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# Project Number: P22015

## Gamification and Performance-Based Monitoring of Sensorimotor Training Activities

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### Abstract

Proprioception is the body's ability to sense movement, action, and location. Proprioceptive training is crucial for astronauts because humans balance system, cognitive functions, and muscle tone heavily rely on Earth's gravity. The goal of this project is to create a training system that strengthens those characteristics to ensure astronauts not only maintain their coordination and cognitive skills, but improve upon them as well. Furthermore, the system's live biofeedback provides astronauts with sensorimotor feedback to correct any balance dysfunction. The completed system prototype and data collected from it will support NASA's knowledge base about the use of gamification for sensorimotor training activities.

### Background/Motivation

As a part of the XHab Moon to Mars initiative, NASA selected several university teams to conceive design solutions that will aid in advancing and executing the Artemis program objectives. Prolonged exposure to altered gravity can lead to changes in proprioceptive function that ultimately affect postural control and locomotion (Wood, 2011). These changes can result in nausea, abnormal eye movements, vertigo, headaches and other ailments. Providing proprioceptive training to astronauts can mitigate these risks during missions and allow for a smoother transition back to normal life post-flight. The use of a gamified training environment can be utilized to enhance astronaut engagement and motivation. The P22015 team was tasked with designing, building, and testing a robust proprioceptive training system that utilizes gaming and real-time feedback for sensorimotor conditioning. The engineering team collaborated with Game Design and Development students to design a virtual reality (VR) training system whose goal was to challenge the balance of its users.

The customer requirements recommended this training system to be beneficial, engaging, adaptable, and portable. Meaning it is capable of maintaining crew members balance and hand eye coordination, entertaining, increasingly challenging and potentially collaborative, and appropriate for transport into space. The resulting engineering requirements the team created included, the score retrieved from the game continuously gets higher/better as game time increases, the game has multiple levels that increase in intensity and 1 person can set up the system. The major stakeholders of this project are the customers at NASA, astronauts and crew members, and other patients who suffer from proprioceptive dysfunction. Currently NASA has several proprioceptive training systems in place such as the Tilt-Translational Device, Device for Orientation and Motion Environments, and exercise equipment on the international space station (ISS) including the Advanced Resistive Exercise Device. Though these systems are exclusively exercise based and do not offer the engaging element of a VR game.

**Description of Design**

The training system can be broken down into several subsystems, the rig itself which consists of the frame and motion floor, the force plate embedded into the motion floor, and the software that integrates the entire system with the VR game.

**Frame**

The frame design was modeled after a 1000 lb capacity power cage intended for workout use. Initially, the chosen material to construct the frame was 80/20 aluminum framing. A stress analysis was conducted to ensure that the factor of a safety of three was met with the maximum weight of a user. The load applied at the center of the cross beam at the top of the structure was 627 lbs (this number is NASA's weight limit for an astronaut, 209 lbs, multiplied by 3). However, this stress analysis failed and the frame was redesigned to be made of 11 gauge steel rectangular tube with 12 gauge flat brackets which passed the stress analysis as seen in figure 1. As shown in figure 2, when constructed, the frame stands 6 ft by 6 ft wide and 8 ft tall. A 3 foot anchor strap will be looped around the top of the frame to support the user in the case of a fall. Initially, a retractable strap was used to connect the anchor strap to the back of the harness that the user would wear. If the user fell, the retractable strap would lock in a similar fashion to a seatbelt and prevent the user from hitting the floor. After constructing the frame it was determined that the fall distance was too short to consistently engage the retractable strap and a 4 to 6 foot adjustable static strap was purchased instead. This new strap will ensure that if the user falls they will be caught before hitting the floor.

