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Haptics in Aviation

Dr. Afsaneh Minaie, Utah Valley University

Afsaneh Minaie is a Professor and Chair of Engineering Department at Utah Valley University. She received her B.S., M.S., and Ph.D. all in Electrical Engineering from University of Oklahoma. Her research interests include gender issues in the academic sciences and engineering fields, Embedded Systems Design, Mobile Computing, Wireless Sensor Networks, Nanotechnology, Data Mining and Databases.

Mr. Joshua D. Neeley, Utah Valley University

Joshua Neeley is an Electronics Engineer working for the United States Air Force. He received his B.S. in Computer Engineering from Utah Valley University. He is currently expecting to begin and pursue a M.S. in Computing from the University of Utah starting in the Fall for 2021. His academic interests include, Haptics, Robotics, and Computer Science.

Nile Edward Brewer

Nile Brewer works as a Controls Specialist and High Voltage Electrician. He received his B.S. in Computer Engineering at Utah Valley University. His research interests are Design and Safety Practices for Power Distribution, Aviation, Embedded Systems Design, Control Systems, Open-Source Applications.

Dr. Reza Sanati-Mehrizy, Utah Valley University

Reza Sanati-Mehrizy is a professor of Computer Science Department at Utah Valley University, Orem, Utah. He received his M.S. and Ph.D. in Computer Science from the University of Oklahoma, Norman, Oklahoma. His research focuses on diverse areas such as: Database Design, Data Structures, Artificial Intelligence, Robotics, Computer Aided Manufacturing, Data Mining, Data Warehousing, and Machine Learning.

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Abstract

The purpose of a capstone design project course is to provide graduating senior students the opportunity to demonstrate understanding of the concepts they have learned during their studies. As with many computer science and engineering programs, students of the computer engineering program at Utah Valley University (UVU) conclude their degree programs with a semester capstone design experience. The intent is for students to utilize competencies developed in the first three years of the curriculum in the solution of an embedded design problem.

Educational excellence requires exposing students to the current edge of research. To ensure that student projects are along the same trajectory that the industry is moving, educators must continually introduce emerging techniques, practices, and applications into the curriculum. The field of haptics is growing rapidly, and there is increasing interest in providing undergraduate students with a foundation in the area. It is crucial that the emerging field of haptics technology be integrated into the undergraduate engineering curricula. This paper presents the details of a haptics project that our undergraduate computer engineering students have done in their senior capstone course.

Background Information

UVU is a comprehensive regional university with over 40,000 students charged with serving Utah county, which is the second largest county in the state. UVU has a dual mission – that of a comprehensive university offering 91 bachelor's degrees and 11 master's degrees, and that of a community college offering 65 associate degrees and 44 certificates.

Engineering and Computer Science Departments

To meet one of the region's most pressing workforce needs, UVU initiated three new engineering programs in Fall 2018. The new bachelor's degree programs in Electrical Engineering, Civil Engineering, and Mechanical Engineering have joined UVU's established programs in Computer Engineering and Pre-Engineering in a new Department of Engineering. The new programs were immediately popular with students, with 300 students enrolling for Fall 2018. Currently, the new Engineering Department has more than 900 students in five programs which are housed in that department. Before forming the Engineering Department at UVU, Computer Engineering program was housed in the Computer Science department which offers a bachelor's degree in Computer Science with two areas of specialization – Computer Science (traditional) and Computer Networking. It also offers a Software Engineering degree. The Bachelor of Science in Computer Science program was one of the first Bachelor of Science programs implemented at UVU in 1993.

Introduction

According to Wikipedia, haptics refers to any form of interaction involving touch. Haptics refers to working with the sense of touch. Haptic technology refers to any technology that can create an experience of touch by applying forces, vibrations, or motions to the user [1].

Haptics is the science of applying touch sensation and control to interaction with computer applications. By using special input/output devices (joysticks, data gloves, or other devices), users can receive feedback from computer applications in the form of felt sensations in the hand or other parts of the body. Several researchers have already developed and used haptics for hands-on instructions of physics, dynamics and control systems, and engineering statics [2-5]. Sitti and Hashimoto [6] have used scaled haptic feedback in real-time from an atomic force microscope (AFM) for doing research in the area of nanotechnology. Jones [7, 8] has used a haptic device to control an AFM for teaching the nanotechnology concepts. Jackson and Taylor [9] have developed a haptic virtual gaming for teaching nanotechnology.

