# Final Project Writeup: Self-Reporting Dice

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## Abstract

Playing tabletop games remotely with other players can lack the enjoyment of playing together in a shared space due to the virtualization of required game components, such as dice. We propose and have developed working prototypes of a die that self-reports the face-value of its rolls and a linked partner die that automatically displays the communicated results. These dice would allow tabletop game players who are unable to play together locally to have a more engaging experience when playing over the internet. Additionally, we review current research in the field that supports our proposed solution.

## Author Keywords

Dice; Tabletop Gaming; Orientation Sensors.

## ACM Classification Keywords

H.5.m [HCI]: Miscellaneous

## Introduction

Recently there has been a rise in popularity of tabletop gaming, ranging from board games to role-playing games. Typically, tabletop games must be played in a shared space, but this has not prevented players from attempting to play remotely with their friends. Currently, this is most often solved with a webcam and random number generator. However, for the player who must rely on these methods to be a part of the game, their game experience is diluted: they miss out on the interactions that come with sitting in the same room with friends and playing together.

Players in this situation often try to improve their game experiences by rolling their own physical dice, but this only further complicates the situation. The die roller must self-report their roll results to their fellow players as opposed to having the random number generator post it for all to see. This adds one additional step to the process of play, which seems small, but given the number of rolls that can take place during one session of play, the time lost will add up swiftly. The self-report is also vulnerable to fabrication; in a critical moment, a player whose dice rolls cannot be seen may lie about their results, changing the outcome to suit their needs. Without the automated self-report to keep all players honest, there might be a degree of cheating that arises from some players.

We sought to make tabletop gaming a more engaging and efficient experience when one or more of the game's players are playing together via an internet connection. In particular, we wanted to improve the experience of dice rolling in tabletop role-playing games. We created a pair of dice, called the self-reporting dice: a player can roll a physical die that sends roll results over the internet, and these results can then be received by a paired die to show the die roll to other players remotely. Our solution retains the tactile experience of dice rolling.

## Related Work

*Virtual & Augmented Gaming*

Several consumer software products attempt to address the problem of playing tabletop role-playing games remotely [1]. However, these only offer a digital environment to play in. Tabletop games are enjoyed in part due to their physical nature: the tactile feedback given in these games, such as a player moving game pieces or rolling dice, can enhance the game experience [2, 6].

Previous research has been conducted to determine ideal ways to augment physical games with digital environments. For example, Hinske et al.'s work involving the tabletop miniatures game Warhammer 40K used digital information collected from natural play to automate some of the more mundane game mechanics, such as determining line of sight for a unit [2]. They also developed augmented dice with RFID tags to automatically determine the roll result, but RFID dice have their limitations: one of the drawbacks is the necessity to use an external sensor, which limits the space a player can roll the dice [3].

Magerkurth et al. have also investigated how to augment the act of rolling dice with the Smart Dice Cup [6]. The Smart Dice Cup mimics the act of shaking dice in a cup and revealing the outcome, such as for the game Yahtzee. An accelerometer detects the shaking motion, which activates the random number generator. Additionally, LEDs on the Smart Dice Cup light up to indicate the roll result. However, the physicality of the dice is lost, as they have become digitized and replaced with a single cup.

*Orientation Sensing*

Orientation sensing technology can allow for a handheld object to report its positioning to a user. While limited research has been conducted about orientation sensing for dice in particular, a great deal of research has been done in regards to orientation sensing technology and its application for smartphone use. Most prominently in this area, smartphone orientation sensors are being explored as potential control mechanisms for the phone, allowing the user to perform tasks by shifting the position and angle of their phone. Specifically, its application as a form of authenti-



**Figure 1:** A standard D20.

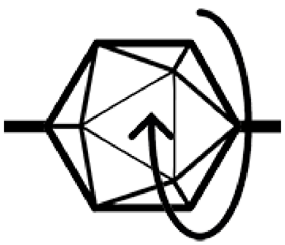

**Figure 2:** First axis of rotation.

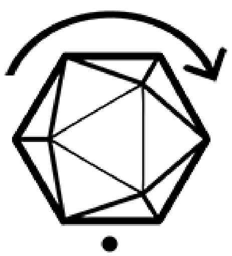

**Figure 3:** Second axis of rotation. Cross-section of axis is illustrated with dot.

cation has been a popular subject with several proposed methods having been put forward [4, 5]. These studies have claimed a high degree of precision from the orientation sensor's readings: the sensors could detect unique subtleties in a user's hand and wrist motion, such that they were able to tell two users apart who performed the same gestures.

