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AiR Drums:
A Virtual Reality Drumming Experience

<u>ECE4011 Senior Design Project</u>

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Executive Summary

Personal Virtual Reality Systems have come a long way in the last few years. With the advent of the Oculus Rift, such devices have become readily available on the market at relatively inexpensive prices. This has led to a new generation of applications that aim to immerse their users in new and unique virtual experiences. The AiR Drums Team intends to extend this technology by integrating it with modern gesture recognition and music synthesis systems to create the world's very first virtual reality drumset. On the surface, the system will consist of an Oculus Rift DK2 and drumstick peripheral devices that will be embedded with Inertial Measurement Unit (IMU) sensors. During operation, the user will be able to play by interacting with a virtual drum system. This interaction will be carried out by the real time processing of the drumstick peripheral kinematic information. This information will then be used by the system to synthesize the final drum sounds which will be played to the user via speakers on the base station computer running the VR application, or through a similar audio device. This project's intended participants are amateur drummers and VR enthusiasts. We wish to provide a system with which an individual may learn or practice the drums without the requirement for expensive and cumbersome kits. The expected output of the design is a fully functional prototype that will cost approximately $515.

A Virtual Reality Drumming Experience

1. Introduction

The Air Drummers Team will design a virtual reality application that that will simulate a virtual reality based drumming experience. The team is requesting $515 to develop an initial prototype for the system.

1.1 Objective

The team will design and prototype a system that simulates a virtual drum set with the movements of physical drumsticks as external inputs. Headsets for Virtual Reality systems will be used to provide head tracking allowing users to look around the virtual world as they would in real life. A game development ecosystem will render this 3D virtual environment and be able to interface with the headset and the peripheral drumstick devices. IMUs (inertial measurement units) will be connected to controllers embedded in the drumstick peripherals which will be responsible for drumstick motion tracking [1]. The game engine will collect this tracking information and will generate the real-time drum sound synthesis which will be played through the headset's base station speakers.

1.2 Motivation

Air Drums will be a new way of experiencing drumming. It will be an entertainment device that will let users have fun while playing the drums and enjoying the 3D virtual world. Drumsticks are the only thing the users will need. The most similar currently available application is Virtual Air Guitar using which users can play guitar in the air with a pair of orange gloves in front of a TV screen. However, our objective is slightly different because we wish develop a prototype that will interface with peripheral hardware, the drumsticks, and an Oculus Rift. Currently the primary customer base is expected to be comprised of amateur drummers and VR enthusiasts. AiR Drums promises to be a unique and new system that is currently not in existence anywhere.

1.3 Background

A recently released Oculus Rift Game, named Tuscany Razer Hydra Demo, combined the Oculus Rift and the Razer Hydra, which features two handheld controllers that track the exact position and orientations of the user's hands. However, this Tuscany Demo is based on the Tuscany demo that is an existing product. And Tuscany demo uses FenixFire to render the virtual environment. Dream is a developing game with Oculus Rift support. This game features interact-able 3D environments and original soundtrack by composer Norman Legies [1], which enables the user to discover dreams and nightmares filled with puzzles and secrets. Unreal development kit, which is a free version of Unreal Engine 3's Software Development Kit (SDK), is used as the game engine to build the game environment.

Three key components of the virtual reality system are head tracking, virtual environment rendering, and drumstick motion detection. The Oculus Rift is equipped with an IMU used to track the rotational movements of the head. An IR camera which is available as a part of the Occulus Rift's kit can also be connected to the user's PC to help increase head tracking accuracy. The second component, virtual environment creating, simulates a drum set so that people can see it through Oculus. Unity provides a complete set of intuitive tools and rapid workflows to create the 3D virtual environment. For the drumstick motion tracking, in order to compensate for the shortcomings of the IMU-based tracking, a LED camera mounted on the drumstick is to be used for more precise detection.

2. Project Description and Goals

The ultimate goal of the Air Drummers team is to develop an integrated system that simulates a visual and audio environment that provides the user with virtual drumming experiences. The system consists of a visual interfacing platform, a virtual reality controller and a peripheral physical interface. The visual interfacing platform is mainly composed of an oculus rift which include a head tracker and a stereo double screen. The virtual controller consists of the processing unit which simulate the interaction of the virtual environment and renders the 3D scene. The main processing algorithm for the simulation and rendering will be based on the unity engine. The physical interface include an IMU, a servo and a drum stick serve as the base physical structure of the peripheral hardware.

