This is despite the various implementation of hand gestured controlled VRs. In context, the VR uses in-built infrared sensors for obstacle avoidance during active motion. A radio frequency module is used as the transmission device. However, an RF module was employed for wireless transmission between the transmitter and receiver. All sub-systems operate as semi-autonomous VRs controlled by hand gestures. The work carried out performance analysis to verify its performance.

III. Design Method and Structure

In the work, the automated vehicle was designed to operate in semi-autonomous and autonomous modes. The transmitter appended on the palm glove was designed first; followed by the design of the robotic vehicle. In contrast to previous works, a dynamic switch was used to toggle between modes. On Semi-autonomous mode, the robotic vehicle received its control from the level of tilt of the hand glove, while in autonomous mode an ultrasonic sensor-controlled it. Five hand gesture positions as shown in Fig. 1, were used. Palm lifted meant forward motion, downward moves the vehicle on reverse while left and right tilts move the vehicle left and right respectively. The palm-on flat rest brings the vehicle to a halt.

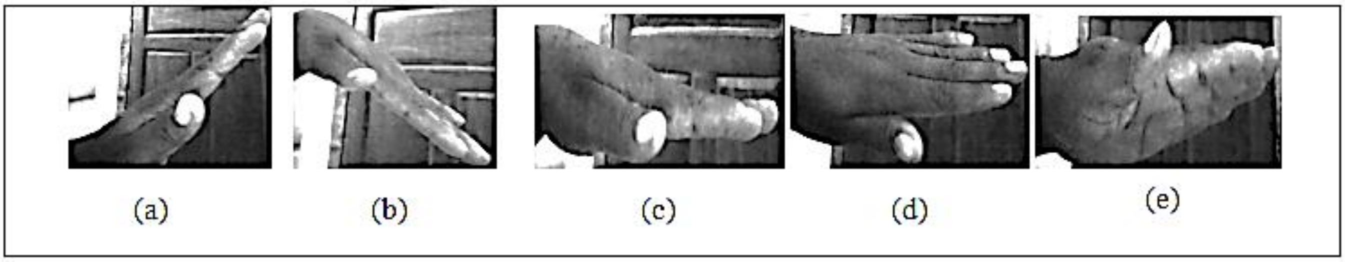

Fig. 1. Five palm tilt control gestures. (a) forward motion gesture (b) reverse motion gesture (c) stop gesture (d) left or right bend (depending on the gloved palm) (e) right or left turn (depending on gloved palm)

A. *Semi-Autonomous Mode*

The transmitter glove contains the transmitter circuit, which contains a 3D accelerometer that translates a tilt angle of the palm into different voltage levels. These serial pulses are transmitted wirelessly to the receiver via a Bluetooth module via a microcontroller as shown in the block diagram in figure 2.

- Transmitter glove design.

The software was written in Arduino IDE, the codes were burnt into the ATMEGA328. The glove transmitter was constructed using, a voltage regulator; an accelerometer (ADXL 355) which varies its voltage output based on its axial position; Bluetooth module (HC05) is the wireless interface between the transmitter and receiver; Resistors; Light Emitting Diode (LED); crystal oscillator; capacitor; Hi-Watt 9V battery. The Bluetooth module when used as master or slave to one another makes use of 3.3v. Using the voltage divider rule it was achieved. 5 x 2k/3k = 3.3 volts.

A 16MHz crystal oscillator was used because of its stability. These components are shown in the circuit diagram in Fig. 3a. The microcontroller was programmed such that when any displacement from the horizontal level of the accelerometer occurs, it transmits signals to the robotic motor to move in the required direction.

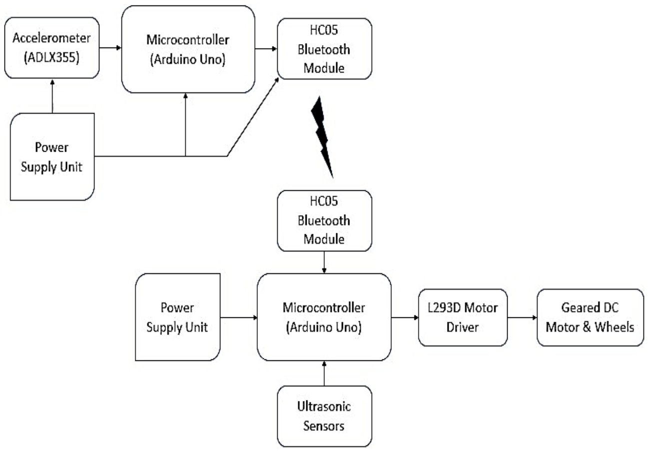

Fig. 2. Transmitter and receiver.

