

ARK: MDR Report

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Abstract—Augmented reality is combining a real environment with computer generated sensory data, such as images and sounds, to create an experience that is different from pure reality. Some video games have been based off of augmented reality technology, but can only incorporate data captured by a camera into the augmented world. Augmented Reality Kick (ARK) is a gaming peripheral and Android app that will allow data from a user's extremities to be incorporated into an augmented environment without the use of a camera. A virtual reality headset holds a phone in front of a user's face while running the ARK app. The app itself displays what the rear camera can see, and overlays a virtual ball and net in a suitably flat area. Utilizing an inertial sensor on the foot, a user can then kick the virtual ball into the net to score points.

I. INTRODUCTION

THE core of this project is augmented reality (AR). AR is the dynamic response of a computer to its environment. Using computer vision or object recognition, a computer “augments” the world it sees, most commonly through overlaid sounds and visuals. A user requires goggles or a screen to use this technology, similarly to Virtual Reality (VR). These are not to be mistaken however, as VR completely constructs and controls the user's visual world. AR is constrained by the user's immediate surroundings and must process and react to the changes in them [1].

AR is of growing popularity among tech companies, particularly Microsoft, Google, Apple. While Microsoft has the standalone HoloLens product, Apple and Google have primarily focused on mobile phone integration. Both have developer-supported AR platforms (ARKit and ARCore, respectively) which enable developers to utilize tools within smartphones that detect and track surfaces, as well as placing models on them [2], [3], and [4].

The potential for gaming with AR has been demonstrated by the massively popular and successful *Pokemon Go!* Released by Niantic in 2016 [5]. As of July 2017 it has been downloaded almost 10 million times. The premise of this game is that as the user walks around in real life, they can find and catch virtual pokemon with their smartphone.

One major limitation of this gaming setup is the lack of a controller. Currently there are no peripherals for augmented reality on smartphones outside of the headsets users wear. When a user is wearing a smartphone on their face, they cannot interact with its touchscreen, which means that the inputs for controls have to come from onboard sensors such as an accelerometers or GPS units. It follows that since the phone is

attached to the user's head, it can only follow the direction or position of the head, and cannot sense the extremities without seeing them with the camera. It is proposed that inertial sensors allow for movement of extremities to be sensed, recorded, and acted upon.

Inertial sensors have been used before in gait reconstruction and limb tracking [6], [7], and [8]. The applications of this technology have proven useful in physical training, whereby trainers and physicians examine how a person moves their body, but with more detail than a visual inspection. As shown by Thiel et al. [9], the use of inertial sensors can demonstrate a congruence between the lateral tilt of a ballet dancer's torso and lower scores from judges. Such observations can also be used in physical therapy; when an injured person demonstrates motion to a doctor, inertial sensors can provide indicators of strong or weak healing of muscles or tendons.

Our goal is to meld inertial sensing with AR technology in smartphones. In this sense, we wish to immerse the user in a game via AR, and substitute a conventional controller or controllers with inertial sensors on the foot. The sensors will collect data about the foot movements of the user, and interpret the data as a kicking input to our soccer-based app.

For an inertial sensor to be used in a more active environment, some requirements must be met. The sensor package must fit on a user's shoe, without overhanging so much as to trip the user or become damaged from clipping an object. The sensor package must also be lightweight, as too much weight on a user's foot can upset their balance or become outright uncomfortable. Lastly, the system must last a long enough time on a single charge for a user to have multiple sessions using the device. Below are the requirements, quantified:

TABLE 1
SENSOR PACKAGE REQUIREMENTS

Requirement	Specification
Maximum Dimensions	5 in. L x 4 in. W x 2 in. H
Weight	< 1 lb.
Battery Life	> 5 hours/charge
Sufficient Delay to Retain Immersion	< 100 ms from movement to game
User Friendly Design	User does not need to ask many questions to use, has short manual

II. DESIGN

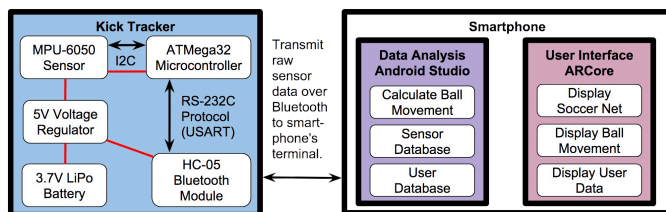


FIGURE 1. BLOCK DIAGRAM.