The final goals of the system include:

- Drumstick motion tracking with IMU
- Visually feedback the drumstick position in the virtual environment
- Recalibration of IMU with optical feedback
- Simulation of drumstick motion in virtual reality
- Physical (vibration) feedback of the interaction with the virtual drum
- Target Users – Amateur drummers and VR enthusiasts
- Target price - $200 (not including the cost of an oculus rift)

3. Technical Specifications

Table 1. Quantitative Specifications

Virtual Reality Headset (Rift DK2)	
Optics/Visuals	
Screen Resolution/Type	1920 x 1080 pixel low persistence AMOLED display
Nominal Field of View (FOV)	100 degrees
Output Interface	DVI/HDMI
Head Tracking	
Rotational Tracking	3 Degrees of Freedom (DOF) provided by Inertial Measurement Unit (IMU)
Positional Tracking	3 Degrees of Freedom (DOF) provided by optical tracking camera
Update Latency	<20 ms
Power Supply	5 V over USB
Weight	379 g
Base Station PC	
Operating System	Windows-based
Drumstick Peripheral Device	
Microcontroller	ARM Cortex-M3
Inertial Measurement Unit (IMU)	
Supply Voltage	2.1 - 3.6 V
Bus Interface	I2C

Degrees of Freedom	3 DOF from ADXL345 Gyroscope 3 DOF from ITG-3200 Accelerometer
Gyro Full-Scale Range	+/- 2000 degrees/sec
Accelerometer Measurement Range	+/- 16 g
Gyro ADC Resolution	16 Bit
Accelerometer ADC Resolution	10 Bit
Wireless Telemetry Link	
Supply Voltage	3.3 V
Protocol	Xbee/IEEE 802.15.4
Transmitter Power	1 mW
Point-to-point Range	100 m

4. Design Approach and Details

4.1 Design Approach

The AiR Drums system consist of three hardware components: a virtual reality headset, a base station laptop computer, and the drumstick peripheral device. The block diagram below visualizes these components with respect to the AiR Drums system as a whole.

