Augmented Reality Climbing Wall

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Abstract—Our project is focused on taking the current augmented reality climbing walls used today and optimizing them to create a smoother, mistake-free gaming experience for the user. To accomplish this, we plan on taking the skeletal tracking system that most augmented reality climbing walls already use and coupling it with our own active sensors that would be attached to the climbing holds. Doing this would remove the reliance on the inconsistent skeletal tracking system and add a second element that can actively sense which climbing holds the user is exerting pressure on. In addition to providing users a better gaming experience, we also plan on developing our own augmented reality climbing wall games that the user will be able to enjoy without error or delays while on the wall.

Index Terms— Face and gesture recognition, Games, Health, Interactive systems, Virtual and augmented reality

1 Introduction

Recently, augmented reality has seen a huge popularity spike in the world of gaming. Since augmented reality consists of real objects being overlaid with digital elements, this creates the potential that regular situations in life can be turned into an exciting game. One such situation is climbing a rock wall at a climbing gym. Augmented reality is perfectly suited for the world of rock climbing because it can create an incredibly immersive gaming experience, and unlike virtual reality, no overburdensome equipment is necessary. Augmented reality climbing walls do exist today and are done using a projector to project the game onto the wall, a game engine running the actual game being played, and a skeletal tracking system that estimates where a user is on the wall. However, this is not exactly a mistake-free system. Skeletal tracking can prove to be unreliable at times such as if a person's body comes in between skeletal tracking system and a hand that is on a hold, leading to the system being unable to track where that hand is and resulting in a flawed gaming experience.

This is the problem that our team was tasked by our client to solve. Our objective is to take the way AR climbing walls are currently done and improve it. Our objective is to provide climbing gyms with an augmented reality bouldering experience that can create a smooth and error-free game for the user. How we plan on accomplishing this is by coupling the already used skeletal tracking system with pressurized sensors placed on the climbing holds. This creates a dual-sensor solution to the current problem as when the skeletal tracking system inevitably fails, the pressurized climbing holds will be able to still accurately detect where the user is on the wall. The main metric of this project is that by the end of the year, we hope to have an augmented reality climbing wall that outperforms the current AR walls on the market.

In addition to creating the pressurized climbing holds, we also plan on creating our own augmented reality game to be played on the wall. This was an idea from our client, with most of us being computer engineers, the idea of creating a game was very exciting. Currently, a lot of the most popular games played on these walls tend to be either Pong, a two-player game that involves trying to knock a ball past the other player, or Whack-A-Bat which is a game where a bat flies around the wall and the player must traverse the wall and strike it by grabbing the hold it rests upon. We plan on providing this game plus the pressurized climbing holds and the rest of the system involved in making the AR wall operational, such as the microcontroller processor, projector, and skeletal tracker, as our main deliverables for this project.

Pairing augmented reality with rock climbing walls is a perfect combination with incredible potential to create amazing gaming and climbing experiences for the users. However, that potential has never been fully realized as the modern way of pairing the two leaves much to be desired. For our project, by taking the skeletal tracking system that is the cornerstone of how augmented reality climbing walls are currently done and combining it with our own pressurized climbing holds, we plan to fully reach that potential and allow climbing gyms to offer their customers an error-free gaming experience.

2 Concept Development

Our client is seeking a commercial product that leverages augmented reality to provide a fun rock-climbing experience for users of any familiarity with rock-climbing as a sport. At its core, our product should address the current issues present in a competing augmented reality climbing wall created by ClimbingSolutions and currently installed at Level99, an interactive arcade located at Natick Mall in the Greater Boston area. If our final product outperforms the experience that ClimbingSolutions provides, then our project will have been a success. This leniency allowed us lots of freedom in choosing what features to include in our final product, as long as we knew that the design would provide a similar experience.

With the system at Natick Mall being our primary source of information in informing our design decisions, our natural first step was to visit the arcade and observe how users interacted with the rock wall, and the kinds of improvements that could be made. When we visited, we observed a number of consistent, reproducible, and important setbacks that the old system contains, which lowered the enjoyment of the overall experience. During almost every game we observed, we saw cases where user position was not being properly registered, where holds judged to be active were rapidly toggling on and off, where users would avoid climbing on the wall because other more effective strategies were employable, and where users would be frustrated and confused by the way the game detects what holds they are on.