As technology progresses, it presents us with new problems. The sensation of touch disappears as tools are built to do our jobs for us. When 4-wheelers added power steering, the riders had a hard time steering due to the lack of feedback. The field of haptic technology adds the sensation of touch back into these devices so one can interact as if the technology isn’t there. Haptics will soon change the way that humans interact with a large part of the environment. Advances in this technology are pushing into the medical field, virtual reality, sports and more. Haptics in Aviation aims to bring it into the field of free flight. This will enable pilots to sense the environment around them so that flight can feel natural.

Technology is advancing to meet the needs of the human body and mind. Smart phones now have sport haptic touch technology which basically means a phone vibrates slightly as one presses an app on the screen. Haptic technology aims to integrate the human body’s need to feel and touch, with the virtual world. The haptic approach to technology is gaining speed, although at first, one might not even notice it. This is the sign of natural integration, one which feels right to the mind and body and creates a stronger connection with technology.

One’s skin specifically is good at remembering touch. This is called haptic memory. In fact, one’s bodies use a combination of visual and haptic cues in order to recognize familiar objects. This ability starts in infants as young as 2 months old [10]. Having both visual and haptic cues is one of the many ways that the body evaluate the surroundings. Understanding this helps to understand the impact of haptic technology. Haptic memory can contribute to habituation as well. This means that when certain stimuli are applied, one’s body can quickly decide how to react based on previous experience with that haptic stimuli. Combining this with muscle memory allows the body to act and react to its surroundings automatically.

Haptic feedback from technology is becoming increasingly more important. As doctors learn to use and integrate robotics to perform advanced surgeries, haptic feedback is allowing for more accurate and faster operations. In this specific case, haptic feedback gives surgeons the feedback they would be getting if it were their actual hands performing the surgery. In the field of virtual reality companies are developing systems that give a more realistic experience to gamers. Rather than just being immersed visually into a virtual world, players can also feel objects in game or perhaps the pulse of an explosion or the pressure from a bullet. Even online shopping can be drastically changed by haptic feedback to online shoppers. Imagine being able to actually feel the fabric or material of the object one is shopping for online. This and much more is possible using haptic technology. Haptic technology helps users to feel the world around them in places where older technology has removed the feedback of touch.

As aviation has advanced, some of the natural feelings and senses of flying have been nullified. For instance, as an aircraft enters angle of attack that would cause a stall, usually the controls would shake. This was the natural response of the aerodynamic buffeting affecting the plane. However, more modern planes do not use fly-by-wire systems which involve cables that would translate the buffeting to the joystick and paddles. Modern planes use servos that are controlled electronically. This advancement makes more advanced flight at higher speeds possible and safer, however it also eliminates those important sensory cues. Using haptic technology, a stick shaker is used to simulate the simpler technology thereby reintroducing the sensory cues that precede a stall [11].

In order to prepare our computer engineering students for the haptic design experience, we offer two courses on embedded systems. However, these two courses on embedded systems design are not enough to teach the students the skills that they need. In order to satisfy the ABET requirements students in computer engineering program are required to take a capstone course. The projects that students do in this capstone course are required to be embedded projects.

Following presents the details of a haptic project that a team of two computer engineering students have done in their capstone course.

Sample Project: Haptic Variometer (Intuifly)

The objective of this project was to design a haptic wearable device for pilots of nonpowered aircraft during operation acting as indicator for rate of climb and descent (vertical velocity indication).

Hang gliding is a recreational activity where a pilot flies a light, non-motorized foot-launcher heavier than air aircraft called a hang glider [12]. Francis Rogallo of NASA invented the first hang glider in 1948 [13, 14] as a form of recovery for space capsules. It took another fourteen years for it to turn into a form of recreation. In the early days every hang glider was built by hand, engineers would take trips to hardware stores to perfect their designs; yes, a hardware store! Pilots who were lucky enough to survive that era were met with a much more advanced market, they would receive their hang gliders in the mail and would use their personal hand tools to put them together in the garage. These stories are very scary for the pilots today. In current time, pilots buy their hang gliders or paragliders from manufacturers that go through very rigorous testing, doing everything in their power to prevent mechanical failures. Indeed, this is a time when accidents are mostly attributed to pilot error.

Figure1: Student Flying a Hang Glide

Man has dreamed of flight since they were smart enough to paint on walls and probably before that. This form of recreation is called “free flight”. Pilots harness the wind in the same way the birds do, flying to great heights. They circle in the wind all the way to cloud base. The sky scape at cloud base is an extraordinary and privileged view. With a gaggle (group of pilots) full of engineers, doctors, lawyers and a few cowboys… they are both skilled and daring to put it lightly. Contrary to popular belief, these pilots often have flights that exceed 100 miles with durations upwards of 6 hours.

