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A LOW-COST MODULAR 3DOF MOTION SIMULATOR WITH VR INTEGRATION

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Abstract: ***In the present paper, research done by many researchers to increase the effectiveness of the Motion platform has been discussed. Through study, it has been found that high-capacity electric actuators, allows for the compensation of platform weight, resulting in reduced loads on electrically actuated jacks, thereby enhancing control and efficiency Applications of the 3-DOF motion platform span various fields, including aerospace training, medical simulations, and gaming, highlighting its versatility and potential impact on user engagement and learning outcomes. Future work will focus on enhancing scalability, improving user comfort, and exploring additional degrees of freedom to expand the platform's capabilities.***

IndexTerms - 3 DOF, Motion platform, micro-operation platform, electrically actuated jacks, electric actuator, Sim Mechanics

I. INTRODUCTION

A. Background

One of the first motion platforms, the Sanders Teacher, was created in 1910. This was a model aircraft connected to the ground by a universal joint. When wind was present, the pilot in training was able to use the aircraft's control surfaces to move the model in the three rotational degrees of freedom pitch, roll and yaw. In 1929 a significant advance in motion platform technology was made with the patent by Edwin Link for what became known as the "Link Trainer". This used the pilot's control stick and rudder controls to control organ-type bellows under the simulator cockpit. The bellows could inflate or deflate; giving movement in pitch, roll, and yaw. In 1958 a flight simulator for the Comet 4 aircraft used a three degrees-of-freedom hydraulic system.

Simulator motion platforms today use 6 jacks ("Hexapods") giving all six degrees of freedom, the three rotations pitch, roll, and yaw, plus the three translational movements heave (up and down), sway (sideways) and surge (longitudinal). 6 DOF motions are powerful cues when combined with outside-world (OTW) imagery. Motion platforms together with OTW imagery are used in: flight simulation, driving simulation, amusement rides, and small home-based simulators. The motion platform is used in military and commercial flight instruction training applications. Also, in entertainment devices in theme parks, with users from single people to many, seated in rows in front of screens in which pictures are projected, synchronized with motions from the platform under the simulator cab.

Low-cost home motion system with 3 rotational degrees of freedom typical high-end motion system is the Stewart platform, which provides full 6 degrees of freedom (3 translations and 3 rotations) and employs sophisticated algorithms to provide high-fidelity motions and accelerations. These are used in a number of applications, including flight simulators for training pilots.

B. About Motion Simulator

A 3 Degrees of Freedom (DOF) Motion Simulator is a mechanical platform that allows movement along three rotational axes: pitch, roll, and yaw. These simulators have been widely researched and applied in fields like aerospace, automotive, and robotics, where realistic movement simulations are crucial. The aim of these simulators is to replicate real-world dynamics in controlled environments, enabling training, research, and testing. Over the years, the development of motion simulators has evolved significantly with advancements in actuator technology, control systems, and simulation algorithms.

A motion simulator or motion platform is a mechanism that encapsulates occupants and creates the effect/feelings of being in a moving vehicle. Simulation is defined as an imitation of some real thing or process. Motion simulator is all about perception. A motion simulator can also be called a motion base, motion chassis or motion seat. The movement is synchronous with a visual display and is designed to add a tactile element to video, simulation, and virtual reality. All full-motion simulators move the entire occupant compartment and can convey changes in orientation and the effect of false gravitational forces. Motion platforms can provide movement on up to six degrees of freedom (DOF).
The use of motion platforms in simulators seems obvious: if the perception of real-world events can be modeled, they will provide the user with a near-identical experience. However, in simulator motion, this can only be achieved in the initial acceleration, which cannot be sustained because of the physical limits of the size of the motion platform.
Fortunately, the motion sensors of the human body respond to accelerations rather than sustained motion, and so a well programmed 6-jack ("Hexapod") motion platform is very effective in motion cueing. The human motion sensors consist of the Inner Ear (the Vestibular Apparatus) with three semi-circular canals for sensing rotations (Pitch, roll, yaw), and Eolith organs for sensing linear accelerations (Heave, Sway, Surge).
The use of physical motion applied in flight simulators has been a debated and researched topic. The Engineering department at the University of Victoria conducted a series of tests in the 1980s, to quantify the perceptions of airline pilots in flight simulation and the impact of motion on the simulation environment. In the end, it was found that there was a definite positive effect on how the pilots perceived the simulation environment when motion was present and there was almost unanimous dislike for the simulation environment that lacked motion. A conclusion that could be drawn on the findings of the Response of Airline Pilots study is that the realism of the simulation is in direct relationship to the accuracy of the simulation on the pilot. When applied to video gaming and evaluated within our own gaming experiences, realism can be directly related to the enjoyment of a game by the game player. In other words, – motion enabled gaming is more realistic, thus more iterative and more stimulating.