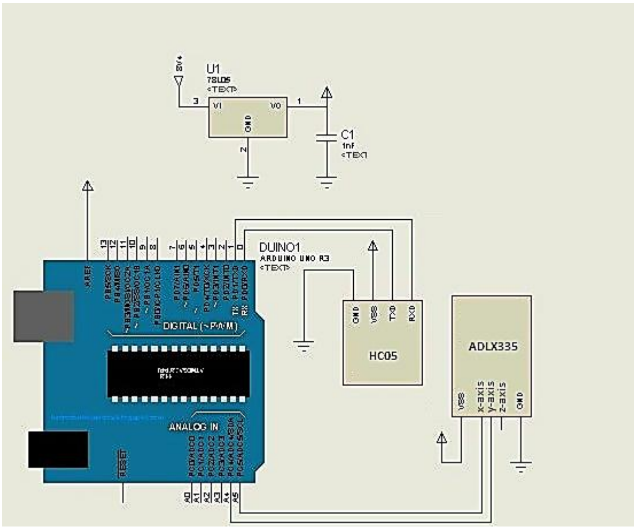

Fig. 3a. VR Transmitter Grove module

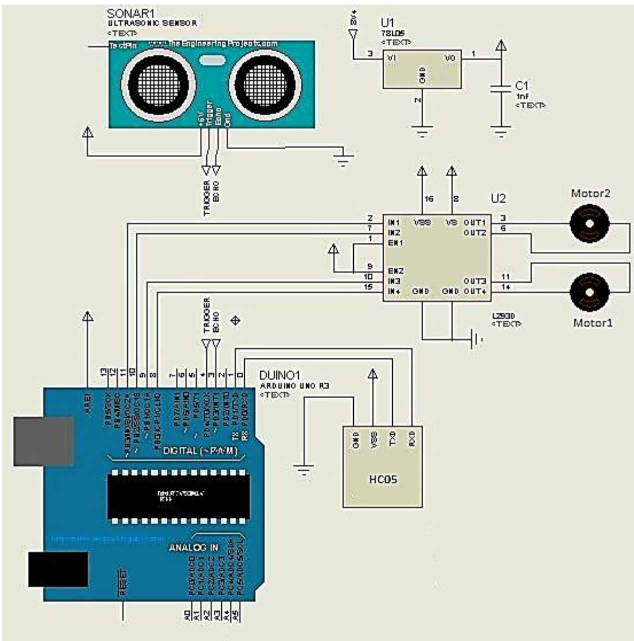

Fig. 3a. VR Receiver Module

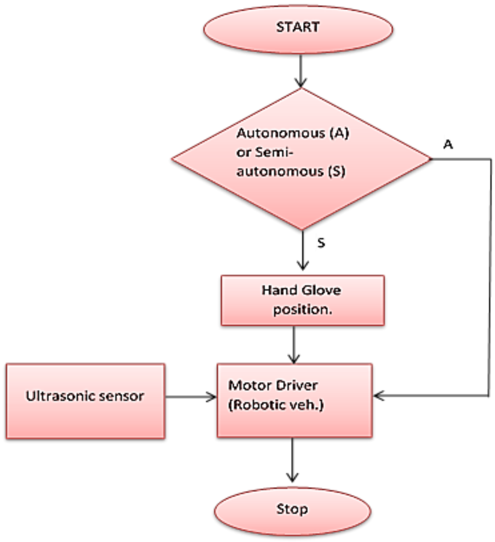

Fig. 4. VR Operational process flow

B. Autonomous Mode

The autonomous mode of the VR is such that the robot performs its functions with minimal input from a user. It uses the mounted ultrasonic sensors to achieve obstacle detection and avoidance. In this mode the vehicle maintains a speed until it senses an obstacle, then it slows down and stops.

- Constructing an Automatic Braking System

This system consists of microcontroller (ATMega328p); Ultrasonic distance sensor; Programmed codes for two autonomous and semi-autonomous modes; motor controller; Geared DC Motor: Operating Voltage: 12vRPM: 3.5, 10, 30, 45, 60, 100, 150, 200, 300, 500, 750 & 1000Shaft Size: 6mm;

The braking system of the robotic vehicle works with the use of ultrasonic sensors. The microcontroller controls the speed of the motors concerning the information gotten from the ultrasonic distance sensor. It also helps in positioning and free drifting of the robotic vehicles in their full autonomous modes. The car slows down when the ultrasonic sensor senses an obstacle. For both modes, the microprocessor was programmed to respond to accelerometer input and ultrasonic sensor inputs.