To create a sensor package as described previously, referred to from here on out as the “kick tracker,” we will need a few core devices, as introduced in the block diagram in Figure 1. These include an inertial sensor, a microprocessor, a wireless module, a voltage regulator, and a battery. These components will be described in further detail in the following blocks.

To start, it was necessary to consider what data we would need to represent the kicking motion. Acceleration data can be used to determine whether one is kicking or not. To deduce more information about a kick, we require the use of a gyroscope. With these two components, we will be able to determine what type of kick the user has made, and reflect this in-game.

Acceleration and rotational data must be pulled constantly from the inertial sensor. There are multiple possible protocols through which this could be implemented. We initially tested with analog sensors, due to the simplicity of interfacing with them. However, other possibilities include Serial Peripheral Interface (SPI) and Inter-Integrated Circuit (I²C), both of which output sensor data in a digital format [10]. We have decided to use I²C, because although both protocols are quite similar, I²C makes sense for our purposes because it uses a single data line, which SPI does not. Since we are only receiving data from the sensor and not transmitting to it, it is a simpler setup. Our current sensor [11] will output 16-bit datagrams to be sent to the processor.

From the processor, we will use Bluetooth LE (BLE) to transfer the data from the sensor to the phone [12]. While WiFi is also an option, it is important to note that this would limit usability, as it requires a network. Bluetooth allows the user to connect the kick tracker directly to their device. Additionally, the latency of the BLE data transfer is as low as 3ms [13]. Given our need for end-to-end latency to be <100ms in order to retain user immersion, this allows plenty of flexibility in additional processing time, while still staying below our delay cutoff.

For the purpose of our virtual game, we quantify what constitutes a kick. This includes setting acceleration thresholds to determine the strength of a kick, as well as using the pitch, yaw, and roll to determine what kind of kick the user is trying to execute. Each piece of data must be compared to these profiles and match with one in order for a kick to happen. Once a piece of inertial data has been transferred to the phone, these comparisons occur as shown in the Data Analysis portion of Fig. 1. At that point, user movement will result in movement of the virtual ball if our system determines that a user has performed a sufficient kick.

All of this needs to be displayed on a smartphone in a generic AR headset. Given advances in AR from both the iOS and Android communities, either option would have been suitable for our end product, but we have chosen to work with the Android OS given our accessibility to AR-capable devices as well as its higher global market share. Fig. 1 shows the intended information to be provided to the user in the User Interface section.

A. Inertial Sensor

The most fundamental piece of hardware is the inertial sensor. Our design will include an Adafruit sensor known as the GY-521 MPU-6050, an inexpensive, thin, and low-powered chip that consists of both a triple-axis accelerometer and a triple-axis gyroscope, as acceleration data and rotational data are essential to our data processing [11]. The digital output accelerometer built into this sensor can measure a full-scale range of $\pm 2g$, $\pm 4g$, $\pm 8g$, and $\pm 16g$. The digital output gyroscope also contains a user-programmable full scale range of $\pm 250\text{deg/sec}$, $\pm 500\text{deg/sec}$, $\pm 1000\text{deg/sec}$, and $\pm 2000\text{deg/sec}$. This sensor also makes use of three 16-bit analog-to-digital converters (ADCs) for digitizing the gyroscope outputs and three 16-bit ADCs for digitizing the accelerometer outputs. These parts allow for precise tracking of both fast and slow motion. The MPU-6050 has a communication interface of I2C, which allows it to read data from external sensors such as magnetometers. This interface will be used to communicate with our choice of a Microcontroller in our design.