II. **Related Work**

Previous work of Simulation Platform designed was not considering the cost and user experience. For instance, M. Young [1] designed simulation platform giving high immersive experience but it has high cost, setup complexity and limitation in realism. Duffy J [2] created a cost-effective and accessible solution for simulating motion but its reliance on simplified models that sometimes compromised the accuracy and realism of the simulated motions, limiting its effectiveness for high-fidelity applications. Zhang, H., & Liu. H [3] focused on enhancing precision and versatility in motion simulations, but its downside was the challenge of achieving real-time performance and maintaining system stability under complex, dynamic conditions.

Feature	This Paper (Proposed System)	M. Young (1989)	Duffy J. (2003)	Zhang & Liu (2017)
Degrees of Freedom (DOF)	3 (Pitch, Roll, Heave)	3 (Pitch, Roll, Yaw)	3 (Limited via simplified models)	3 (Precise rotational control)
Actuator Type	Electric Linear Actuators	Pneumatic bellows	Simplified mechanical model	Parallel Manipulator
Cost	Low (Student-built, budget focus)	High (Historical commercial sim)	Low (but limited fidelity)	High (research-grade)
Real-Time Control	Moderate (Arduino with delay)	Limited (manual control)	Basic (less real-time feedback)	Advanced with stability issues
VR/AR Integration	Yes (Meta Quest 2 with UE5)	No	No	No
Ease of Assembly	High (Modular, no welding)	Low	Medium	Low
Portability	Yes	No	Yes	No
Latency	~0.5 seconds	N/A	Moderate	Variable

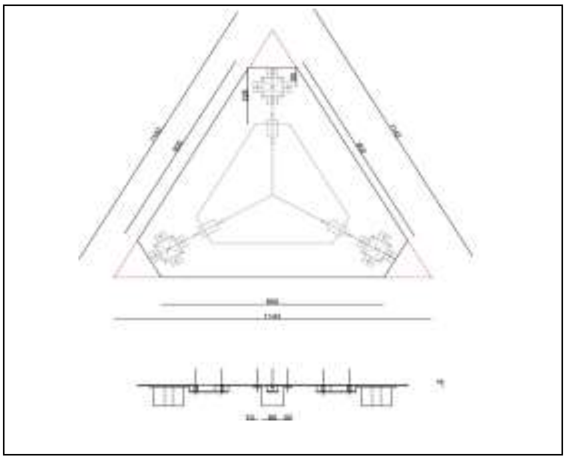
Feature	This Paper (Proposed System)	M. Young (1989)	Duffy J. (2003)	Zhang & Liu (2017)
Motion Range	±27° pitch/roll, 300mm heave	Basic	Basic	High-precision motion
User Comfort	Considered (Seating + VR immersion)	Not optimized	Limited	Research-oriented only
Applications	Training, Educational, Gaming, Simulation	Pilot training (historic)	Educational Simulations	Robotics Research