Concepts for tracking orientation sensor positioning via the internet have also been proposed. Uhchikoshi et al. have created a method of tracking a smartphone' s location from data provided by a smartphone's orientation sensor and camera and transmitted via wi-fi, allowing users to reclaim a misplaced phone. Difficulties exist when executing this method in real-time however, due to the pronounced processing cost [7].

## Proposal

At the start of this project, we proposed an internet-connected twenty-sided die, or D20 (see Figure 1), that would send its roll outcome via wi-fi. This information would be sent to a paired D20 that would be rolled to match the other D20's outcome. The D20 was chosen due to its iconic status in role-playing games like Dungeons & Dragons: typically D20 rolls determine the outcome for major events in the game. For clarity, we will refer to the first D20 as the *wi-fi die*, and the other as the *display die*.

The wi-fi die would contain an absolute orientation sensor, a Photon, and a battery. The orientation sensor would integrate data from an accelerometer, magnetometer, and gyroscope to determine the orientation of the die. The Photon would process the orientation sensor data to indicate what side the D20 landed on, and it would also send this data using the Particle Cloud. The battery would power the Photon in order for the wi-fi die to be wireless.

A node.js server would be used as an intermediary between the wi-fi die and the display die. When the server receives the final die roll result from the wi-fi die, this information would be then sent to the display die via serial port.

The display die would consist of a 3D-printed D20 moved around by two stepper motors. The stepper motors would serve as external forces to automatically re-position the D20 so that the rolled side is facing upwards, in order to indicate what the wi-fi die landed on. One stepper motor would rotate the D20 around an axis through two opposing points of the die (see Figure 2). The D20 would appear like it is suspended in air, as we intend to use a clear material, such as acrylic, for the motor axle. The D20, stepper motor, and axle supporting the D20 would then be attached to a platform. The platform would have a stepper motor built into it that would be capable of rotating the entire platform. This gives the D20 a new axis of rotation (see Figure 3). With these two rotation axes, it would be possible to spin any side of the D20 to face upwards.

To indicate activity on the wi-fi die side, the display die would randomly spin around and then eventually land on the wi-fi die's outcome. This action would help the user of the display die know when to pay attention to the display. Furthermore, it helps to mimic the typical characteristic of randomness inherent in all standard dice. The stepper motors would be controlled by a motor shield attached to an Arduino. The motors would be powered by a wall power adapter, due to the amount of power the two motors would require to run.

We planned to take the following steps in order to successfully implement our project. The steps for the wi-fi die and the display die would be completed in parallel:

*Wi-Fi Die*

1. Wire orientation sensor and battery to Photon.
2. Test and calibrate the orientation sensor.
3. Solder internal components for smallest form factor.
4. Design a D20 case that houses internal components.
5. Prototype D20 cases to check for proper size and durability.
6. 3D print the final D20 case and integrate internal components.
7. Collect data to determine what orientation information corresponds to which side of the D20.
8. Test sending this data to the node.js server.

*Display Die*

1. Wire stepper motors to Arduino.
2. Test the stepper motors.
3. Test commands sent to Arduino via serial port for controlling the stepper motor positions.
4. Build and test first axis of rotation rig that is directly connected to D20.
5. Build and test second axis of rotation platform that supports the first axis rig.
6. Test sending actual data from wi-fi die to display die and displaying the correct output.


**Figure 4:** The wi-fi die.

## Implementation

The dice we created match with what we initially proposed to develop.

