University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document (PDD)

CHAIR - Cueing via Haptics And Inner Ear Responses

Approvals

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2.1 Project Customers

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Table 1: Team Member Information

3. Problem or Need

In aerospace defense, improvements in pilot safety have led to a push for more remote operation of military aircraft in all possible situations. With the emergence of Unmanned Aerial Vehicles (UAVs), there has been a growing need to develop technologies which aid remote pilots in achieving better performance while operating behind a screen. Additionally, spatial orientation and loss of situational awareness are major factors in aircraft loss or pilot fatality, so the development of cueing systems may even complement the flight experience through disorienting situations [2]. The most successful solutions to this issue come in the form of realistic sensory cues that mimic the environment of a conventional crewed-vehicle flight. These aids allow the pilot to improve their reaction times and accuracy of flight by utilizing or enhancing their sensory perception during training or flight.

This project seeks to provide two additional sensory modalities to provide a more holistic experience. The final result will be achieved through a low cost setup and a form factor that is suitable for the office-like environment that remote pilots will be expected to operate in. Current professional grade flight simulators are classified as synthetic trainers. This is in part due to the lack of perceived g-force that is experienced during maneuvers [5]. With a successful demonstration in combining both tactile and vestibular stimulation technologies in concert, the current performance of remote and simulator pilots can be improved.

4. Previous Work

Previous advances in aircraft simulation have been developed by the U.S. Air Force and documented by Albery et. al. in 1978 [1] for the following sensory modalities: vestibular, visual, non vestibular proprioceptive, and tactile, in this order of refinement. The work completed by the Air Force (AF) included a high-G tactile seat that utilized sets of cushions to provide pressure to the body in order to simulate contact pressure during flight. This simulation effort mainly focused on localized flesh pressure changes, skeletal posture shifts, impacts on field of view, and flesh scrubbing due to sustained g-conditions. The seat included a 6 degree-of-freedom system that utilized seat cushion mosaics of pneumatically activated elements, and a variable tension belt across the abdomen.

The limitations of this project mostly arise from the mechanism limitations of the seat operating in a 1-G environment.The pressures on the back and neck areas are limited by the 1-G weight of the participant and the posture provided by the seat. In addition, some of the higher-frequency phenomena such as vibrations from the vehicle itself could not be modeled. With some of the human factors data missing, such as body contact pressure loading and body movement within the cockpit during flight, and which forces are most critical to replicate and their corresponding perception times, prohibited this previous developmental work from being a first-principles solution for flight simulation. However, for the purposes of this project, the achievements of the AF project serve as goals (rather than a baseline). Due to the additional project scope that includes the vestibular modality, the team cannot also replicate the AF tactile seat while pursuing a novel vestibular stimulation technology and integration. The human factors data are also less relevant, as producing a fully novel tactile cueing seat is out of scope. Rather, the novel factor the team seeks to provide is the integration of two sensory modalities in harmony – namely the tactile and vestibular cueing.

Studies on mono- or bipolar GVS stimulation have found that a direct mastoid-mastoid current results in the perception of rotation about an axis about 15 degrees above the horizontal plane. More recently, studies have begun using multipolar GVS setups in an attempt to isolate different axes of rotation. One preeminent sensory cue which can be reproduced remotely are the tactile forces which are felt on the body during linear and angular accelerations along with the vestibular stimulation which help inform the pilot of their spatial orientation. Galvanic Vestibular Stimulation (GVS) consisting of strategically placed electrodes on cranial mastoids can stimulate postural single-axis responses in a non-invasive manner. This study was documented by Kazuma, et al in 2015 [4] in an attempt to support the two and three pole notion of virtual roll and pitch motions while also creating a contrasting four pole GVS stimulation which produces three axes of virtual motion, containing the sought-after yaw rotation.

5. Specific Objectives

Level 1

1. Computation
   - 1.1. The software shall be able to simultaneously communicate to both the GVS and chair elements to induce the sensation of angular acceleration along the roll-axis.
   - 1.2. The software shall allow the controller to induce either left or right rolls to be induced by the GVS and Tactile Cueing System (TCS).
2. GVS
   - 2.1. The GVS will induce continuous 0-1G cueing of a single axis roll maneuver.
   - 2.2. Users will not report any pain caused by the GVS during operation.
3. TCS
   - 3.1. The TCS will induce continuous 0-1G cueing of a single axis roll maneuver.
   - 3.2. The chair shall be designed to fit a TBD person.
   - 3.3. Users will not report any pain caused by the TCS during operation.
4. Systems Integration and Verification
   - 4.1. The GVS and TCS shall work in concert to simulate single axis maneuvers.
   - 4.2. The test subject will correctly identify direction of roll induced by controller.