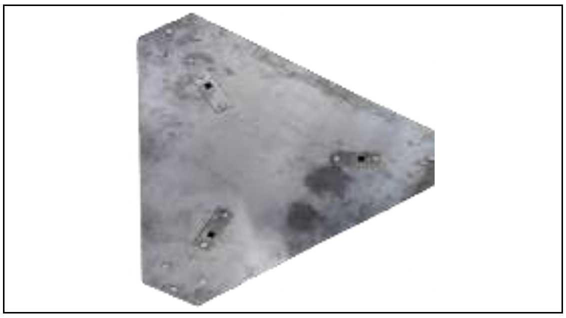
II. SYSTEM DESIGN AND ARCHITECTURE

A. Mechanical Design

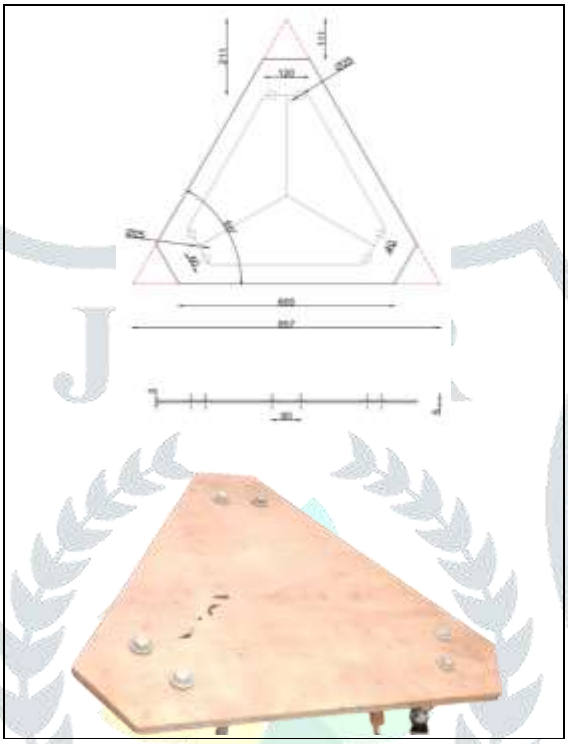
3d model of 3dof motion simultion platform
fig no. 1

While developing this simulation platform use of SolidWorks & AutoCAD for developing 3D & 2D model as shown in fig. 1.





main base
fig no. 2

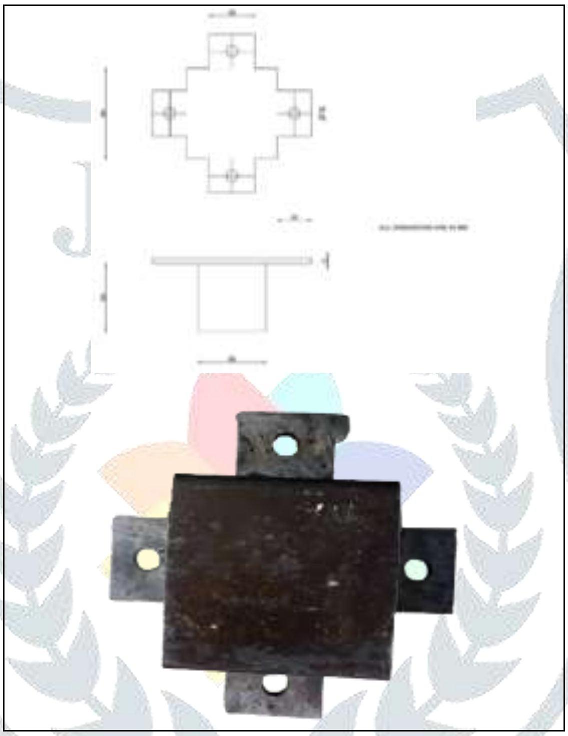


upper frame
Fig no. 3

Upper Frame (Plywood) and Base (Mild Steel Sheet) of simulation platform was designed triangular shape of dimension (sides= 600mm & thickness= 18mm) and (sides= 800mm & thickness= 5mm) respectively as shown in fig 2 & 3. The Base was slightly bigger and heavier than Frame because a strong foundation is needed for simulation platform, so it can handle more weight and will not lean while the platform is in motion.

fig no. 4

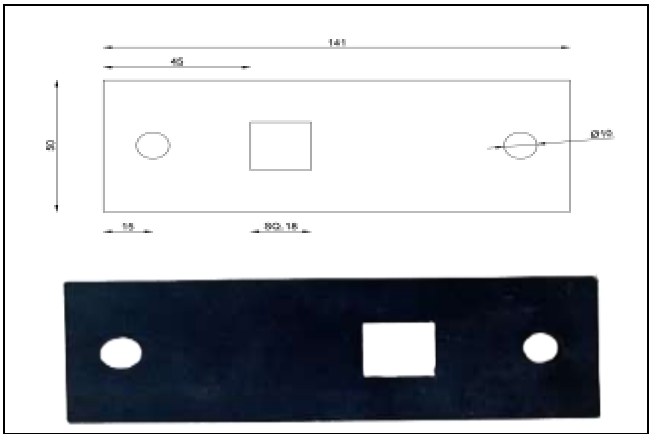
"Fish Eye Ball Joint" is used to connect the Actuators and Upper Frame in order to achieve more angle in pitch and roll movement as shown in fig 4.