All of these factors were attributable to the way the system relies on detecting which holds are being activated by the user. The way the current system does this is by mounting an Xbox Kinect system behind the user where the projector is, and using the onboard skeletal tracking system of the Kinect. This skeletal tracking system attempts to locate the endpoints of the users hands and feet, and needs unobstructed line of sight in order to do this accurately. After these positions are found, the system sees if the positions are nearby a grid of preprogrammed points which are meant to be on top of where the climbing holds are located on the wall. If it detects a limb near any point, the point is judged to be active, regardless of whether or not contact is made with the climbing hold. Because this was the method of detection, it was clear why the four previously observed problems were occurring: The Kinect skeletal tracking is unable to detect limbs that are obstructed, so anytime a user's hand or foot is located on a hold that is directly in front of their torso, the hold will never be judged as active. The skeletal tracking system is unsure whether things it detects are appendages or not, so holds are often toggled on and off very quickly when the system is confused. Users did not need to be actively holding on to the holds for the system to detect them as active, so jumping off of the ground to briefly activate a hold became a viable strategy, though against the spirit of the game. It's not obvious to users that detection functions in this way, and users likely expect that the system would somehow detect their movements in a more accurate way. None of the users we watched took particular care in ensuring that holds that they wanted to activate were not directly in front of them.

It was clear to us that the issues currently present in the game were all attributable to the lackluster skeletal tracking system used to detect whether or not a hold was active. In developing our final product, we decided that it would be of utmost importance that hold activation is made as smooth and as accurate as possible. For this to happen, we first thought of how to tackle the first problem we noticed: user appendages are never detected if they are directly in front of the user, since the camera cannot see through them. In identifying possible solutions, we came up with a few ideas. One idea was to use cameras placed at different angles and positions on the wall, which would give a complete picture of a user's location, rather than relying on a single camera behind them. Another possible solution was to write more robust skeletal tracking software, which would detect a user's arms as directly in front of their torso if no arms were detected at all. Another solution was to use an active sensing mechanism in each of the holds on the wall, and communicate that information to the CPU instead. Each of these ideas had different advantages and disadvantages. Because we wanted our product to be deployable at any climbing gym willing to buy it, we ruled out adding additional cameras since most gyms follow similar structures and could not support mounting side-cameras particularly well. Along those same lines, we wanted to minimize the focus on skeletal tracking since mounting a projector is already a big ask, so we opted to use active sensors on the climbing holds instead. Using only skeletal tracking would also likely not work even if presumptions are made about arm locations while they are obscured. It wouldn't be fair to assume the user has their arm in the right place just because it is obscured, so we felt that implementing it this way would take away from the true challenge of the game, and not remove the problem of users not actually climbing the wall. This left us with active sensing holds, which certainly have their own design complications, but we felt that was our best option and would offer a fresh idea into the space.

When constructing our active sensors for the holds, we had a few ideals in mind. First, it was crucial that we do not remanufacture all of the climbing holds that a gym could possibly want to use. For our product to be robust and enticing, we thought it would be important that a gym or recreational climber could reuse all of the holds that they currently own, and could install this onto any course that they have currently built. With this design choice in mind, we settled on building a non-intrusive insert that would go between the hold and the rock wall. The insert would need to detect that the user is pushing down on it, send that data back to a CPU, and not be so bulky as to interrupt the experience for the climber. Luckily for us, currently existing wireless data transfer and wireless power transfer technologies have already transmitted signals around the same distance that we are working with, and work through materials such as those traditional rock walls are made of. While we had also thought about transferring power and data via wire, there would not be enough space to do this without going through the wall directly, and we thought it would be more difficult to construct a system that passes through a bolt hole in the wall than a wireless connection entirely.

To accompany our hold sensors, we would also need a system that differentiates between different incoming signals and maps them to the locations the holds are actually located at, to be used in the game logic that the user is playing. For this, we calibrate the holds with a computer vision algorithm that automatically detects the holds on the wall, and asks the installer to pres s down on each hold one-by-one until the system knows all of the locations. A potential alternative for this decision was making the user input the locations manually, but we thought that this would be too technical to have a purchaser do, so we wanted to make it as automated as possible so that the client has an out-of-the-box system that doesn't need much custom modification.

3 System Description

The system consists of several components, including hold sensors, a central computer, a projector, and a body tracking system. The hold sensors and body tracking work in unison in order to determine when the player is interacting with a hold. When the user interacts with the hold, a button above it depresses and triggers a switch, which signals through the wall that the user is interacting with it. On the back of the wall a series of wires connects the holds to a central computer. This computer uses a combination of the hold data along with the data obtained from the body tracking system in order to determine the user's position. This ideally removes the uncertainty caused by bodily obstruction when the user is in between the wall and the body tracking system. Once the computer has the data it processes it accordingly depending on the currently running game and then generates what should be displayed on the projector. The user then sees this, completing the loop and allowing the game to be played.