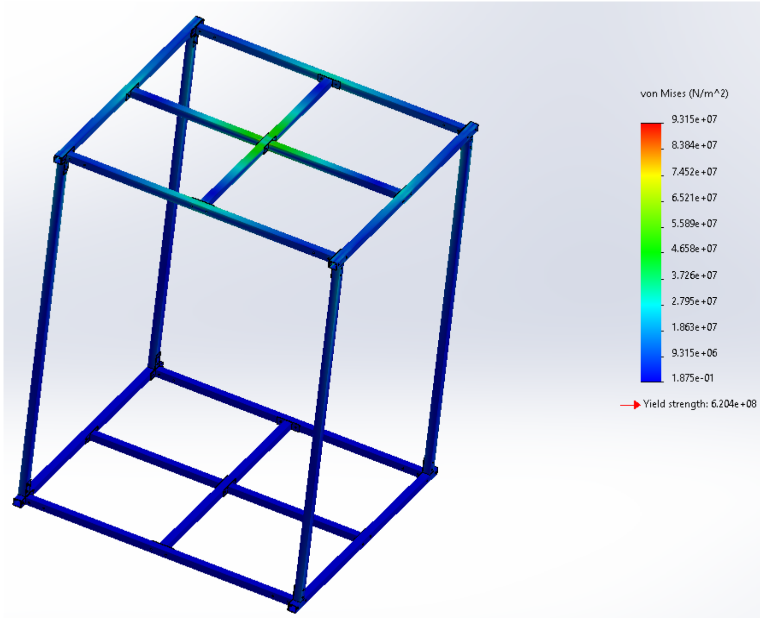


*Figure 1 - SolidWorks Simulation of the stress analysis of the redesigned steel frame, the max stress is $9.315*10^7$ $N*m^2$ which is under the yield strength $6.204*10^8$ $N*m^2$.*

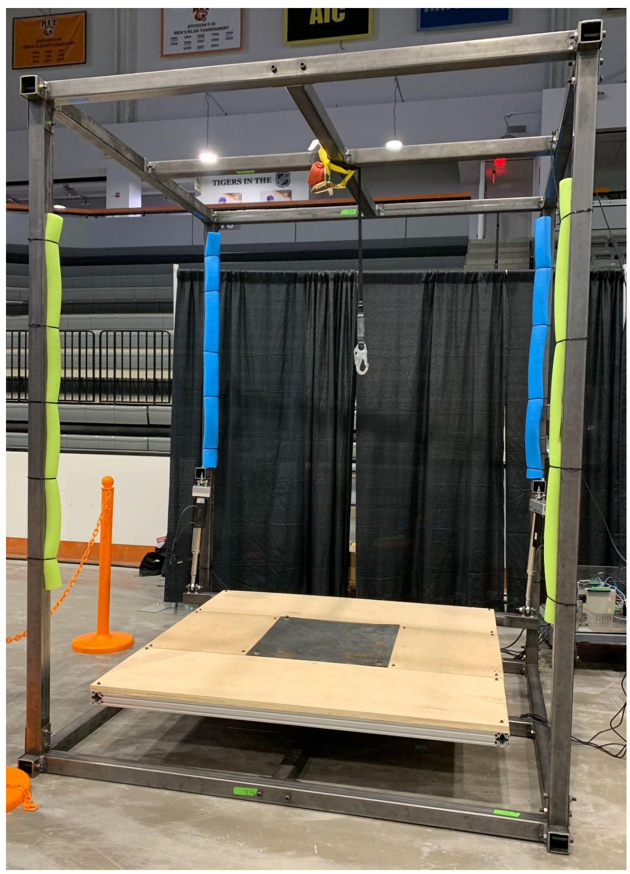


*Figure 2 - shows the assembled rig and motion floor with attached anchor point and retractable harness strap.*

**Motion Floor**

The user will become fully immersed into the VR game while playing through the use of synchronized game stimuli and floor movements. The motion floor is a 5 foot by 5 foot platform built out of 80/20 framing as shown in figures 2 and 3 below. During the design phase, the team initially looked into using a hydraulic or pneumatic system to power the floor. However, these were ruled out as these types of systems require gas cylinders, pumps and hoses that would not allow for the rig to be portable. A system like this would also likely generate more power than necessary and would be quite costly. The final design of the floor is powered by two linear actuators, also shown in figure 3, which are much more cost effective, feasible with the amount of force needed and easier to transport. The platform was limited to 2 degrees of freedom for portability and the actuators will provide a range of motion of 10° ± 10° for a total of 20°. In order to move the floor, the unity game sends the desired angle to a python server which converts the data to a usable format for the motors. The python server then writes this converted data into an excel file that the logic controllers can read from and drive the actuators accordingly.