Birds find rising air through touch as wind pushes on their feathers. Hang glider and paraglider pilots don’t have this feedback system. There are complex instruments to aid pilots in finding lift to extend the duration of their flights. These systems are old and outdated. Not only do they create noise pollution that detracts from the beauty of free flight, they also ignore the needs of those who require adaptive equipment, including those who are hearing impaired. There are adaptive programs for skiing, swimming and several other sports. Recently, equipment for adaptive flying has been introduced and this product hopes to contribute to that community.

Variometers (vertical velocity indicators) have been used in the aviation industry for many years. Over time as technology and innovation grew, nonpowered flight became more popular. Nonpowered flight is characterized as, flying under the power of the wind using lift over drag. Every glider has a different glide ratio. Currently hang gliders may range from 9-1 to 20-1, paragliders may range from 5-1 to ~10-1 and sail planes can have a glide ratio that exceeds 70-1. So, as glide ratio works, a craft with 9-1 can travel 9 miles laterally from one mile (5300’) off the ground. The sink rate of a hang glider is ~150-230 ft/min and a paraglider sink rate is ~200- 240 ft/min. A sail plane sinks at a rate of ~100 ft/min. The sink rate comes from a variety of factors but the most influential change to improve glide and sink rate is the aspect ratio (how long the wing is relative to how wide). Knowing the gliders sink rate will tell the pilot how much lift they need to maintain altitude or to climb.

Pilots can use thermals (hot air rising from the ground), ridge lift, waves and other convergences. Using an instrument to signal these changes enable extended flight durations. In nonpowered flight these variometers (often referred to as 'varios') use an audible beep to signal increase in altitude and a slightly different tone to indicate decrease in altitude. The typical variometer will use a sequence of audible beeps that increase in frequency as the rate of change increases. In current instrumentation, lots of separate functions have been added.

- Vertical speed indication
- Ground speed
- Flight Logging, time in flight, also including max and min lift during the flight
- Current altitude
- Air speed probes
- GPS
- Topographic maps
- Color screens
- Audible airspace warnings (with FAA sectionals preloaded on the devices)
- Pre-plotting waypoints for competitions

These are nice features but none of them are necessary for piloting the craft. When flying without power one can find themselves in extremely turbulent air. One can tumble a hang glider (flipping it), if you let go of the control frame during a tumble you can fall into the frame and break it in half. If you are paragliding, the glider can collapse and if it reopens and you are unable to manage it, you can find yourself above the canopy where you can fall into it. This is called a gift wrapped (or bagged). In either incident (hang glider or paraglider) you will be falling from the sky at a great rate of speed and unlikely to have the ability to throw your emergency parachute. Both are likely to end in death. There are parallels in all forms of unpowered flying. The only early warnings one has to these events is intuition and the variometer. In the wind and with extreme focus you are hoping to "hear" your instrument.

While paragliding, it can be difficult for the human body to notice changes in altitude. This confusion comes from misleading, or inadequate visual cues that the body and mind need to notice subtle changes in altitude. Given that the only way to extend a paragliding flight is to find and catch thermals, or pockets of rising air, it is very important to be able to detect those rising air currents. The instrument that paragliders use to tell them these things are called variometers. There are already devices on the market that will tell the pilot their altitude, rate-of-ascent, and rate of descent. However, these devices use digital screens to display data in text form. They also use a beeping sound to indicate whether the paraglider is ascending or descending and at which rate. These methods of communicating data in a real-time system are simply outdated. The beeping sound is annoying, and the screen requires constant attention if the paraglider chooses to mute the device. In this situation the paraglider must choose between safety and comfort. In the case where a paraglider is deaf or severely hearing impaired, there is no choice.

This is where haptic technology offers a solution to the problem. As shown by the previous example of advanced aircraft, haptics can be used to simulate sensory cues that are natural. In the paraglider's case, haptic technology can enhance the senses they already have rather than just report the data. This device would essentially use vibrations on the top or bottom of the paraglider's arm to indicate ascent or descent and the rate at which either is occurring. This enables a hands free, silent, and more natural approach to the problem. Rather than see the data in a textual form or hearing it in an annoying beeping sound, the paraglider can feel, or sense, their change in altitude.

This capstone project takes measurements with a sensor and calculates rate of change in altitude (vertical velocity). It sends signals through vibrating motors so that the flight will feel more intuitive. The vibrations will be subtle and intended to help the pilot build a natural response to the feeling of lift rather than the burden of listening for an audible beep. In addition to making the fight more intuitive, it will also give access to the hearing impaired (who currently have no alternative). It could also aid military in making night descents less dangerous, by creating a silent device and one that does not require you to divert your visual focal point.