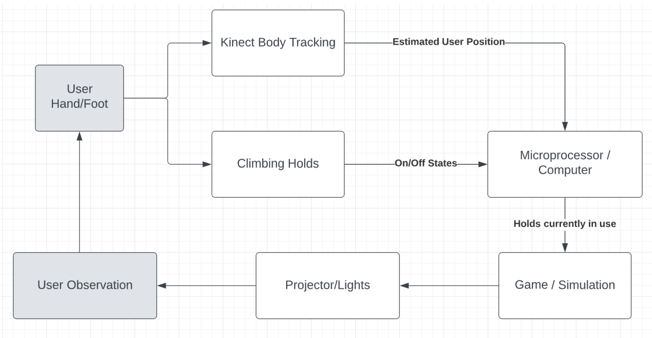

Figure 1. System Block Diagram
(Larger picture in Appendix 3)

The sensors on the wall holds are designed to be as modular as possible, and consequently are compatible with existing climbing gym bolts and holds. As opposed to using custom made bolts or holds, the installation process with our sensor requires no holes to be drilled in the wall and no equipment to be modified. The sensor we provide consists of a circuit, with a 1.25 inch diameter coil. This coil allows the hold sensors to function with wireless power transfer in order to remain as modular and unobstructive as possible. As previously mentioned, the coil is activated via button. We made this decision, because, unlike a pressure or touch sensor, a button allows us to detect the state of the hold, without needing a microprocessor/driver inside the hold. We found that it could theoretically be possible to use either a pressure or touch sensor without further processing inside the hold, but still decided upon the button, because it was less prone to current leakage and damage, which would both hurt the battery life and performance of the product over time.

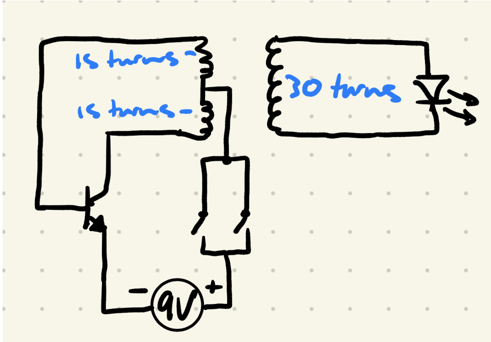

Figure 2. Circuit Diagram

This coil is currently powered by a 9V battery, however in the future we plan to replace this with a much more compact lithium ion battery or eventually even wall power. The current circuit and 9V battery can transmit enough power to light up an LED from several inches away. Both this distance and amount of power are more than the final product will need, as most rock walls are not more than an inch or two thick and the final signal transmitted does not need to be strong enough to light an LED, but rather just signal a clear on or off state to the microprocessor. This means using the 1200mAh lithium ion batteries we have, we could ideally get 300 hours of play time before needing recharging. Reducing the current in the coils to around 100mA gives us 12 hours of constant battery life; Assuming we have 100 holds across a rock wall and only 4 (at most 8 for two people) are being used at a time, then each hold is used a maximum of 8% of the time, meaning that for 1 player the wall can provide up to 300 hours of playtime and for 2 up to 150 hours. Once again the ideal final implementation will be powered from an electrical outlet and have indefinite power, but even if that fails, our current play time of 300 hours per charge is very manageable.

Figure 3. Hold Sensor Prototype

The entire system comes with a control software that is used for setting up and calibrating the rock wall. It uses image processing to detect where each of the holds are in real life and map them virtually for simulation. This allows for the configuration of the wall to be changed without having to enter tedious amounts of data each time. Additionally, this software aids in initial calibration, determining not just where each hold is, but how far apart the actual mounting points are. This knowledge allows the software to generate custom placements for the holds based upon the users desires.

4 First Semester Progress

To start off our project we first had to study the current system in place located at Natick Mall Level 99. After seeing the major issues, a new system was conceptualized which is detailed in section 3. Instead of just a climbing wall with skeletal tracking to detect whether the players are overlapping with the lights illuminated on top of the holds, we will have sensors on the holds themselves which will allow more accurate identification of the players' positions.

After the system was developed, one of the major areas of contention was whether the holds would communicate with the microprocessor remotely and likewise for the power supply. As of now, we have decided that the hold sensors will communicate with the microprocessor through wires and the power transfer will happen remotely (as seen in Figure 3).

During this semester we focused on developing and constructing the pressure sensing climbing holds as we explained above. We were able to accomplish that in our first prototype test which was a success. In addition, we also completed the development on some of the software elements of the project such as the grid system for detecting where the holds are located on the climbing wall and the actual augmented reality game that will be played by the user while they are on the wall. The team is in contact with Fitrec to conduct installation and performance tests with our future prototypes.