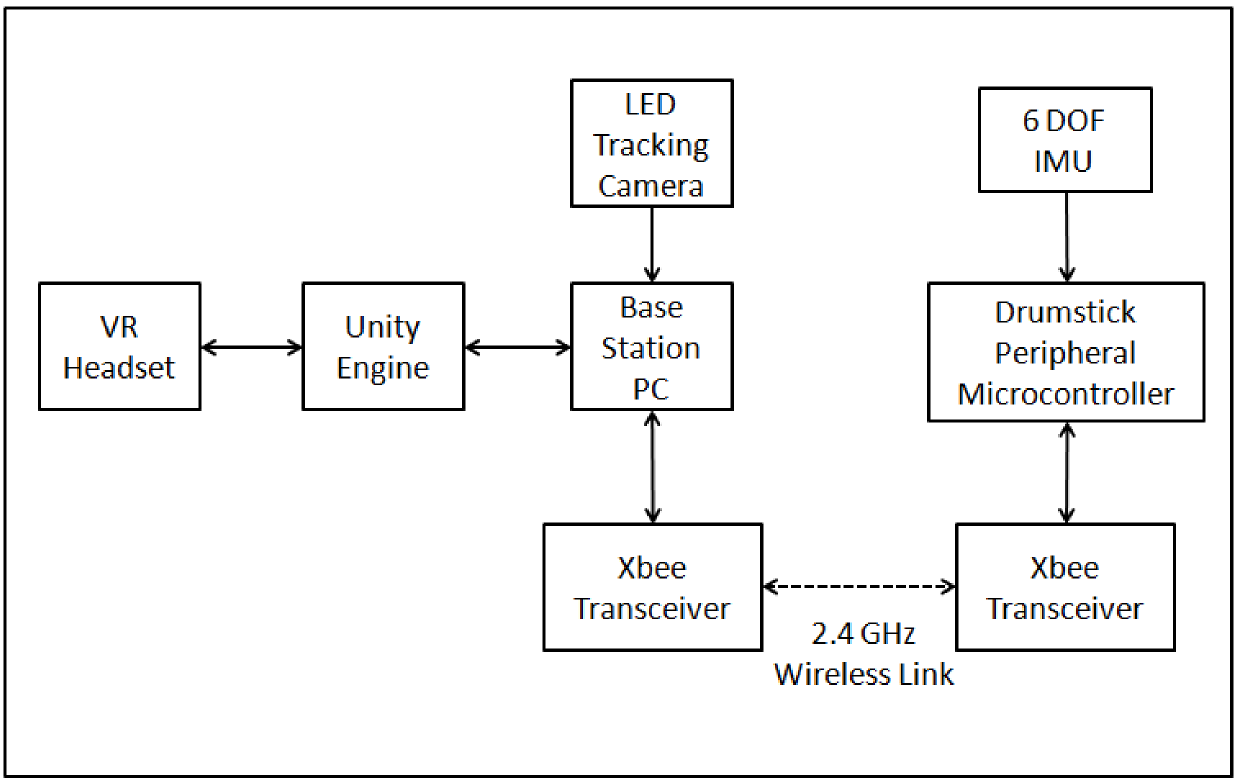

Figure 1. Functional block diagram of the AiR Drum system.

4.1.1 VR Headset

The system will leverage an Oculus Rift Development Kit version 2 (DK2) to present an immersive 3-dimensional virtual environment to the user. The Oculus DK2 is equipped with an IMU consisting of a 3-axis accelerometer, 3-axis gyro, and 3-axis magnetometer to measure the rotational orientation of the user's head [2]. Additionally, positional tracking is provided via an IR camera attached to the Oculus DK2 unit. This allows the Oculus VR system to provide full 6 Degrees-of-freedom (DOF) head tracking. The IMU sensor data will be processed by the Oculus SDK in conjunction with the Unity game engine to produce and display a virtual environment via the Oculus Rift's stereoscopic screen, which will respond to the user's head motion during operation.

4.1.2 Unity Engine

In order to reduce development time and ensure tight integration with the Oculus Rift VR headset hardware, the Unity engine will be used to render the virtual environment and process the Oculus Rift IMU data to visualize head motion. Additionally, custom modifications will be performed to the Unity engine to allow it to interface with the drumstick peripheral device, and handle the data stream from the drumstick's controller [3, 4]. This data will be used to localize the position and orientation of the drumstick in 3D space, and render the peripheral in the virtual environment for display to the user. Lastly, the real-time drum sound synthesis and positional audio will be implemented directly in our Unity application.

4.1.3 Base Station PC

By virtue of the Unity engine, the software application for the AiR Drums virtual environment can be cross platform, with minimal hardware requirements. At this time, we have decided upon developing a Windows-based Unity application, hence the primary requirement is that the base station computer use a Windows operating system [5].

4.1.4 LED Tracking Camera

The AiR Drums implement a computer vision recognition system to track the position of the drumstick peripheral in 3D space. LEDs will be mounted on the body of the drumstick, in order to provide reference points to the camera and the tracking system. This aspect of the system is intended to complement the IMU-based dead reckoning for the drumstick peripheral's position, and in particular compensate for shortcomings in IMU-based tracking such as accumulated drift and measurement error. By using a camera in conjunction with hue-recognition or similar computer vision algorithms, an absolute position can be determined for the drumstick which will allow the system to automatically correct for IMU drift errors during normal operation. It is important to reiterate that this method of drumstick positional tracking will likely not be sufficient to completely replace the IMU, and it is intended to assist the dead reckoning which will provide the primary estimation for the drumstick's position. The AiR Drum system will automatically perform recalibration of the drumstick's IMU using the vision-estimated position at regular intervals. The vision-estimated position will be transmitted to the drumstick peripheral to allow the unit to integrate the correction into the dead reckoning calculations.

4.1.5 <u>Drumstick Peripheral Device</u>

The drumstick device will be a fully encapsulated embedded system responsible for performing dead reckoning of its orientation using the sensor inputs from its IMU. The drumstick IMU will allow 6 DOF rotational tracking by performing dead reckoning on the sensor data from an ADXL345 accelerometer, and an ITG-3200 inertial gyroscope. The primary controller used in the drumstick peripheral will be an mBed (ARM Cortex-M3), and the IMU will interface with the controller via an I2C bus connection. The mBed system-on-chip (SoC) platform will be responsible for filtering the sensor data inputs to produce a smoothed position and orientation estimate. This data will be packetized for transmission over an attached XBee Series 1 Transmitter to the base station PC, and subsequently processed by the Unity engine [6, 7]. The drumstick peripheral will be powered by a rechargeable battery, however as of yet the specifics of this power source have not been determined. Additionally, the drumstick controller will be responsible for correcting its estimates using vision-estimates from the base station performing the camera recognition processes. On a related note, the drumstick peripheral will be equipped with several multicolored LEDs to aid in the corrective camera recognition of the drumstick’s position and orientation. Lastly, the drumstick will make use of motors or solenoids to produce haptic feedback to simulate the impact of collision between the drumstick and a virtual drum. In order to ensure the drumstick is portable and unhindered by wiring, a rechargeable battery will be used to provide a power source for the peripheral’s electronics [8].