This design uses an ESP8266EX microcontroller (Figure 2) made by Espressif Systems to receive functions from a BMP 180 Digital Pressure Sensor (Figure 3), accelerometer to read the data given and compute rate of change in altitude.

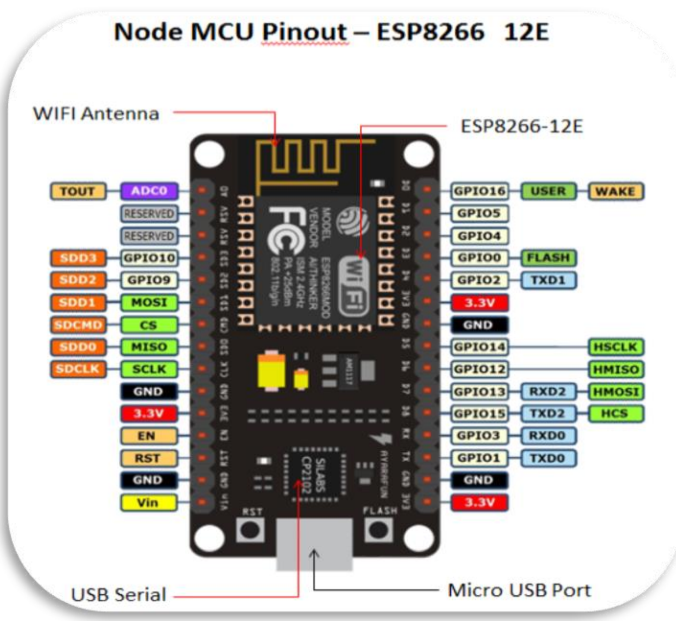

Figure 2: ESP8266 NodeMCU ESP -12E

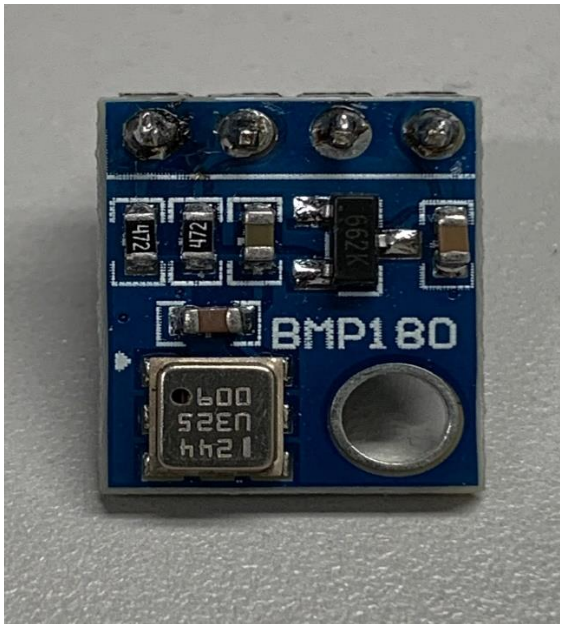

Figure 3: BMP 180 Pressure Sensor

The vertical velocity calculated is transmitted through vibrating motors (eccentric rotating motor or alternative with relative function) to signal the pilot. This design uses four Eccentric Rotating Mass Motor (ERM) which are brushless DC motors. These EMR’s are being used as a haptic feedback solution, replacing an audible speaker from the existing products.

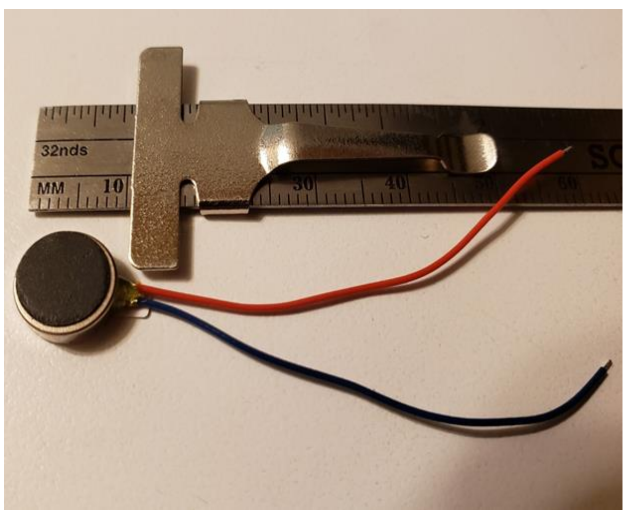

Figure 4: ERM Vibrating Motor

Figure 5 shows the prototype wiring of the design.