Our client, as previously mentioned, has provided us with an ArduCam Time of Flight (ToF) Raspberry Pi "Nividia Jestsons" camera that we plan to use for our display. We have not implemented a prototype yet that includes the Arducam yet, but we are beginning to research how we can implement the suggested camera into our design and have it communicate with the microprocessor.

With our current design we have a button above the climbing wall hold to detect when a player is in contact with a hold. They're are several shortcomings that come with this. The player has to make contact with the hold and the button which is likely to not be easy in many situations. Our client has suggested a few options when it comes to implementing a pressure sensor, pressure sensor being our most viable option moving forward. The two main options for pressure sensing are to make our own or by using a pressure sensitive film, Pressure Sensitive Conductive Plastic (Velostat/Linqstat), that we will put either around or on the climbing wall holds. When it comes to putting a film over the hold, we would have to think about the longevity and stability of the sensors due to players being in contact with the film constantly, the ability for the players to maintain a good grip for playability and safety reasons and lastly the ease of this to be applied and removed from a hold. The other option was to make a pressure sensor ourselves with something like a tin foil film which we would similarly put over the holds. We are more leaning towards buying a pressure film as finding a proper film material and inserting a pressure sensor may prove both challenging and time consuming.

Concerning our current phase of our project, we are still in the research phase when it comes to finding alternatives for contact sensing of the players on the holds. This includes the research of how we are planning to incorporate the camera into the system. The research phase has extended a bit further than originally planned but we believe we should be able to complete future tasks in a timely manner.

5 Technical Plan

Task 1. Interconnection of Holds and Microprocessor
The microprocessor must take in the data that a specific hold is pressed or not. This data should then be accessible by the game engine to be used for the game logic. A system connected to the back of the wall needs to be created to collect the wirelessly transmitted data from the front.
Lead: Taylor Hartman

Task 2. Pressure Sensor Research and Installation
Implement the Pressure Sensitive Conductive Plastic (Velostat/Linqstat) on to the holds and determine the accuracy rate of detection for the plastic film. This includes making sure that the film can interact with the microprocessor to correctly detect that a player is making contact with the corresponding hold.
Lead: Michael Igwe

Task 3. Microprocessor Programming
A computer will intake the input of all the holds on the climbing wall and correlate each hold with the respective position on the virtual grid. Lead: Tom Panenko

Task 4. Game Programming
Implementing a Python algorithm for the game we created into the microprocessor so it can accurately and quickly determine the next state of the game. This will include collecting input from the skeletal tracking and the sensors on the holds to determine the state and sending the output to the camera.
Lead: Ryan Smith; Assisting: Tom Panenko

Task 5. Game Simulation/ Visualization
A projector will broadcast the current game state to the users, so a user design needs to be implemented for the games that are broadcasted.
Lead: Ryan Smith

Task 6. Deployment of Final Design
The inserts on the front and back of the wall

must be manufactured en masse in order to complete our final product. A complete rock wall is expected to house approximately fifty climbing holds, and so we must manufacture this many to showcase our final design. These parts will be tested on a rock climbing wall provided by our client. Lead: Taylor Hartman; Assisting: Michael Igwe

6 Budget Estimate

Table 1. Current Budget of Project

Items	Description	Total Cost
1	Rides to/from Level99	$60.43
2	Lithium Batteries	$47.82
3	Battery Charger / Connection Cables	$39.27
	Total Cost	$147.52

Since the main focus of this semester was the development of the climbing hold pressure sensors and the grid system, the budget reflects that. The grid system is exclusively software, so it did not require any components for which the budget needed to be allocated to purchase. The climbing hold pressure sensors, on the other hand, were hardware, and, thus, we needed to purchase lithium batteries as well as charging cables to add to the circuitry whose components we were able to gather from the Senior Design Lab. The remaining part of our budget this semester was spent on rides to and from the recreation center Level 99 located in the Natick Mall. This was necessary because our end deliverable is supposed to be an improved version of the augmented reality climbing wall being used at Level 99, so a trip was needed to inspect the device and observe improvements that we could make for our project.

Additionally for our project, we obtained important components that we did not have to allocate our budget towards. Specifically, from our client, we received an Intel RealSense to use for the skeletal tracking aspect of our project. One of our teammates also already has a projector that can effectively serve the needs of this project. Both of these devices can be very expensive, so obtaining a skeletal tracking system and projector without having to allocate our own funds definitely freed us to pursue other investments.