4.2 Codes and Standards

1. The IMU accelerometer and gyro make use of the Inter-Integrated Circuit (I2C) protocol to allow serial communications to the mBed. Both devices are actually joined on a shared I2C bus, and the device addressing built into the protocol allows master-slave based data transfer. We plan to run the I2C bus at the protocol mandated standard speed of 400 kHz.
2. The XBee protocol, codified as the IEEE 802.15.4 wireless standard, will be used to transmit the IMU telemetry from the drumstick peripheral to the base station computer. The XBee standard allows communication on either the 868-868.8 MHz, 902-928 MHz, or 2400-2483.5 MHz band using Direct Sequence Spread Spectrum (DSSS) modulation.

4.3 Constraints, Alternatives, and Tradeoffs

As an alternative to implementing wireless communication between the drumstick peripheral and the base station, wired communication allows an easy and direct link [9]. This would dramatically reduce the efforts required in order to interface the drumstick peripheral with the base station, however the identified tradeoff includes a loss in freedom of movement. As the AiR Drums system attempts to provide a realistic simulation of a drum kit, the unhindered mobility afforded by a wireless setup is preferred.

Another alternative to the Oculus Rift DK2 kit that was considered during initial design involved the use of cheaper VR headset platforms such as the Google Cardboard kit [10]. These would dramatically lower the cost of the system, and eliminate the need for independent wireless transceivers as they would be integrated into the smartphone platform in the form of bluetooth radios. However, as the bulk of the project effort was predicted to be in the software development stage, the decision was made to opt for the Oculus Rift DK2 as the platform is directly supported by the Unity engine. Additionally, we could retain the use of a cheaper VR kit such as Cardboard through Unity's ability to deploy to mobile platforms in addition to PC [11].

5. Schedule, Tasks, and Milestones

The design team is divided into two subteams, hardware and software, for the development of the product. Appendix A contains the list of all the major milestones, the person(s) assigned to those tasks, and their related risk level. Appendix B contains the entire Gantt chart with the breakdown of specific tasks and their associated timelines, start date, end date and duration. Significant milestones occur in the middle of March and April, with the completion of the initial hardware and software designs, respectively. The hardware implementation of the project is scheduled to be completed by end of February to provide a stable development environment for the software development. Following this point will be testing and debugging and working on project demonstration and final presentation.

6. Project Demonstration

The system is designed to be portable and can be demonstrated in any classroom. During the demonstration, the user will interact with the virtual drumming environment and receive corresponding the visual, audio and physical feedback from the system. The demonstration will include the validation of the following fundamental feature of the system.

Drumstick motion tracking with IMU

The user will move the drumstick and the tracking data received from the Xbee transceiver will be displayed on the processing PC, verifying the rotation and acceleration data from gyro and accelerometer.

Visually feedback the drumstick position in the virtual environment

The user will put on the oculus rift and move the drumstick. The drumstick in the virtual environment moves accordingly.

Recalibration of IMU with optical feedback

The user will put on the oculus rift and hold the drumstick still in front of him/her for around 30 second. The drumstick stays still in the virtual environment. Then the user will wave the drumstick from left to right for 10 times and move the drumstick back to front. The position of the virtual drumstick should change accordingly while waving and return to the initial front position at the end [12].

Simulation of drumstick - drum interaction

The user will hit the virtual drum with the drumstick. The processed data will be displayed on the processing PC indicating the drum number hit and the interaction state.

Physical (vibration) feedback of the interaction with the virtual drum

When the user hit the virtual drum with the drumstick. The physical drumstick will vibrate as the virtual drumstick make contact with the drum.

Real-time drum sound synthesis

The user will put on the head phone and hit two different drum at the same time. The process data will be displayed, indicating the drum number hit and the user will hear the sound of the two drum mixed.