Level 2

1. Computation
   1.1. The software will interface with a joystick input to cue a single angular acceleration on the test subject.
2. GVS
   2.1. The GVS will induce linear scaling, 0-1G, angular acceleration of a single axis.
3. TCS
   3.1. The TCS will induce linear scaling, 0-1G, angular acceleration of a single axis.
4. Systems Integration and Verification
   4.1. The lag time between the GVS and TCS will be reduced to 200ms or less.
   4.2. The GVS and TCS will induce the test subject based on joystick input from test subject.
   4.3. The test subject will correctly identify direction and axis of rotation induced by controller.

Level 3

1. GVS
   1.1. The GVS will induce linearly scaling angular acceleration of all three axes independently.
   1.2. The GVS will induce continuous 0-1G linear acceleration of y-axis.
2. TCS
   2.1. The TCS will induce linearly scaling angular acceleration of all three axes independently.
   2.2. The GVS will induce continuous 0-1G linear acceleration of y-axis.
3. Systems Integration and Verification
   3.1. The lag time between the GVS and TCS will be reduced to 100ms or less.
   3.2. The lag time between joystick input and GVS and TCS cues will be reduced.
   3.3. The test subject will correctly identify angular or linear accelerations induced by the controller.

Level 4

1. GVS
   1.1. The GVS will induce linearly scaling angular acceleration of multi-axis maneuvers.
2. TCS
   2.1. The TCS will induce linearly scaling angular acceleration of multi-axis maneuvers.

6. High Level Functional Requirements

1. **Requirement 1:** The test subject will receive multisensory cueing to simulate the vestibular and tactile perceptions experienced by a traditional pilot. This will increase the ability of the test subject to command and correct the aircraft.
2. **Requirement 2:** Test subject will not report any pain caused by the operation of the system.
3. **Requirement 3:** The GVS and TCS will be integrated to respond to test controller input.
4. **Requirement 4:** The TCS will be able to operate within a small space comparable to that of an office, no larger than the average cubicle size: 6' x 6'.
5. **Requirement 5:** The total development of the combined software and hardware systems must not exceed a total cost of 5,000 USD.