B. Microprocessor

The next piece to our kick tracker is a microprocessor. We have chosen Atmel’s low-power CMOS 8-bit microcontroller ATmega32/L due to its inexpensive cost, its versatility in interfacing, and reasonable size [14]. This processor contains several communication interfaces that will be used for our design which includes I2C and ADC for collecting sensor data from the MPU-6050 sensor, and a serial programmable USART to communicate with the Bluetooth module. This processor is also capable of obtaining a high throughput of up to 16 MIPS (million instructions per second) at a clock rate of 16MHz.

C. Wireless Module

Our wireless interfacing device is the HC-05 Wireless Bluetooth Serial Transceiver, a simple Bluetooth module that provides the link between kick tracker and smartphone [15]. This part is also inexpensive with a USART interface that will allow it to communicate with the ATmega32 processor.

D. Power System

Lastly, we will be powering the system with a 3.7V 18650 lithium ion rechargeable battery cell [16]. These batteries can be purchased inexpensively ($\sim \$5$ to $\$9$ per battery) and contain a nominal capacity typically between 2500mAh and 3000mAh, which is more than enough energy to power our system. Some safety features included within these batteries consist of a safety vent to prevent from an excessive buildup of pressure and a built-in PTC (Pressure, Temperature, Current Switch) to protect against current surges. The battery is contained in a plastic battery storage case that will be enclosed to prevent it from being damaged when attached to the “kick tracker” [17]. These

batteries can also be recharged up to 1200 times. We are using a 3-in-1 functional battery charger that prevents batteries from being over-charged, over-discharged, supplied with too much voltage or current, or short circuited while charging [18].

E. Data Analysis

The data analysis performed on the phone will be executed through Android Studio, which has built-in commands for accessing Bluetooth data. This data can be parsed and sent to be stored to a local file on the phone through Android Studio as well. The most significant component of the data analysis is the calculation of the ball movement, which can be achieved by processing the raw data in by making comparisons between incoming data and predetermined thresholds. A few megabytes of data will be allocated for sensor data storage in order to ensure that all the necessary datagrams to constitute a single kick are updated. Additionally, space will be allocated to store user data in reference to gameplay.

These calculations will occur on the phone itself, so that we can retrieve the raw sensor data from the processor as quickly as possible, then store it until all of the necessary three-axis data has been retrieved.

F. User Interface

Using Google’s ARCore API, we will implement a basic soccer ball/net environment, overlaid on the physical space that the user’s smartphone camera can see from its headset mounting [3]. This system then is best used in a relatively open space, in order to provide realistic depth perception.

While the user will see both the virtual ball and net, as well as their leg if it comes into view, the kicking will not be vision-based. The app’s display of a kick will be entirely based on the input from the kick tracker.

III. PROJECT MANAGEMENT

The following is a table of our proposed MDR deliverables and their completion status at the time of our MDR presentation:

TABLE 2
MDR DELIVERABLES

Deliverable	Status	Team Member
Select and purchase inertial sensor, microcontroller, Bluetooth module, and battery	Completed (except battery)	Matteo & Ethan
Assemble purchased components together	Completed	Matteo, Jackie, Chad, & Ethan
Send data from inertial sensors to phone over Bluetooth	Completed	Jackie, Chad, & Ethan
Display data from sensors in Android App	Completed	Jackie & Chad

In the week following MDR, we were able to address ordering the battery, so now all listed MDR deliverables have been completed.

The first deliverable was accomplished by researching all components in detail and selecting appropriate options for our

project. More details can be found for the components in the design section of this paper. The next deliverable was to assemble all the components onto a breadboard correctly, which we were able to do with ease. The third deliverable was the most challenging of all, which required us to properly receive data over Bluetooth.