7. Marketing and Cost Analysis

7.1 Marketing Analysis

Immersive virtual reality(VR) systems rely on technology that submerges the perceptual system of the user in computer-generated stimuli[13]. There are many gaming products on the market which allow the user to visualize the game world as a normal world. Current gaming VR products use consoles to interface with the virtual world. AiR Drums is a unique concept that is different from current gaming products in that the actual human motions are detected and interfaced with the virtual environments to provide a truly immersive VR experience. The target market for this product will be musicians and VR enthusiasts.

7.2 Cost Analysis

The estimated total development cost of the prototype is $515.55. Table 2. shows the breakdown of the material costs of the prototype. The most expensive equipment is the Oculus Rift, but it is a standalone commodity that must be bought separately [14]. Hence, we remove that cost while calculating the sales price. We include the cost of the Oculus Rift in our calculations since we need to use it for our prototype. The LEDs will be free of cost.

No.	**Product Description**	**Quantity**	**Unit Price (in $)**	**Total Price (in $)**
1.	Oculus Rift	1	350	350
2.	Pixy camera (CMUcam5)	1	80	80
3.	Microcontroller (Arm Cortex M3)	1	15.65	15.65
4.	Inertial Measurement Unit (ITG3200/ADXL345)	1	39.95	39.95
5.	XBEE Trace Antenna	1	24.95	24.95
6.	Drumsticks	2	5	5
7.	Leap Motion - alternative to (2)	1	80	80 (alt)
	Total - (Cost of Oculus Rift)			**165.55**
	Total			**515.55**

Table 2. Cost of Product Components

The Oculus Rift is powered with a 5V USB port. However, the mbed might require an external 5V battery source and is factored into overhead costs. The development costs shown in table 2 were determined with an assumed labor cost of $35 per hour. Fringe and overhead costs are factored into labor costs. They will be amortized over all the units produced. Developing the game engine will require the highest number of labor hours. The audio processing and computer vision component will be the next most complex part of the project.

No.	**Project Component**	**Labor hours**	**Costs ($35 per hour)**	**Total Component Costs**
1.	Planning, Presentation, Documentation	70	$2450	$0
2.	Group Meetings	70	$2450	$0
3.	Virtual Reality - Software Development	100	$3500	$430
4.	Audio Processing	80	$2800	$0
5.	Tracking and Computer Vision	80	$2800	$0

6.	Peripherals and Assembly	40	$1400	$85.55
7.	Testing, debugging and reiterating components	100	$3500	$0
	Total Labor Hours	540		
	Total Labor Costs		**$18,900**	
	Total Component Costs		+	**$515.5**
	Total Labor and Material Costs			**$19415.5**

Table 3. Material and Labor Costs

We consider fringe benefits to be 30% of total labor, sales expenses to be 20% of labor costs and overheads to be 80% of material and labor. This adds to the component and development costs as shown in Table 3.

Component Costs - Oculus	$165.55
Labor Costs	$18,900
Fringe Benefits	$5670
Sales Expenses	$3780
Other Overhead Costs	$15,532
Total Development Costs	**$44,397.9**

Table 4. Total Development Costs

Development costs without the Oculus Rift will be $44,047.9. The production run will consist of 6000 units sold over a 5-year period at a price of $200. The total materials cost of development is $820,000. Using the profit scheme described below, the profit per unit is $63.33 per unit over a period of 5 years.

Sales price per unit	$200
Total sales price	$1,200,000
Total development costs	$820,000
Total profits	$380,000
Profit per unit	$63.33

Table 5. Profit Scheme

8. Current Status

Currently, the team has performed some research on the software and hardware components required to create the product. Each member of the team has written a technical review paper based on a different aspect of the project. All team members have collaborated together on completing in-class activities as well as the project summary, and project proposal. The team has investigated the use of different kinds of game engines, virtual reality devices such as the Oculus Rift and Google Cardboard, and have discussed primary controller choices. The team intends to start building the system from the beginning of Spring 2015 semester.

