Building RFID-Based Augmented Dice with Perfect Recognition Rates

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Abstract. We report on the construction of real-world dice equipped with radio frequency identification (RFID) technology that support the automated readout and processing of rolled results. Such augmented dice help to build "smart" tabletop games that are able to unobtrusively detect the players' actions, allowing them to better focus on the gameplay and the social interaction with other players. Since the technology is completely integrated into the play environment, the look and feel of the dice is unaltered. This article provides an overview of the challenges in building augmented dice and describes the various prototypes that we built. Our latest model resembles a regular die of about 16mm side length and achieves a perfect recognition rate of 100%.

Keywords: Augmented dice, radio frequency identification (RFID) technology.

1 Introduction

For millennia people have enjoyed playing games and the social integration provided by such gatherings. Be it for a nice chat, the inner urge for competition, or simply for the feeling of belonging to a group – playing games can be regarded as one of the main recreational activities of mankind. Hitherto, a countless number of games have been invented: some focus on the players' physical skills, others on their mental abilities, some simply test the players' luck. Given the latter category, dice have become the standard game piece whenever an element of randomness is required – either as a part of the game (e.g., Monopoly) or as its core element (e.g., Yathzee).

Depending on the game and the random component required for advancing the game, there are several die types in use with the "D6" being the most prominent one. Many games use one or two six sided dice to simply advance game figures on a board, yet more complicated uses of dice rolls are also common, e.g., looking for a particular combination of eyes, requiring the sum to exceed or undercut a certain value, or comparing several dice with each other. Some games require the usage of many dice which can result in spending quite some time on "eye counting". While modern electronics might allow for other approaches to provide this random component (e.g., an electronic random number generator that simply displays the results of the above mentioned calculation at the push of a button), people might prefer the use of traditional dice for three reasons: the haptic and spatial experience;

the transparency of the process (one can see the numbers being "generated"); and the feeling that one can influence the result (i.e., the idea of having a "lucky hand").

So-called "augmented dice" aim at combining both aspects, that is, to allow players to continue using typical dice in the traditional sense, while the results can be automatically retrieved and forwarded to the gaming application. The idea is to embed computers and sensors into both the gaming environment and, due to the continuous miniaturization of these technological components, even into individual game pieces. This allows us to map the users' real-world activities onto a virtual game model that in turn can drive displays or other game elements.

This paper describes our continuing work on RFIDice [4], our initial prototype of an RFID-enhanced traditional D6. Compared to our earlier models, we were able to significantly increase the recognition rate while reducing the form factor, making our augmented die no bigger than a standard, off-the-shelf D6. To the best of our knowledge, we are the first to present RFID-enhanced augmented dice that could actually be used in real world gaming applications.

2 Using RFID Technology for Realizing Augmented Dice

There are basically three approaches to build an augmented die:

- A *visual approach* using, for example, a scanner or video camera to capture and analyze the results shown on the die sides.
- An *internal sensors* approach that employs some kind of integrated sensor (e.g., an accelerometer, or force pressure sensors) that internally detects the position and sends it to an application.
- An *external sensors* approach that detects some (non-visual) quality of the rolled die using, e.g., sensors embedded in the tabletop surface.

We have discussed the advantages and disadvantages of the three approaches previously [4] and thus only summarize them briefly in Tab. 1. The use of external sensors offers high robustness, a small die size, and low costs, at the expense of a limited rolling area, however. We believe that these advantages outweigh this limitation and thus decided to explore the use of external sensors in our system.

Table 1. Advantages and disadvantages of different approaches for building augmented dice.

Criterion	Visual approach	Internal sensors	External sensors
Size of rolling area	limited	unlimited	limited
Maintenance of die	n/a	batteries, damaged h/w	n/a
Configuration / calibration	yes	possibly	n/a
Robustness of die	very high	low	high
Size of die	small	large	small
Costs of one die	very low	high	low

RFID technology is a representative of this category inasmuch that the actual reading is done by an antenna integrated into the environment which reads identification strings from small, battery-less transponders that can be unobtrusively embedded into everyday objects, allowing us in effect to bridge the gap between the real and the virtual world [1]. Several projects have demonstrated how well-integrated RFID technology in toy and game environments can yield better player support and even enable a range of novel gaming applications [2,3,5]. In the case of an augmented die, the die itself is equipped with passive RFID tags (one tag for each face of the die), which do not require any internal power supply but receive energy through the radio field induced by the reader. The availability of very small tags makes it possible to equip a die with multiple tags that do not require any further maintenance.

Using RFID technology for realizing an augmented die has a number of advantages compared to other technologies, which become apparent when examining the requirements of an augmented die: first, rolling an augmented die must feel the same as rolling a traditional die; second, an augmented die should still be usable in the "old-fashioned" way if the technology is switched off or inoperable; third, the detection system that automatically reads the rolled result must be hidden and unobtrusive; fourth, the system should moreover be inexpensive and easy to use, i.e., the user should not be burdened with configuration, calibration, or maintenance tasks.