6.1 Concept of Operations (CONOPS)

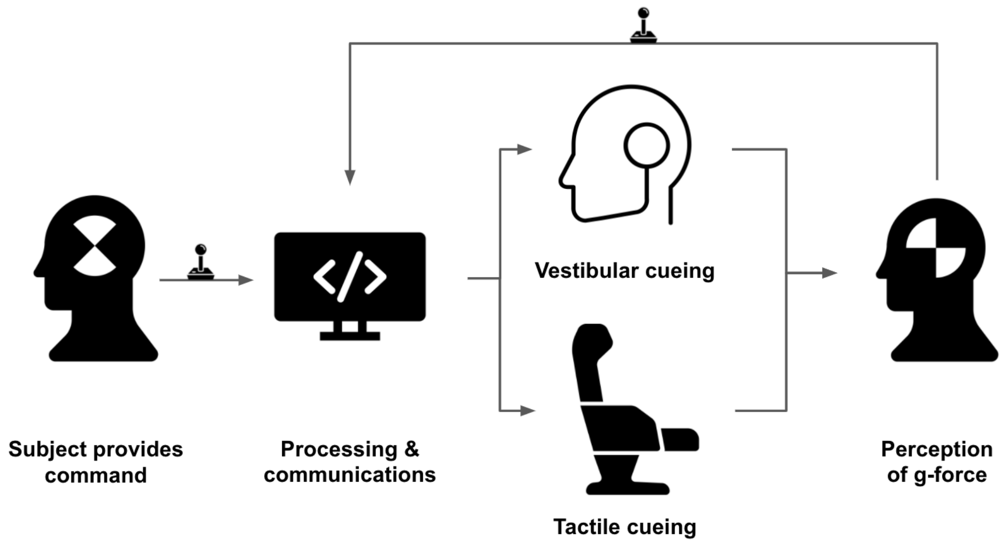

Figure 1: CONOPS

7. Critical Project Elements

Technical		
T1	Tactile Cueing System (TCS)	The CHAIR must be able to physically cue the pilot into their change in orientation. This critical project requires expertise in component design, manufacturing, and human factors.
T2	Galvanic Vestibular Stimulation (GVS)	The CHAIR must be able to cue the pilot into changes in their orientation through galvanic vestibular stimulation, creating artificial feelings of rotation. This critical project element requires knowledge of biology, electronics, and human factors.
T3	Pilot Input	The CHAIR must respond to pilot inputs to cue orientation. For level 1 success the pilot will be fed prescribed maneuvers as a replacement for user input. For level 2-4 success the pilot input will be part of a closed loop feeding inputs via a controller into CHAIR. This critical project element requires an understanding of controls, electronics, software, and human factors.
T4	Software	The CHAIR must be able to convert pilot input into signals that produce the appropriate response in the GVS and Chair systems as outlined by the requirements in section 6. This CPE requires knowledge of software, controls, and human factors.
T5	Electronics	The CHAIR must be able to communicate information between pilot input, software, GVS and TCS. This requires expertise in circuit design and human factors.
Logistical		
L1	Test Space Acquisition	The CHAIR will require testing for the verification of the requirements outlined in section 6. Understanding of safety, scheduling, and budgeting are necessary for this CPE.

Table 2: Critical Project Elements

8. Team Skills and Interests

Team Member	Skills/Interests	CPEs
Cody Bahan	Manufacturing, Software, Component Testing	T1, T2, T3
Rhys Bass	C++, Python, C Assembly, MATLAB , Electronics, SolidWorks, Embedded Software	T4, T5
Sarah Foley	Component Testing, Manufacturing, Software	T1, T2
Laney Franklin	Java, C++, Controls, Mission Planning and Modeling, CAD, Component Design	T1, T4, T5
Daniel Cole Gray	C++, MATLAB, Controls, Component Design, Manufacturing, Electronics	T1,T2,T5
Carter Jackson	Electrical Engineering, Manufacturing, Electronics Testing, Software	T1, T4, T5
Michelle Lin	Human Factors, Ergonomics, Mechanism Design, Mathematical Modeling, Manufacturing, Robotics	T1, T2, T3
Jason Magno	Software, Unit Testing, Manufacturing	T1, T4
Baily Rice	SolidWorks, MATLAB, Fabrication, Structures, Power Systems, Electronics Hardware	T1, T5, L1
Andrew Ringer	Python, C++, C, Java, Verilog, Hardware Testing and Integration, RF, Controls	T4, T5
Dean Widhalm	C++, Labview, Microcontrollers, Networking, Thermodynamics, Remote UAV Piloting, Neurology	T2, T3, T4, T5
Aiden Wilson	MATLAB, R, Systems Engineering, Interface Design, Data Analytics, Human Factors	T1, T2, T3

Table 3: Team Skills and Interests

9. Resources

Project Elements	Resource/Source
Chair or base platform	COTS
Controller for user input	COTS
Seat production/modification	CU Aerospace Manufacturing Lab
Software	TBD
GVS Hardware	TBD
Micro-controllers	COTS

Table 4: Resources

References

[1] Albery, William B., et al. “Motion and Force Cueing Requirements and Techniques for Advanced Tactical Aircraft Simulation.” 1978, doi:10.21236/ada064691.

[2] Albery, William B. "Multisensory Cueing for Enhancing Orientation Information During Flight". Aviation, Space, and Environmental Medicine, Volume 78, Supplement 1, May 2007, pp. B186-B190(5).

[3] Soterix Medical. (2020). Galvanic vestibular – Soterix medical. Soterix Medical - Neuromodulation and Brain Stimulation Technology – Soterix Medical. https://soterixmedical.com/research/vestibular

[4] Aoyama, Kazuma, et al. “Four-Pole Galvanic Vestibular Stimulation Causes Body Sway about Three Axes.” Scientific Reports, Nature Publishing Group, 11 May 2015, www.ncbi.nlm.nih.gov/pmc/articles/PMC4426693/.

[5] Abend, Les, et al. “The Ever-Changing Landscape of Flight Simulation.” Flying, 2019, www.flyingmag.com/ever-changing-landscape-flight-simulation/.