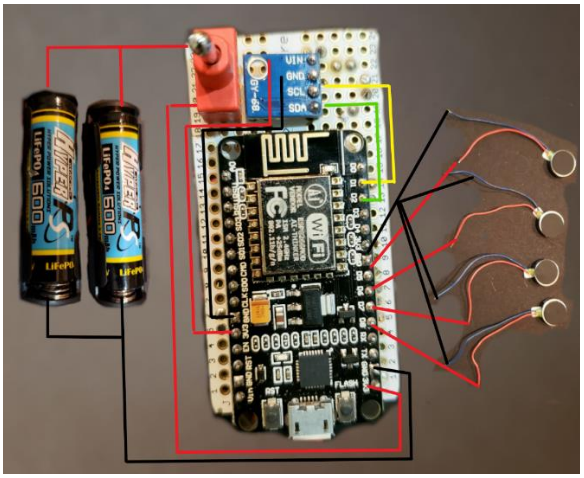

Figure 5: Prototype Wiring

Haptic variometer may be worn as a watch and may include (but not limited to) iterations that signal helmet, gloves, chest, leg, arm or feet. Figure 6 shows the interior of the first prototype.

Figure 6: Interior of the First Prototype

Figure 7 shows the testing of the design in an elevator and Figure 8 shows the testing in an actual flight.

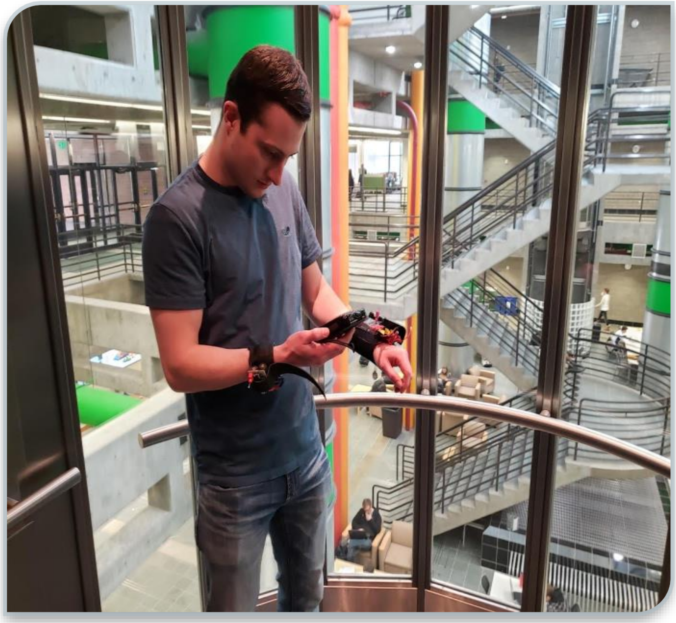

Figure 7: Testing the Design in an Elevator

Figure 8: Flight Test

Arduino IDE was used for the software development of the prototype. The Arduino IDE integrates well with the ESP8266 NodeMCU and has a couple of tools that are very useful for debugging embedded systems.

There may be an LED light to indicate ascent or descent as a backup should the motor fail. Some iterations to include other non-essential data collection and distribution through an application or directly onto an LCD that may be mounted to the device. The wristbands or alternate body location attachments may be sewn or bonded in any way known to the art on relevant industry alternatives.

Following is a summary of this design and its functionality:

- Intuifly is a haptic variometer. It may replace the notification of a piloting required function out of a complex instrument and attempt to make the action of flying more intuitive. The redesigned notification is to make this necessary function more tolerable and intuitive.
- Intuifly will aid hearing impaired pilots by giving them access to technology that until now has only been designed for those without special needs.
- Military drop zones may be easier to hit and safer to fly to.
- Recreational flight will be made safer by making it more intuitive.

Summary and Conclusion

This paper discussed recent senior design projects in the area of haptic design where one team worked on designing a haptic variometer. Our senior design course is structured as a collection of independent student projects. Students find this course both challenging and rewarding as they are required to design, build and troubleshoot a fully functional embedded project. These projects give the students the chance to use their technical expertise and knowledge gained during years of study. Students work very hard to have a working project by the end of the semester. These projects provide students many opportunities to engage in self-directed learning. They develop the ability to debug, seek and find information they need, and the ability to understand and reverse-engineer poorly written documentation. The students' feedback and their final project presentation indicate that they have pride in their project accomplishments and have gained confidence in their engineering abilities.

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