welded base support bracket and base support block

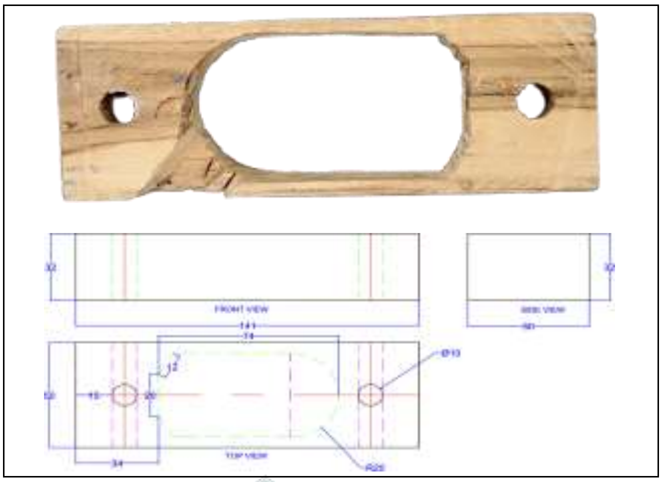
fig no. 5

Welding is avoided so that there will be less chances of failure during working as shown in fig. 5. The only welded portion is the "Base Support Bracket and Base Support Block ".



lower acutator bracket

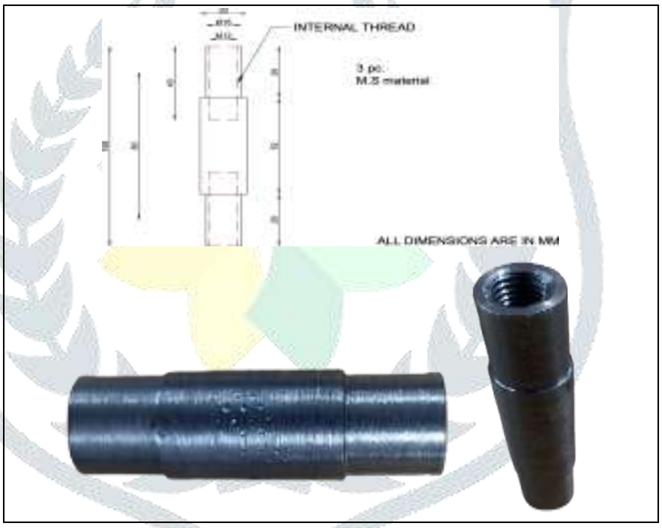
fig no. 6



upper actuator bracket

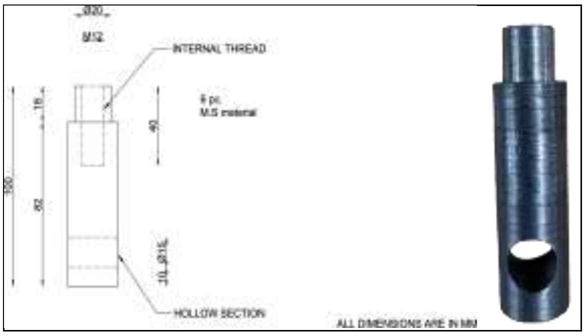
fig no 7

There are two actuator brackets used to support the actuators, the upper bracket (teak wood) and lower bracket (Mild Steel Sheet) as shown in the fig. 6 & 7. The lower actuator bracket has a square cut similar to the lower square of the actuator which will hold the actuator from below the base and the upper actuator bracket has a shape similar to the actuator motor and shaft so it will help the actuators to remain stable during the motion it places above the base. And these both brackets are attached together with the help bolts & nuts.



main shaft

fig no.8



support shaft

fig no.9

Mild Steel Shafts are used for joining the fish eye ball to the upper frame shown in fig. 1. The “Main Shaft” passes through the fish eye ball whose inner diameter dimension is M20. So the main shaft middle portion as shown in fig. 8, has a diameter of 19.96mm, so it can have a little free movement. And now the “Support Shaft” helps in supporting and holding the upper frame.