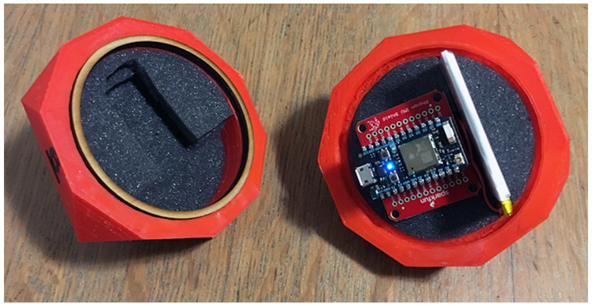

**Figure 5:** The contents of the wi-fi die.

*Wi-Fi Die*

The circuit inside the wi-fi die consists of a Photon, a SparkFun IMU shield, a SparkFun Photon battery shield, and a 3.7V battery. Since all of the circuit pieces already had headers soldered to them, no additional soldering was necessary.

The die container is composed of 3D printed PLA filament (see Figure 4). It is approximately 11 cm in diameter in order to house all the circuit components. We filled the remaining space inside of the container with foam to provide padding for the circuit when the die is rolled. Since the battery must be recharged, the die can be re-opened for easy access to charge the battery via the Photon (see Figure 5). When the die is closed, a wooden ring acts as a lip to secure the two halves of the die together.

The firmware on the Photon sends relevant sensor information to the Particle cloud. Particularly, it sends 3-axis gyroscope data for angular velocity measures as well as 3-axis absolute orientation data, calculated from the 3-axis accelerometer and 3-axis magnetometer values. Readings are sent every second to a node.js server.

*Node.js Server*
The node.js server handles receiving the orientation readings from the wi-fi die via the Particle cloud and translates these values to the corresponding die side that was rolled. To determine the mapping between orientation data and die sides, we collected approximately 50 orientation data points for each of the 20 sides of the wi-fi die once the circuit was placed inside the container. Ranges for each side's pitch, roll, and heading values were determined from these measurements. We use these minimum and maximum values as thresholds for categorizing a measure sent by the wi-fi die. The average of 3 readings is calculated to determine if a side has been rolled. Any averages which do not fall into one of the 20 sets of data ranges are not categorized as a side.

To ensure orientation readings are only used to determine a side when the die is stationary, we also collect angular velocity data from the wi-fi die. We calculated the standard deviation of approximately 50 gyroscope readings when the wi-fi die was at rest. We then used this value as a threshold to differentiate between when the die could be considered rolling and when it most likely was finished rolling.

Once a side has been determined, this side value is then sent to the display die via a serial port connection. The server also sends a flag for when the die begins to move, based on the gyroscope readings.

*Display Die*
The display die is also made from 3D printed PLA filament and is approximately 3 cm in diameter. It is surrounded by a laser cut acrylic support system for the two stepper motors that enable the die to be rotated (see Figure 7). We used a clear material in order to increase visibility of the die. The die spins around a wooden dowel. A 12V 32-step unipolar stepper motor with a 1/16 reduction gear set spins

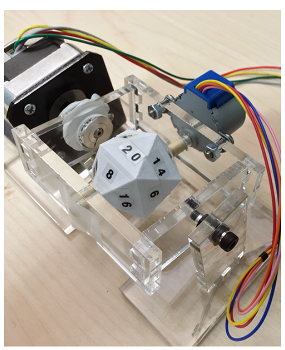

**Figure 6:** Side view of the display die.

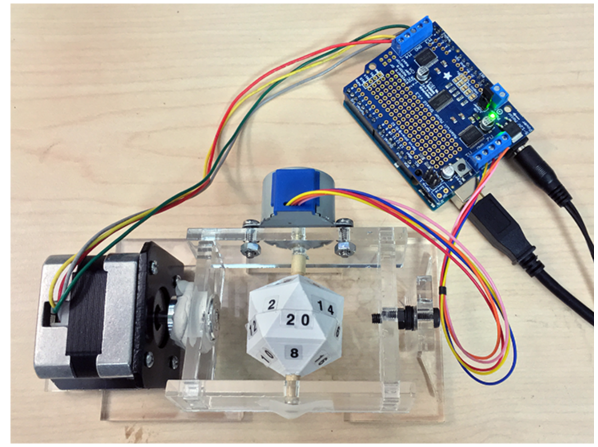

**Figure 7:** The display die. Here it indicates 20 has been rolled.

the wooden dowel for the display die's first axis of rotation (see Figure 2). This motor is attached to the acrylic support system.