The problem, though, is that RFID technology was not designed for precise localization: the main purpose is to detect and identify items in read range of an antenna, e.g., at a loading dock or on a smart shelf. In our case, however, we do not want to read any tags except for one – the one at the bottom of the die – in order to infer which side of the die lies on top. One option would be to dynamically lower the reader field strength until a single tag remains (hopefully the one at the bottom), another to measure the individual field strength reflected from each tag and inferring that the strongest measurement comes from the bottom tag. Unfortunately, RFID readers that support these options are rather bulky and very expensive, rendering their usage suboptimal for entertainment appliances.

To ensure that only a single tag would be read, we initially investigated the use of metallic shielding on the inside of the die to limit the signal strength from all tags but the bottom one. Tags were mounted on the inside and insulated via spacers from an inner aluminum-lined shielding cube. This approach, however, yielded only 80% recognition rate even under ideal conditions. In most cases, the antenna recognized more than one tag, making it difficult to infer with certainty which side was being read. As the tags we used were rather big (i.e., 4x4cm and 2x1cm, respectively), and since the read range of an RFID tag is proportional to the size of its antenna coil, we concluded that smaller tags would yield much better results. In addition to that, smaller tags would also allow for a smaller form factor than our initial prototypes.

3 An Augmented Die with Perfect Recognition Rate

We began work on the next version of our augmented dice using the newly available Philips I-Code1 tags, which feature a size of only 9mm in diameter and very short read ranges. Consequently, we were able to move tags much closer together than before and thus reduce the physical dimensions of the dice. As with our previous version, only standard off-the-shelf RFID components were used: a FEIG ID

ISC.MR101 mid-range reader (HF 13.56MHz), a FEIG ID ISC.ANT100, 10x10 cm antenna, and passive Philips I-Code1 tags (HF 13.56MHz).

The basic recognition principle remained unchanged: by ensuring that only the tag at the bottom of the die is detected, we can unambiguously infer which face of the die is on top. While the read range of the new tags was now much lower, it turned out to be still too high when we simply placed the tags directly on the die surface – more than one tag was detected. As before, our idea thus was to reduce the read range with the help of metallic insulators. We successively constructed three 30mm dice, followed by one 16mm die, all made of spruce wood, with each new die generation iteratively evolving from the previous. Each prototype was subject to an extensive test series similar to [4] to evaluate its performance.

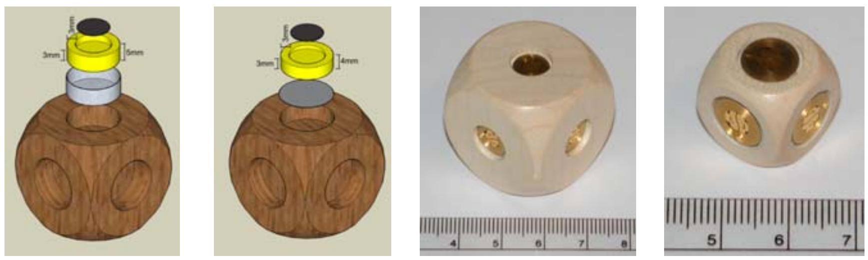

Figure 1. The explosion models of the first and the second versions of the 30mm dice (leftmost and left), the third version of the 30mm prototype (right), and the 16mm prototype (rightmost).

In the first 30mm prototype (see Fig. 1 leftmost and Tab. 2) we inserted aluminum foil cylinders into circular holes of 7mm depth and used wooden spacers to separate the aluminum from the RFID tag. The spacer had a height of 5mm and such a diameter that it would just fit into the drilled hole. A 2mm thin wooden cylinder was put as a cap on the top of each hole to fill the remaining gap. The values were chosen more or less randomly to get a first impression of the behavior. The resulting die performed worse than our previous models: the aluminum cylinders shielded the tags too much, i.e., even the bottom tag would not be detected by the table antenna.

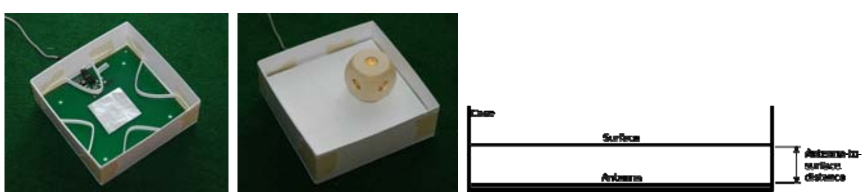

Figure 2. The antenna of the dicing ground with a metallic foil in the center (left), the dicing ground of the 30mm prototype, and the cross-section of the dicing ground construction (right).

For our second die, we reduced the depth of the holes to 5.5mm and used a circular PVC insulation layer instead of a cylindrical, to reduce the shielding effect (see 2nd image from the left in Fig. 1). Initial measurements were significantly better, but still far from perfect: while the tag at the bottom was now always recognized, one or two other tags were as well. We thus attempted to increase the distance between the antenna and the die, by raising the tabletop surface slightly above the antenna (see Fig. 2 right). After a few tries, we managed to find a solution that turned out to work perfectly: adjusting the antenna-surface-distance to 5mm finally resulted in a recognition rate of 100% according to our test series of several hundred rolls (cf. [4]).