9. References

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Appendix A

Task	Task Lead	Risk Level	Start Date	End Date	Duration
Planning, Presentation and Documentation	All	Low	15-Oct-14	2-May-15	199
UPDATE & SUBMIT PROJECT PROPOSAL	All		12-Jan-15	12-Jan-15	0
FINISH PROJECT PRESENTATION (TBD)	All		24-Apr-15	24-Apr-15	0
DO PROJECT DEMONSTRATION (TBD)	All		27-Apr-15	27-Apr-15	0
SENIOR DESIGN EXPO	All		30-Apr-15	30-Apr-15	0
Technical Review Paper	All	Low	15-Oct-14	27-Oct-14	12
Project Proposal	All	Low	25-Nov-14	4-Dec-14	9
Parts Ordering	Justin, Jingyan	Medium	12-Jan-15	19-Jan-15	7
PDR Presentation	All	Low	23-Mar-15	30-Mar-15	7
Final Project Presentation	All	Low	13-Apr-15	27-Apr-15	14
Final Project Demonstration	All	Medium	27-Apr-15	4-May-15	7
Final Project Report	All	Low	13-Apr-15	30-Apr-15	17
Peripherals and Assembly	Justin, Jingyan	High	20-Jan-15	20-Feb-15	31
FINISH IMU & WIRELESS IMPLEMENTATION	Justin, Jingyan		20-Feb-15	20-Feb-15	0
COMPLETE DRUMSTICK ASSEMBLY	Justin, Jingyan		25-Feb-15	25-Feb-15	0
Interface IMU with microcontroller	Justin, Jingyan	High	20-Jan-15	27-Jan-15	7
Develop wireless link between basestation PC and Drumstick	Justin, Jingyan	Medium	27-Jan-15	3-Feb-15	7
Finalize assembly of drumstick electronics	Justin, Jingyan	Medium	3-Feb-15	10-Feb-15	7
Integrate passive recalibration of IMU utilizing CV recognition	Justin, Jingyan	Medium	10-Feb-15	17-Feb-15	7
Audio Processing	Shurjo	High	20-Jan-15	20-Feb-15	31
FINISH REAL TIME AUDIO FILTER	Shurjo		24-Feb-15	24-Feb-15	0
Processor receiving data from Drumsticks	Shurjo	Medium	20-Jan-15	27-Jan-15	7
Processing the received data	Shurjo	Medium	27-Jan-15	3-Feb-15	7
Real time synthesis of drum sound	Shurjo	High	3-Feb-15	10-Feb-15	7
Audio signal testing	Shurjo	Medium	10-Feb-15	20-Feb-15	10
Tracking and Computer Vision	Pujun, Qisi	Medium	20-Jan-15	24-Feb-15	35
FINISH IMPLEMENTING TRACKING ALGORITHM	Pujun, Qisi	Medium	7-Mar-15	7-Mar-15	0
Mounting pixy camera to Oculus Rift	Pujun, Qisi	Low	20-Jan-15	27-Jan-15	7
Interfacing camera with microcontroller	Pujun, Qisi	Low	27-Jan-15	3-Feb-15	7
Mounting colored LEDs on Drumsticks	Pujun, Qisi	Low	3-Feb-15	10-Feb-15	7
Hue Tracking algorithm for tracking LEDs	Pujun, Qisi	Medium	10-Feb-15	17-Feb-15	7
Algorithm for passive recalibration of IMU using optical feedback	Pujun, Qisi	Medium	17-Feb-15	24-Feb-15	7
Virtual Reality Software using Unity	Justin, Mallika, Pujun	High	20-Jan-15	15-Apr-15	85
FINISH 3D ENGINE PROTOTYPE	Justin, Mallika, Pujun	High	30-Mar-15	30-Mar-15	0
Installing Unity and SDK Dev Environment	Justin, Mallika, Pujun	High	20-Jan-15	27-Jan-15	7
Constructing 3D models for drums and drumsticks in Unity	Justin, Mallika, Pujun	High	27-Jan-15	10-Mar-15	42
Implementing 3D collision detection using graphics engine	Justin, Mallika, Pujun	High	10-Mar-15	17-Mar-15	7
Algorithm to account for real time interaction between drums and drumsticks	Justin, Mallika, Pujun	High	1-Apr-15	7-Apr-15	6
Sending collision feedback for Audio Processing	Justin, Mallika, Pujun	Medium	7-Apr-15	15-Apr-15	8
Sending heptic feedback to drumstick	Justin, Mallika, Pujun	Low	7-Apr-15	15-Apr-15	8
Improvements	All	Medium	20-Apr-15	1-May-15	11
Contingency Planning	All	High	21-Feb-15	15-Mar-15	22
FINISH LEAPMOTION CONTROLLER IMPLEMENTATION	All	High	10-Apr-15	10-Apr-15	0
Limit hue based tracking of drumsticks	Pujun, Qisi	High	21-Feb-15	28-Feb-15	7
Use Google Cardboard and open source API for graphics generation	Mallika, Justin, Pujun	High	1-Mar-15	8-Mar-15	7
Use simple sounds for components of drumset	Shurjo	High	8-Mar-15	15-Mar-15	7