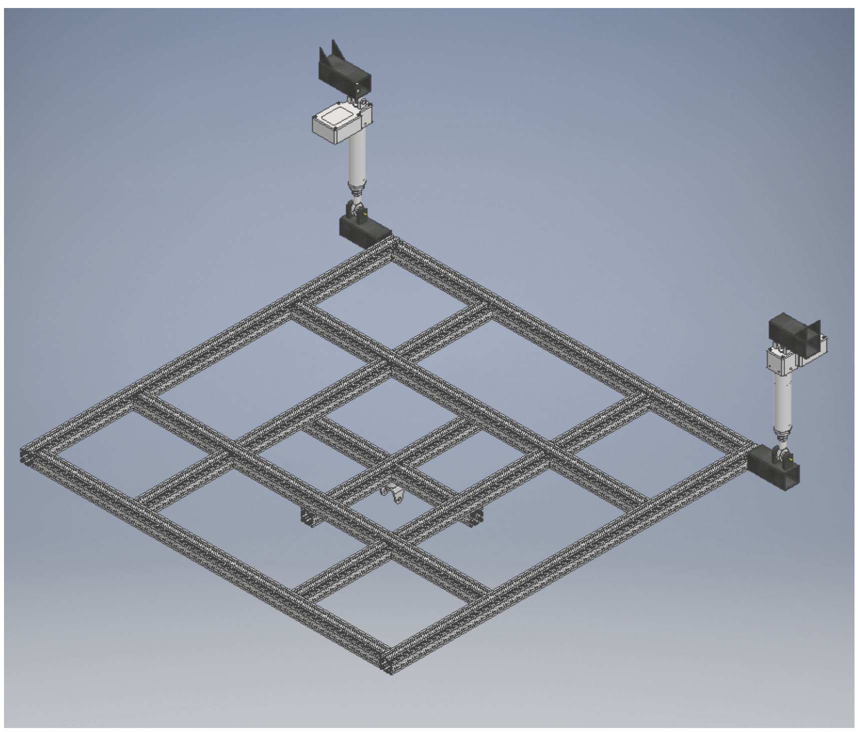

*Figure 3  - CAD model of motion floor and the linear actuators that drive it.*

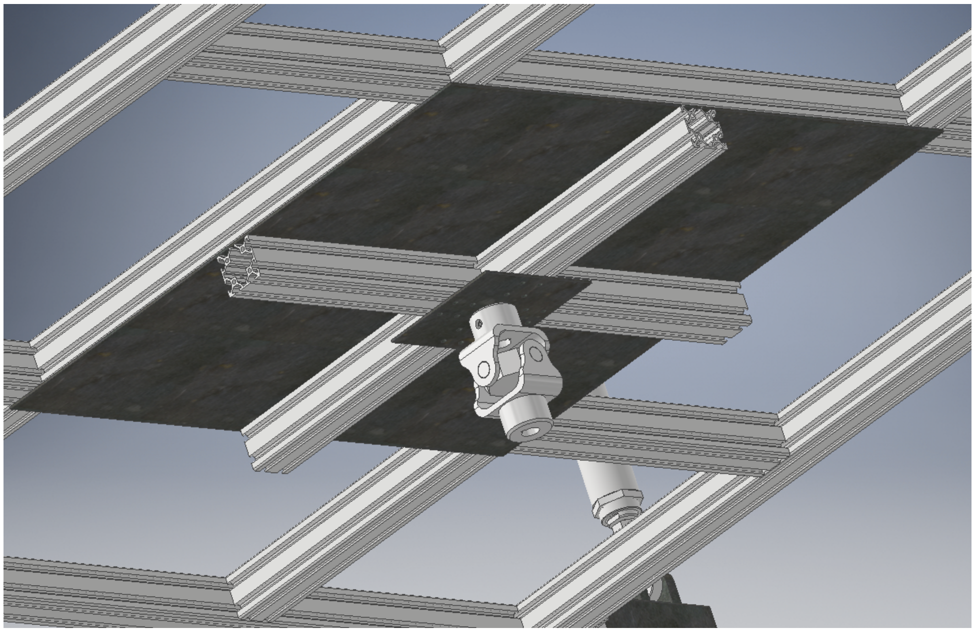

*Figure 4 - CAD model of underside of motion floor and U joint that will attach the floor to frame.*