Given these results, we wanted to investigate if we could build a die completely without insulation layers and spacers, by only working with the distance between the antenna and the surface. Using drilled holes of 3mm depth and 10mm diameter, we directly placed the RFID tags inside and covered them with simple stickers. Using the trial-and-error approach as before, we found the optimal distance to be 14mm, again yielding a 100% recognition rate. Another advantage of this approach is the much simpler construction process as well as the reduction of potential imbalances due to construction flaws (i.e., preventing that one side has a higher probability of being rolled); the probabilistic correctness of the dice was also tested by us.

Table 2. Characteristics of the four prototypes

Parameter	30mm die (3 prototypes)			16mm die
Hole diameter	15mm	15mm	10mm	10mm
Hole depth	7mm	5.5mm	3mm	2mm
Insulation Material	Aluminum foil	Aluminum foil	n/a	n/a
Insulation from	Cylindrical	Cylindrical	n/a	n/a
Spacer material	Wood	PVC	n/a	n/a
Spacer height	5mm	4mm	n/a	n/a
Cap material	Wood	Wood compound	Wood compound (opt.)	Wood compound (opt.)
Antenna-to-surface distance	0mm	5mm	14mm	22mm

Having achieved perfect recognition rates with the 30mm die, shrinking the die to the more common 16mm size seemed straightforward. However, initial testing with the 16mm die revealed recognition problems at the borders of the surface – the reliable detection of the bottom tag was only possible in the center of the antenna. We realized that the smaller height of the die had moved the side tags closer to the antenna surface. Since the electromagnetic field at the edge of the antenna runs nearly parallel to the surface, the lower height had moved the side tags into antenna range again. In many cases, the reduced height even allowed the tag on the top side of the die to be identified. Simply increasing the distance between antenna and surface further did not help: at a height of 22mm, no tags were detected near the edges of the antenna anymore, but both the top and the bottom tag were still identified when the die was placed squarely in the antenna center.

To help even out the antenna field, we used two approaches: first, in order to weaken the field strength at the center, we placed a 35x35mm aluminum foil as an insulator at the center of the antenna (see Fig. 2 left). Second, to avoid the problematic border region, we added a physical barrier that restricted the tabletop surface to 90x90mm (compared to 100x100mm before, see Fig. 2 center). These modifications finally yielded a recognition rate of 100% using the 16mm die, though at the cost of a slightly smaller dicing area.

4 Conclusions

In this paper we presented the improved version of an RFID-based augmented die that features a perfect recognition rate. Our final prototype fully resembles an off-the-shelf die with 16mm side length and is thus an appropriate replacement of traditional, non-augmented dice.

While our current setup correctly identifies 100% of all random rolls in our test, it comes at the expense of a carefully constructed "tabletop surface." Increasing this area will most likely involve another careful round of tuning. Previous investigations into bigger (off-the-shelf) antennas, as well as into the use of antenna arrays, showed that the created field is too heterogeneous. Additionally, due to the nature of RFID, our setup is sensitive to the immediate environment, especially the table it is placed on. A solution could be to include a shielding construction around the whole dicing ground, but this would come at the price of increased size and a more expensive construction.

Admittedly, using RFID for constructing augmented dice is a "hack," as this technology was never designed for precise localization. The high sensitivity of the RF field requires an unwieldy trial-and-error process. Furthermore, we have yet to confirm whether our dice are capable of being rolled several thousand times without compromising the perfect recognition rate, which would be the prerequisite for real-world applications.

Nonetheless, in our opinion, the benefits of using RFID technology for external detection outweigh its disadvantages: an RFID-based solution is maintenance-free and the detection devices can be invisibly integrated into the environment (e.g., a game board). The continuously decreasing costs for standard RFID equipment, as used in this project, further strengthen this assumption. In our previous work we concluded, "if we are able to construct an even smaller version of our dice, e.g., 1x1 cm in size, we could close the gap between the real and virtual worlds in a truly pervasive and unobtrusive way." We hopefully have come significantly closer.

References

1. Benford, S., Magerkurth, C., and Ljungstrand, P.: "Bridging the physical and digital in pervasive gaming". Communications of ACM, 48(3):54–57, 2005.
2. Bohn, J.: "The Smart Jigsaw Puzzle Assistant: Using RFID Technology for Building Augmented Real-World Games", Proceedings of 1st International Workshop on Pervasive Gaming Applications (PerGames '04), Vienna, Austria, April 2004.
3. Floerkemeier, C., Mattern, F.: "Smart Playing Cards – Enhancing the Gaming Experience with RFID." Proceedings of PerGames '06, Dublin, Ireland, May 2006
4. Hinske, S., Langheinrich, M.: "RFIDice – Augmenting Tabletop Dice with RFID". Proceedings of PerGames '07, Salzburg, Austria, June 2007
5. Magerkurth, C., Memisoglu, M., Engelke, T., and Streitz, N.: "Towards the next generation of tabletop gaming experiences". Proceedings of the 2004 conference on Graphics interface (GI'04), School of Computer Science, University of Waterloo, Waterloo, Ontario, Canada, 2004, pp 73–80