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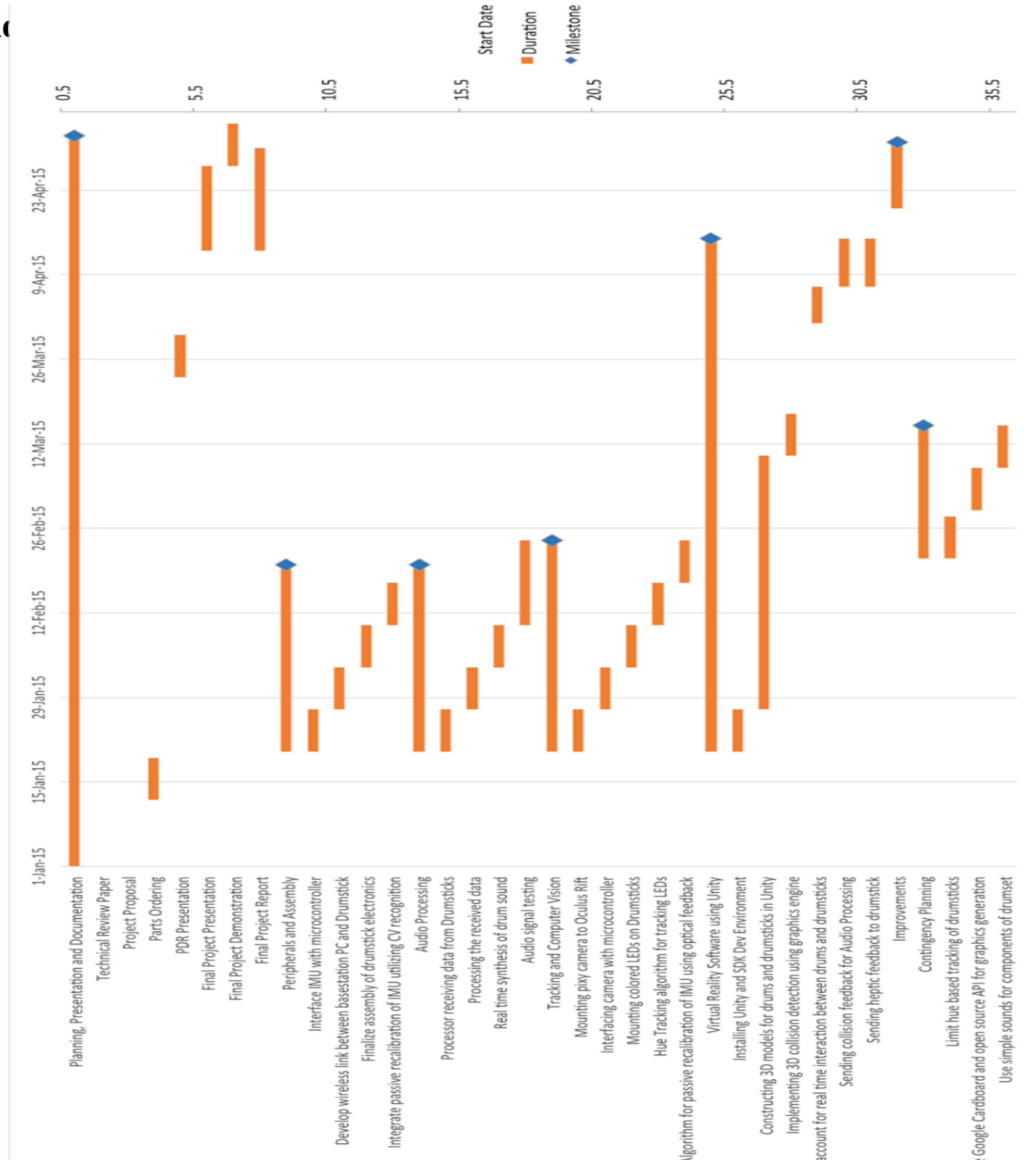

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