A 12V bipolar 200-step stepper motor then rotates the rectangular acrylic support system to create the die's second axis of rotation (see Figure 3). To achieve this, the support system rotates around both the motor's drive shaft and a bolt held up by an acrylic post (see Figure 6). Additional bolts and nuts secure the motors to the acrylic.

To hold up the center support system when the motors are not on, a small acrylic stand can be placed under it. This ensures that the zero state of the second motor is consistent.

An Arduino Uno with an Adafruit motor shield (V2) controls the two motors. The motors are powered by a 12V power adapter.

The side facing up (parallel to the floor, like a standard die) on the display die indicates the rolled side for the wi-fi die. The absolute position of each side for this configuration, in units of steps for the two motors, is hard-coded into the Arduino's firmware. When a side value is sent, the motors then spin the die to show that side

Additionally, when the wi-fi die first begins to move, the display die's first axis will rotate back and forth to mimic a rolling motion. It will continue to rotate until a side value has been received. This transparently indicates to the display die user that the person controlling the wi-fi die is currently rolling it.

## Conclusions

Creating a pair of dice that are aware of their respective orientations and are able to communicate with each other proved to be a feasible, if sensitive, endeavor. The wi-fi die successfully rolls and transmits accurate data on its final positioning without either the Photon or the 3D printed case becoming damaged from use, while the display die receives and re-orients itself correctly in response to the wi-fi die's data.

With the dice being operationally successful we feel they offer some distinct advantages over the use of random number generators in online tabletop play. The primary benefit is that using these dice requires no special knowledge or training beyond that of regular set of dice. The wi-fi die functions exactly the same as one would use a standard 20 sided die; merely roll the die and read the number on the side facing up. While the display die has a more complex support arrangement around it, understanding its output is no different that the wi-fi die's. Additionally in the case of the wi-fi die, it functions as a "magic object" as, apart from its larger than normal size, the die's orientation sensing and wi-fi functionality remain wholly hidden from a user.

There were some disadvantages to the dice's current design however, with the first being the large size of the wi-fi die. This proved to be unavoidable given the materials and technologies we had available to work with as the die needed to fit a Photon, a Photon IMU shield, a battery, and foam for protection within itself. With access to other, smaller versions of these same technologies it should be possible to construct a wi-fi die that is more approximate in size to its non-electronic counterparts.

Related to this point is an issue with the layout of the wi-fi die's insides. The hollow space within the die requires some form of shock absorption lest the electronics it contains suffer damage when rolling the die. We settled on several layers of foam padding to meet this need. While this kept our electronics secure, it did mean that after long periods of use or any particularly forceful throws, the Photon shifts its placement inside the die, leading to skewed results from the IMU shield about its orientation and requiring minor manual readjustment.

The internal electronics together with the minor imperfections in the 3D printed exterior pose an additional issue to the wi-fi die: they ensure that the die is not balanced and therefore is not truly random in its results. While most common dice have minor imperfections that lead to the same sort of problem, the presence of electronics increase the effect to a much more pronounced degree. We postulated that this could be corrected for with a cleaner 3D print and a careful application of internal counterweights, but doing so was outside the scope of our intentions for this project.

The display die as well could be further improved. As it currently stands, the display die requires a bulky rig of motors around it to make it rotate. Our original intentions for the display die were different however; previously the die was to be free-moving, similar to the wi-fi die. We soon discovered that to carry through with this goal would require crafting complex gearwork inside the die, which, even if we were able to construct such a mechanism, would result in a final die much larger and far heavier than the wi-fi die, rendering it impractical to use.

With these successes and limitations in mind, we believe our project illustrates the potential value toward applying the ubiquitous technology principles to the field of tabletop gaming. Integrating technology into the pieces and tools of these games should make play more engaging and more streamlined of an experience for players.

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