7 Attachments

7.1 Appendix 1 - Engineering Requirements

Table 2. Engineering Requirements

Requirement	Value/Range
Hold enclosure dimensions	3.5in x 4.4in x 0.3in
Hold sensor power source	9V battery
Hold enclosure thickness with 9V battery	0.75in
Hold enclosure thickness with lithium ion battery	0.3in
Hold sensor current draw	100mA - 200mA
System use time before battery recharge	Up to 300 hours

7.2 Appendix 2 - Gantt Chart

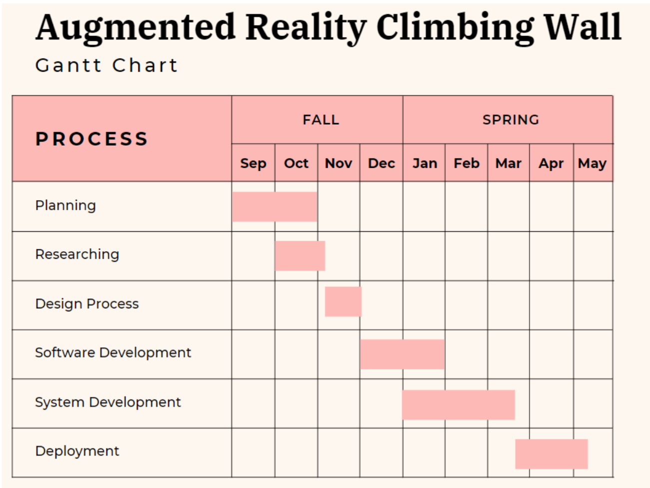

Figure 4. Gantt Chart

7.3 Appendix 3 - Other Appendices, Sources

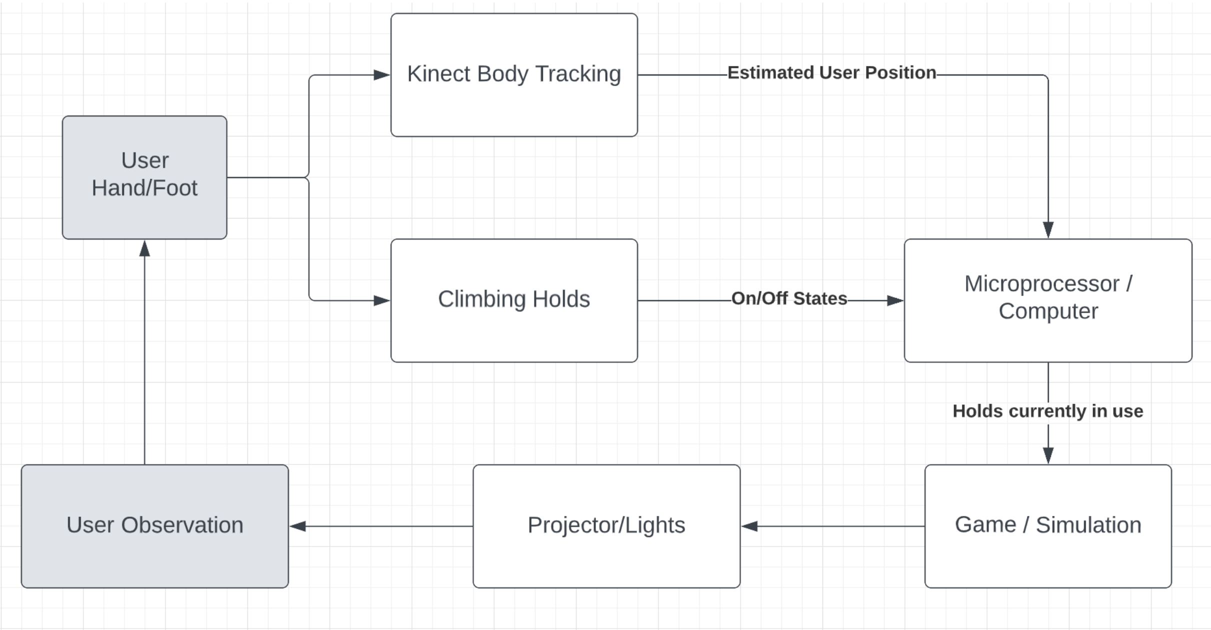

Figure 1 Enlarged. System Block Diagram

Table 3. Prototype Test Results

Action	Correct? (1/0)
Button successfully depresses	1
LED lights when button pressed directly	1
LED turns off when button released	1
LED lights up within 1 second of button being pressed	1
LED lights when hand on hold	1
LED lights when foot on hold	1
Coil is not noticeably hot after 10 seconds of activation	1
Total	7/7