C. Robotic Vehicle /Receiver

The material's specifications were 4.2v Lithium-ion Battery; voltage regulator (7805); L293D Motor Driver: the specifications: same as the motor driver used in the braking systems; DC motors: the specifications are same as the geared DC motor in the braking systems; ATMega328p. The receiver's behavior can be summarized in the flow chat in Fig. 4, while its designed block diagram and the circuit are shown in Fig. 2 and Fig. 3b respectively. The receiver robotic vehicle had a Bluetooth module used for the reception of the signal from the transmitter. The microcontroller served as the brain which interpreted the information and sent the required signal to the motor driver, which in turn controlled the geared DC motor to turn the tires. The various subsystems were assembled and tested.

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IV. Result and Discussion

This section presents results from the experimental trials.

A. *Designed System*

The designed vehicle and the glove are shown in Figs. 5 and 6.

Fig. 5. VR Proof-of-Concept (Receiver module active)

Fig. 6. VR transmitter on palm glove.

B. *Semi-Autonomous Mode Results*

- Response time of the receiver.

The receiver takes approximately 1s to respond to wirelessly transmitted information.

- Glove tilt angle to forwarding speed

Table I shows the comparison between accelerometer tilt angle and forward speed. This was carried out to ascertain the minimum, medium, and maximum forward speed possible at various tilts.

- **Glove tilt angle to reverse speed.**

Table II shows the relationship between the glove tilt angle and the inverse motion of the vehicle. It provides both byte speed and mechanical speed of a motor in the reverse direction. The byte speed was more sensitive to voltage variation than mechanical speed.

TABLE I. Comparison of Tilt Angle, Byte, and Mechanical Forward Speed.

Tilt angle (degrees)	Voltage levels	Speed of motor in bytes	Actual speed in m/s	Description
0	1.33	255	0.55	Stop
10	1.37	229.5	0.55	
20	1.41	204	0.55	
30	1.45	178.5	0.63	
40	1.49	153	0.63	
50	1.54	127.5	0.63	
60	1.58	102	0.71	
70	1.62	76.5	0.71	
80	1.66	51	0.91	
90	1.70	0	0.91	

TABLE II. Comparison of Tilt Angle, Byte, and Mechanical Backward Speed

Tilt angle (degrees)	Voltage levels	Speed of motor in bytes	Actual speed in m/s	Description
0	1.70	255	0.55	Stop
10	1.74	280.5	0.55	
20	1.77	306	0.55	
30	1.81	331.5	0.63	
40	1.85	357	0.63	
50	1.89	382.5	0.63	
60	1.92	408	0.71	
70	1.96	433.5	0.71	
80	2.03	459	0.91	
90	2.07	510	0.91	

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Also, Table II shows the distinction between the levels of speed based on tilting angle. Tilted angle range 0-30 degrees resulted in a minimum speed of 0.55 to 0.63m/s, 30-60 degrees gave a medium speed of 0.63 – 0.71m/s and 60-90 degrees yielded a maximum speed of 0.71 – 0.91 m/s.

The accelerometer voltage levels for both reverse motion and forward motion revealed an interesting pattern. Even though the accelerometer and bytes speed had different values for each tilt angle, the mechanical speed was not as responsive to changes in tilt angle. Thus the byte speed was more sensitive than the actual mechanical speed. This is shown in Table III, the minimum speed range 0.55m/s was the same for 0, 10, 20, and 30 degrees tilt. While byte and voltage response was more sensitive to the changes in these tilt angles. The same behavior is observed in the reverse motion of the robotic vehicle. A study of forwarding and reverse motion is shown in Fig. 8 and as expected the mechanical speed is the same for both forward and reverse motion since the tilt angle is the same but just in a negative direction.