**Force Plate**

The team designed force plate consists of 4 load cells, their corresponding amplifiers and an arduino as shown in figure 5. The load cells use strain gauges to convert the pressure from the user standing on the plate into an electrical signal that is read by the arduino. As the pressure applied increases or decreases the resulting electrical signal changes proportionally. The force plate is integrated into the system through a python server that prompts the arduino to send recorded data from the load cells. The format of this data is four values that represent the data from each sensor. The arduino code will send data to the python server until an end signal is sent. The python server will then combine the readings from the four sensors to generate the center of pressure (COP). The COP is measured continuously for 30 seconds, from the data points collected during this measurement the mean and standard deviation of the COP is calculated. These measurements are then used to generate a balance score which is displayed to the user to show how their balance has improved. A graphical representation of COP and the scoring algorithm is shown in figure 6.

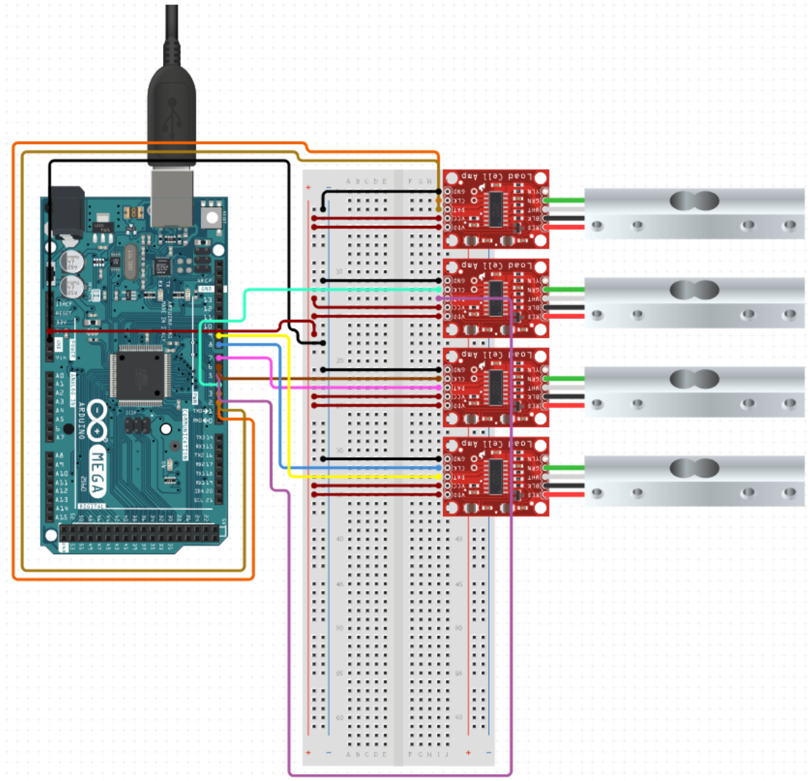

*Figure 5  - from right to left, shows the load cells, their amplifiers, and arduino.*