It has a hole drilled of diameter 15mm same as the main shaft two end diameter as shown in fig. 8 & 9. The upper portion of the support shaft is of 20mm diameter which I same as the drilles hole in upper frame as shown in fig. 3.

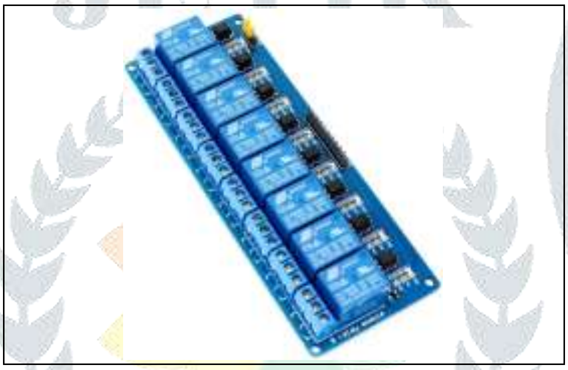
The whole assembly can be easly assembled and disassembled as there are no welds and there is use of screw, bolts and nuts in the platform. This makes the platfoem more sturdy, easy to handle, has better asthetics & more reliable & also makes it affordable.

B. Hardware Components

arduino

fig no. 10

The ATmega328P serves as the foundation for the Arduino UNO microcontroller board. It features a 16 MHz ceramic resonator, 6 analog inputs, 14 digital input/output pins (six of which can be used as PWM outputs), a USB port, a power jack, an ICSP header, and a reset button.



channel relay

fig no. 11

Since there are eight relays on a single module, the eight channel can be utilized to switch several loads simultaneously.

power supply

fig no. 12

A typical electrical component used to supply a steady 12-volt direct current (DC) voltage to a variety of devices and applications is a 12V power supply. These power sources, which provide adaptability and dependability for a variety of applications, are crucial in both consumer electronics and industrial environments.

actuator
fig no. 13

To move things in a straight line, a linear actuator transforms rotational motion into linear motion. Usually, an electric motor and a lead, ball, or roller screw are used to convert the motor's rotating motion into linear motion.

jumper wire
fig no. 14

Electrical cables known as jumpers are used to join two places without the need for soldering. They are employed in the construction, testing, and modification of circuits.

meta quest 2 vr headset
fig no. 15

Because the Meta Quest 2 is self-contained, it can function without a phone or computer once it is linked to Wi-Fi. When wearing the headset, you can see the surroundings thanks to passthrough cameras, hand-tracking controls, and an integrated software store.

C. Electronic Implementation

The electronic implementation of a 3-DOF motion platform using Arduino, relays, a power supply, electric linear actuators, a joystick, and a VR headset involves the Arduino reading joystick inputs to determine desired platform orientation (pitch, roll, heave). These inputs are translated into signals that control relays, which in turn switch the high-power supply to the linear actuators, causing them to extend or retract and create the 3D motion. Simultaneously, the Arduino may send motion data to the VR headset (if supported by the headset's API or through intermediary software) to synchronize the visual and physical experiences. This setup allows for interactive motion controlled by the joystick, enhancing the immersion provided by the VR headset.