TABLE III. DIRECTIONAL SENSITIVITY OF ULTRASONIC SENSOR

Direction	Echo Output (cm)	Trig Input Distance (cm)	Actual Stop distance (cm)
FORWARD	127	102	64
BACKWARD	102	76	50
LEFT	12	12	Nill
RIGHT	12	12	Nill

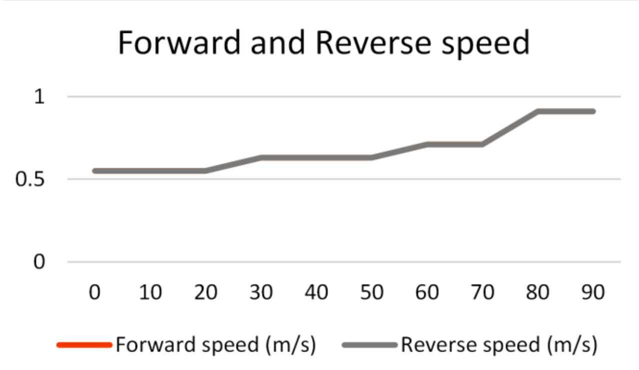

Fig. 7. Comparison of tilting angle variation against forwarding and backward speed.

C. *Autonomous Test Results*

The ultrasonic sensor responses to obstacles were examined in Table III. The vehicular sensitivity to objects along its part was assessed by allowing the UAV to move in a forward and reverse motion while placing objects at its part. The vehicle could sense objects about 100 cm from it but only came to a halt about 55cm from such objects.

- Blind Spot:

Four Ultrasonic Sensors (US) were used at four cardinal points north, south, east, and west of the vehicle. These positions thereby create a blind spot at exactly 30-60 degrees in between the four cardinal points. This result was confirmed by placing obstacles at these points and the vehicle was found not to sense such obstacles. This could have been corrected by a better ultrasonic sensor capable of having broader coverage.

- Speed against Distance from Obstacles.

A study on the speed of the vehicle as it gets closer to an obstacle is shown in Fig. 8. Forward speed remains at its maximum when the vehicle is on auto mode until the ultrasonic sensor senses an obstacle at an already programmed distance (150 to 170 cm). At this point, the backward movement set in to counter the forward movement thereby slowing down forward motion. Thus the backward movement increases as the forward declines. An accelerometer in the robot is used for these measurements. The performance of the ultrasonic sensor is as postulated by the manufacturer's datasheet. Vehicle speed in absence of an Obstacle was 0.97m/s.

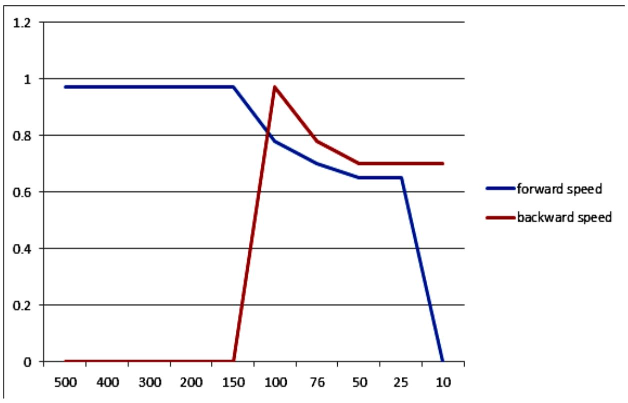

Fig.. 8. Obstacle Distance from vehicle to Speed of vehicle.

V. CONCLUSION

This paper has presented Robotic vehicles controlled by hand gestures for risk reduction in human life. The system improves motorized wheelchairs and their mobility control. The design and analysis of hand gesture controlled robotic vehicle, with Bluetooth as an alternative transmission module offers huge benefit.

Besides, the designed system was able to operate at two different modes which made it more flexible than previous designs. A glove transmitter and receiver robotic vehicle were designed and implemented in this work. It is comprised of an autonomous mode. The transmitter part was incorporated with an accelerometer which gives the gesture readings to the Bluetooth module through C+ programmed ATMEGA328p IC. The work realized the receiver module in semi-autonomous mode using RF signals for motor drive actuation through ATmega328pIC controller. On autonomous mode, the work highlighted how the drivers were actuated by control signals received from the ultrasonic sensors. Results showed that in the autonomous mode, the observatory sensors offered 30 degrees blind spot at each quadrant. The VR robot also had a faster speed of

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0.97m/s as against 0.91m/s found in semi-autonomous modes. Consequently, the work observed that the gesture-controlled performance revealed a more sensitive voltage response to mechanical speed response to tilt angles. The mechanical speeds at both reverse and forward motions were the same and categorized into the maximum, medium, and minimum speeds. Future work will focus on machine learning optimization of the vector controls.

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