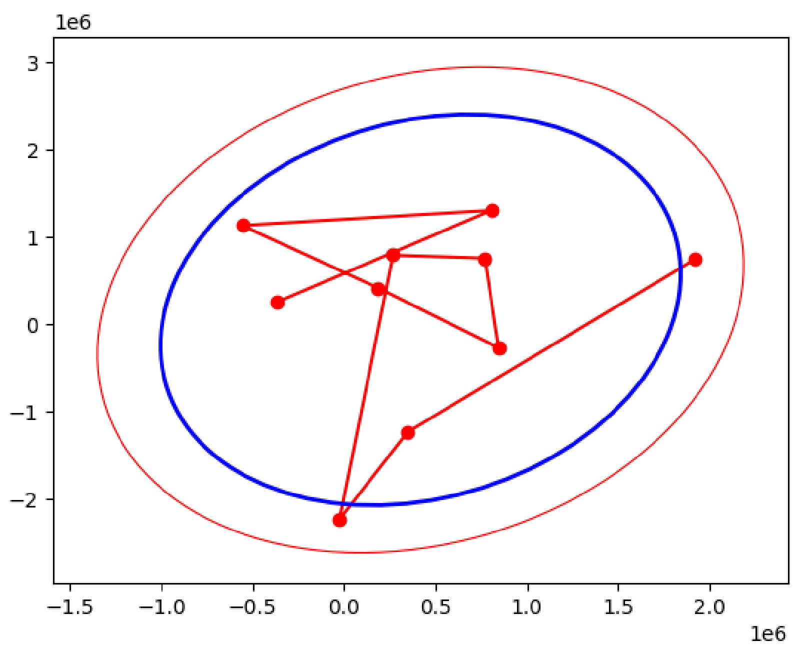


*Figure 6 - Graphical representation of COP and some of the extracted parameters.*

**Software**

The team has also developed a desktop user interface (UI) that allows the user to start the VR game. The UI accesses the database, which contains user information and their corresponding scores for games, and displays them in a format where the highest ten scores are displayed. The UI also starts a monitor thread for the killswitch, so that if the kill switch is hit, the normal operation of the training program is stopped. The UI provides the opportunity for users to login and view their previous game scores. The UI also starts the python server, which communicates with force plate and the Unity game. The communication between the devices is handled through serial connections. The typical behavior is that the Unity game will send a message to the python server and then the appropriate behavior is communicated to the motor actuators or sensors.

**Supporting Feasibility Evidence**

Due to the time constraints of the assembly process and global supply chain issues, limited full system testing was conducted. Preliminary testing was conducted for each of the subsystems in order to ensure functionality.

The Arduino and Python communication was tested with sample data to ensure that the Python server and database was receiving and processing force plate data correctly. Then, the force sensors were individually tested to ensure that they output uniform data and calibration factors were found. For the software integration testing, the communication for the peripheral devices was tested to determine if the data communication was successful and stable. Through repeated communication tests, it was determined that the peripheral integration of the VR headset, the kill switch and the force plate was successful. The motion floor's communication with the python server was tested repeatedly without any users on the floor to ensure safety prior to use. Issues were troubleshooted before integration with the VR game and human test subjects.

**Results/Conclusion**

When each of the subsystems in the prototype were tested it was determined that the majority of the subsystems worked individually at achieving their specific goal. The game ran successfully on its own as did the motion floor. The only subsystem that was not properly tested in the prototype was the balance scoring system, due to time constraints. To complete development of the algorithm, we would need to run a lot of test runs to establish the range of values of the extracted parameters from the COP. Then, we would be able to format scores from an arbitrary to a 0-100 scale.

After constructing the training system prototype and integrating all the subsystems together, it was determined that while some of our designed subsystems worked well together, others did not. There were issues that arose in the communication of the gaming system and the python server. This resulted in the floor not moving in sync with the game. Though the floor was able to successfully move with the control of team members. Further troubleshooting is required to ensure seamless motion floor and game communication.

Future improvements that could be made include the portability of the system, as this was one of the major customer requirements not met. The steel frame and the motion floor system resulted in the prototype weighing over 600lbs. Additionally, due to the large size and weight, many people are needed to assemble and move the prototype to its correct orientation as it is built laying down. Another aspect that would benefit from further improvements was the force plate. The thin sheet of metal used for the plate would warp slightly when users stood on it compromising the measurements taken by the load cells. Future designs would ideally have a thicker plate to prevent this from happening.

Ultimately the training system did challenge the balance of team members that tested it. Proving that while there are improvements to be made, the prototype does meet its primary goals.

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**References**

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