D. Software Architecture

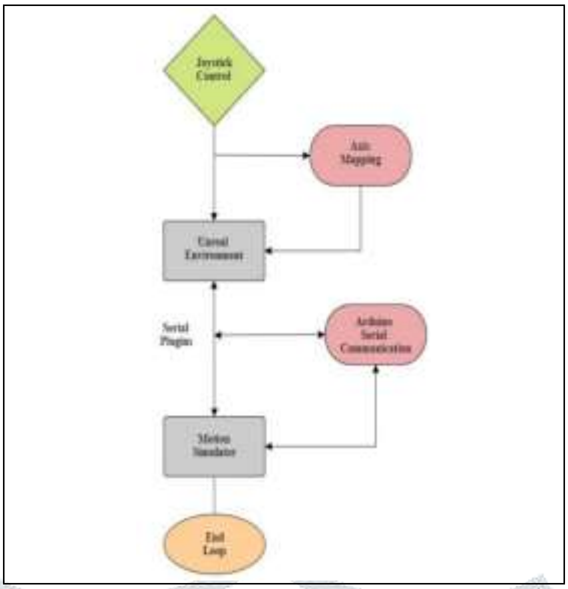


fig.no 16

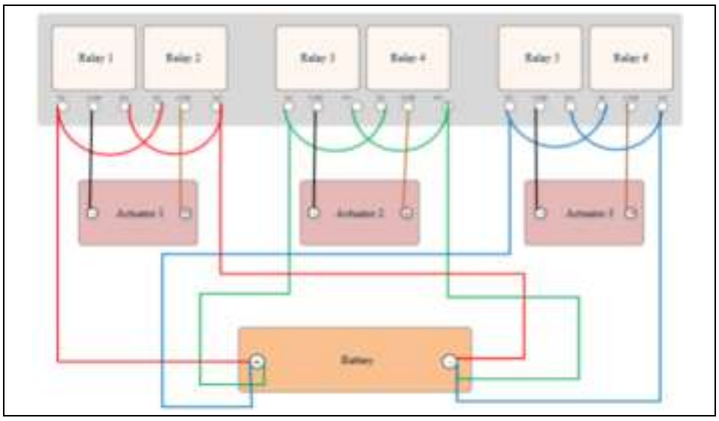
The software architecture, designed for real-time motion synchronization, uses Unreal Engine 5 at the top to output telemetry data like position, velocity, and orientation as strings via the UE4 Duino Plugin or custom Blueprints. This motion data is sent through UDP, Serial, or API to a middleware app, usually in Python, C++, or C#. This app gets the data via UDP or TCP, parses and scales it, applies smoothing filters, and then sends processed position commands to the microcontroller (MCU) over Serial (USB). The Arduino board (Nano, Uno, or Leonardo) is programmed in Arduino C/C++ and parses serial commands, maps the motion data, and turns it into PWM or actuator control signals, maybe like "1", "2", "3", "4" for pitch and roll. Finally, the 3DOF Motion Platform uses servos or linear actuators driven by an H-Bridge, controlled by the Arduino's output, aiming for accurate real-time physical reflection of the virtual world.

E. AR/VR Training Interface

An AR/VR training interface immerses users in a 3D environment via a headset, with head movements dictating the viewpoint, eliminating the need for handheld controllers. Training can proceed automatically step-by-step or be activated by various triggers, including time delays, gaze detection (achieved through line tracing), or external inputs from devices like Arduinos or keyboards connected to a PC. To effectively guide users, the system employs multimodal feedback such as visual highlights and arrows, audio instructions or narration, and floating 3D text or progress indicators. A safety procedure demonstration serves as a typical example, where a machine appears, a voice prompt directs the user to look at the emergency stop button, gaze at the button advances the training to an animation explaining its function, and the session concludes with a completion screen. Building this interface is facilitated by tools like the SteamVR Plugin or OpenXR within Unreal Engine, with Unreal's Blueprint system managing timers and input events, and collision boxes or trigger zones tracking user gaze. The required hardware includes a SteamVR-compatible headset (e.g., Valve Index, Vive, Meta Quest via Link) and a PC running Unreal Engine, with optional integration of external input devices. The core components comprise Unreal Engine for application development, the SteamVR Plugin for headset integration, the VR headset for display and tracking, and potentially external input devices, while all training logic and feedback mechanisms are orchestrated within Unreal Engine.

III. IMPLEMENTATION

A. Electronic Assembly



electronic connection

fig no. 17

The assembly of electronics were put altogether in wooden casing. In which the Arduino was connected to the laptop and the Relays was connected to the Arduino. The Power Supply unit with the relays which give the desired output. The 3 actuator wires were connected to 3 relay which gives output of 12V DC. As shown in fig no.17.