The main challenge was with the complexity of the sensor we selected, which used the I2C protocol and also required additional programming. We ultimately realized that this sensor would not be optimal to use with our design and we were able use an analog sensor to complete this deliverable in time for MDR. However, an analog sensor is not ideal for this system so we will be using a simplified I2C sensor instead. We will need to interface with this new I2C sensor by the beginning of the spring semester. The last deliverable was achieved by creating an Android app that could sample the analog data and use it to create a real time graph. The data was displayed in three separate charts, one for each axis, and displayed realistic data from the analog sensor according to how it was moved in real time.

TABLE 3
CDR DELIVERABLES

Deliverable	Member
Augmented reality must be implemented to show soccer goal and soccer ball	Jackie
Backend of app must store sensor data, model data to analyze foot movement	Chad & Ethan
Kick accuracy measurement	Ethan
Design PCB, send for fabrication	Matteo
Design foot mount structure and enclosure	Matteo

Our proposed CDR deliverables are listed in Table 3. These deliverables are also displayed chronologically in a Gantt chart shown in Figure 2. The team will be separated as follows so that the team members with strongest software abilities will be working with the app, and the team members with the strongest electrical and mechanical backgrounds will be working on creating the physical device and packaging it so that it can be attached to one's foot.

Jackie and Chad, who have the strongest background in software, will be focused with programming the augmented reality and backend data management of the app respectively. Ethan, who is strong in both software and hardware, will be assisting Chad with the backend of the app and will also be working on testing the device for accuracy. Matteo, who is the strongest with electrical and mechanical components and wiring, will be devoted to working on the PCB and physical structure of the device. Our team communicates each week for one hour with our adviser and together for about one hour without our adviser.

Assignee	Task	Start	Bench			Bench	CDR		Break	Bench			FDR	
		Jan. 22	Jan. 29	Feb. 5	Feb. 12	Feb. 19	Feb. 26	Mar. 5	Mar. 12	Mar. 19	Mar. 26	Apr. 2	Apr. 9	Apr. 16
Matteo	Design, Order PCB													
Jackie	Develop App, Soccer Goal													
Chad	Develop App, Backend													
Ethan	Integrate Sensor w/Backend													
Matteo	Design Foot Mount, 3D Print													
Jackie	Develop App, Soccer Ball													
Chad	Develop App, UI													
Ethan	Assess Accuracy of App													
Matteo	Assemble PCB, Foot Mount													
Jackie	Develop App, Motion Accuracy													
Chad	Develop App, Motion Accuracy													
Matteo	Assess Accuracy of App													
All	Final Integration of System													

FIGURE 2. GANTT CHART.

IV. CONCLUSION

After PDR, there was a redirection in the the aims of the project. It was initially intended that an omnidirectional treadmill for use in VR would be created, but it proved infeasible to innovate on given the current number of existing solutions and variety of implementations. It was therefore decided to change the direction of the project from VR to AR, with the intent on overcoming the obstacle of creating a controller. After some investigation, the use of inertial sensors for research purposes was discovered. Originally used for gait reconstruction or motion analysis on dancers, it was clear that there was an ability to extrapolate information from this form of sensing.

Given our project-changing PDR, we hope to make rapid progress in the initial weeks of spring semester. We plan on making the prototype portable and attaching it to the foot, collecting data in January so that we can create the motion mappings as soon as possible. The most difficult part of the project is expected to be the dynamic detection of the kicks. While it could be relatively trivial to have a small set of possible ways to kick the ball (e.g. high, mid, low), ideally we would like to have a system that responds as much as possible to the user’s foot. What we are attempting to discover is the limit of extrapolation from a single inertial sensor in tandem with a camera for location detection. We do not yet know how feasible it will be to discern the angle of a foot mid-kick, or how similar a small punt might look like a normal stride. The only way we can find out is by getting the sensor on-foot as soon as possible and seeing what data we can collect from it.

Part of the design philosophy behind sending the inertial data directly to the phone is that modern smartphones are incredibly capable devices, and have much more power and versatility in the calculations they can perform than any microcontroller. This in turn allows us the flexibility to decide exactly how our data will be processed without having to worry about the limitations of our processor on the foot.

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