B. Control System Implementation

The control system uses an Arduino-based architecture with the following code structure:

```
char inChar;

void setup() {
  pinMode(3, OUTPUT);
  pinMode(4, OUTPUT);
  pinMode(5, OUTPUT);
`
  pinMode(7, OUTPUT);
  pinMode(8, OUTPUT);

  digitalWrite(3, LOW);
  digitalWrite(4, LOW);
  digitalWrite(5, LOW);
  digitalWrite(6, LOW);
  digitalWrite(7, LOW);
  digitalWrite(8, LOW);

  Serial.begin(9600);
}

void loop() {
  while (Serial.available()) {
    inChar = Serial.read();
    Serial.println(inChar);
  if (inChar == '1') {

    Serial.print("Pitch Positive");
    digitalWrite(3, LOW);
    digitalWrite(4, HIGH);
    digitalWrite(5, HIGH);
    digitalWrite(6, LOW);
    digitalWrite(7, HIGH);
    digitalWrite(8, LOW);
  } else if (inChar == '2') {
    Serial.print("Pitch Negative");
    digitalWrite(3, HIGH);
    digitalWrite(4, LOW);
    digitalWrite(5, LOW);
    digitalWrite(6, HIGH);
    digitalWrite(7, LOW);
    digitalWrite(8, HIGH);
  } else if (inChar == '3') {
    Serial.print("Roll Positive");
    digitalWrite(3, LOW);
    digitalWrite(4, HIGH);
    digitalWrite(5, HIGH);
```

```
  digitalWrite(6, LOW);
  digitalWrite(7, LOW);
  digitalWrite(8, HIGH);
 } else if (inChar == '4') {
  Serial.print("Roll Negative");
  digitalWrite(3, LOW);
  digitalWrite(4, HIGH);
  digitalWrite(5, LOW);
  digitalWrite(6, HIGH);
  digitalWrite(7, HIGH);
  digitalWrite(8, LOW);
 } else if (inChar == '5') {
  Serial.print("Heave Positive");
  digitalWrite(3, LOW);
  digitalWrite(4, HIGH);
  digitalWrite(5, LOW);
  digitalWrite(6, HIGH);
  digitalWrite(7, LOW);
  digitalWrite(8, HIGH);
 } else if (inChar == '6') {
  Serial.print("Heave Negative");
  digitalWrite(3, HIGH);
  digitalWrite(4, LOW);
  digitalWrite(5, HIGH);
  digitalWrite(6, LOW);
  digitalWrite(7, HIGH);
  digitalWrite(8, LOW);
  else if(inChar=='7'){
  Serial.print("Home Position");
  digitalWrite(3, HIGH);
  digitalWrite(4, HIGH);
  digitalWrite(5, HIGH);
  digitalWrite(6, HIGH);
  digitalWrite(7, HIGH);
  digitalWrite(8, HIGH);
  }
 }
}
}
```

IV. EXPERIMENTAL RESULTS

fig no. 18

After the setup and connections were made the final output was pretty good as per our expectation. We achieved 27°angles for pitch & roll movement. And also achieved 300mm of stroke for heave movement. There is a delay of half a second between the simulation on laptop/pc and the actuators while following the motion. The weight capacity we got during our experiment was 50kg. The experience after connecting AR/VR was unbelievably good. As shown in fig no.18.

VI. CONCLUSION AND FUTURE WORK

This paper proposed a 3DOF Simulation Platform having a user-friendly experience with the help of AR/VR and also with Joystick Control. This Simulation Platform showed appreciable perform at a low budget and giving the satisfaction to the user. The mechanical design shows fish eye ball joint helps in achieving better tilting angle for pitch and roll movement (Fig. 1) and the upper frame was designed for equivalent weight distribution (Fig. 2) and gives a seating comfort.

Future work will include increasing the Degree of Freedom (i.e.6 DOF Motion Simulation Platform), it's weight carrying capacity by redesigning the mechanical structure and improving accuracy for user to experience real-time motion in the applications used. And the latency issue will be solved using motor drivers. Also, as there is no weld the whole simulation is portable. Using the motor driver increases weight carrying capacity significantly and also structural improvement like using connecting rods, U-frame for upper frame supported,etc.

VII. ACKNOWLEDGMENT

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We also extend our heartfelt gratitude to VES Polytechnic for their unwavering support, cooperation, and guidance. Their motivation and encouragement have played a crucial role in shaping this project, inspiring us to push the boundaries of innovation and excellence.

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