An RFID-based Infrastructure for Automatically Determining the Position and Orientation of Game Objects in Tabletop Games[1]

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Abstract. Radio Frequency Identification (RFID) technology already plays a major role in many areas. In business applications, for example, the idea of smart shelves or tables equipped with RFID technology has been around for some time now, especially for retailing. Current solutions, however, are designed to only identify objects in range, which is sufficient for most of the envisioned shop applications. For other uses, however, not only the identification, but also the exact position and orientation of objects would be interesting, if not necessary. A good example are miniature war games, where the current game state usually depends on what objects are located where, and, in some cases, how these objects are oriented. In this article, we present an approach to determine the position and orientation of (multi-tagged) objects. We introduce the conceptual idea, as well as the technical realization based on the example of an augmented miniature war game. We then describe our findings so far and summarize our next steps.

Keywords: Augmented Games, Pervasive Games, Tabletop Games, Miniature War Games, Localization, Radio-Frequency Identification (RFID).

1 Introduction

Despite the record-breaking sales of consoles and video-games, traditional *tabletop games* continue to find many players. *Miniature war games* are a particularly popular type of tabletop games, in which two or more players engage in battle with each other, commanding an army of numerous game objects representing combat units, usually with the goal of eliminating the adversarial forces. Warfare in such games very much depends on the exact location and orientation of game pieces, in order to properly assess the visibility of enemies, or the range and effect of an attacker's weapons. Computing these effects is currently a laborious and time-consuming task, where players use rulers and goniometers to measure the distances and angles between units and their orientation. Our goal is to support players of such games by automatically

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[1] Parts of this article are based on earlier publications by the authors [9].

capturing this information and providing it to them in an automated and unobtrusive fashion.

We developed an infrastructure for tabletop games in general (and miniature war games in particular) that enables the automatic and relatively precise tracking of the location and orientation of game objects on the playing field. Our design follows two main goals: Firstly, the technology should be integrated unobtrusively, so that the natural game experience is not disturbed nor rendered unusable if the technology fails (i.e., the game can still be used in the traditional way). Secondly, the rich social interaction of tabletop games should not be negatively influenced by the system. Both goals have some implications on what kind of technology is to be used and how it should be implemented. The first goal requires

- An invisible integration of the technology into the game environment,
- An almost maintenance-free operation, and
- Providing players with simple and efficient access to information.

The second goal additionally emphasizes

- Minimizing secondary user interfaces such as graphical displays (GUIs).

Ideally, the game objects remain the major (tangible) user interfaces (TUI), in order to avoid shifting the players' focus to screens and other methods of input (e.g., keyboards or mice) [11, 33].

We met these requirements by employing Radio Frequency Identification (RFID) technology, a semi-mature technology for unobtrusively identifying tagged artefacts passing through an antenna field. By increasing the number and density of antennas and tags, we are trying to exploit additional information from overlapping read ranges and tag sightings to provide improved tracking and orientation detection. The result is an infrastructure that supports players by providing them with information that they otherwise would have to gather themselves executing rather cumbersome tasks (i.e., measuring), without the need for additional steps on the players' behalf.

This article presents our initial prototype system and is structured as follows: Chapter 2 introduces the problem of determining the position and orientation of game objects, using the example of a popular miniature war game, “Warhammer 40,000” (or, “Warhammer 40k”). Chapter 3 discusses several techniques of using RFID technology to determine the location and orientation of objects. In this chapter, we also compare RFID technology to other technologies. Chapter 4 then presents the results of our preliminary evaluation and discusses system performance (and potential improvements). Chapter 5 summarizes the main ideas and contributions, and outlines future work.

2 Augmenting Miniature War Games

People have enjoyed playing games for recreational purposes and amusement for thousands of years. Among all evolved and existent games, *tabletop games* certainly belong to the most popular and most often played games. In recent years, several projects have addressed the issue of augmenting tabletop games with various kinds of technology. Equipping tabletop games with pervasive computing technologies to enhance the gaming experience has led to interesting new applications, e.g. [1, 6, 13, 15-18, 21, 22], also cf. Chap. 3.1.

Tabletop games are games that are typically played on a table or a more or less flat surface. They can be further subdivided into the following categories:

- Miniature war games,
- Board games,
- Card games, and
- Dice games.

For the purpose of this paper, we will focus on *Miniature War Games*: Due to their inherent complexity and high degree of detail, they demonstrate best how players can benefit from automatically determining the position and orientation of game objects. Nonetheless, all ideas and findings can also be applied to other tabletop categories.

Fig. 1. A typical Warhammer 40k battlefield.

Miniature war games originated in the beginning of the 19th century, when Georg Leopold Baron von Reißwitz developed so-called "Kriegsspiele" (war games) to train the strategic skills of Prussian officers [14]. In principle, these games have not changed very much since then and the basic idea still remains the same. Miniature war games consist of many game objects that represent combat units. Two or more players engage in battle with each other, commanding an army (or, at least a part of an army), usually with the goal to eliminate the adversarial forces.

Miniature war games often depend on frequent tasks such as measuring distances, and angles. These tasks can be time-consuming and perceived as rather annoying since they have to be executed countless times. Thus, electronically supporting the players with these tasks in an unobtrusive and non-invading way can certainly increase the players' entertainment and gaming experience, since they can focus on social interactions and the game itself (i.e., on strategic movements, etc.).

Popular miniature war games like “Warhammer”, “Warhammer 40k”, and “The Lord of the Rings”[2] are excellent examples of games that continuously require precise information about the location and orientation of all game objects. In this paper, we will focus on “Warhammer 40k”, though other games could have served as examples as well. Fig. 1 displays a typical battlefield in the Warhammer 40k universe: There are numerous game units and landscape components scattered over a large table; the players stand around the table, positioning their units and measuring distances between these units.

Fig. 2. A group of miniature war figures and a tank in the background.

There are two categories of army units that we need to distinguish (see Fig. 2): The first category consists of foot soldiers, meaning a single figure representing a single soldier or a figure of equivalent size and “firepower”. The second category includes bigger combat units, such as tanks. Besides the greater firepower and longer distance in the sense of speed and weapon range, the main difference is that the large units can

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[2] All by Games Workshop http://www.games-workshop.com

usually only fire at targets within their viewing angle, while foot soldiers are allowed to shoot at any target around them. This is to simply reflect the faster reaction and turning speed of a human(-like) unit, compared to a big turret on top of a tank. As a consequence, we not only need to know where a tank is currently located, but also how it is oriented. So far, this is done manually with rulers (see Fig. 3), goniometers and templates (see Fig 4).

Fig. 3. A player measures the distance between two units on the battlefield using a ruler.

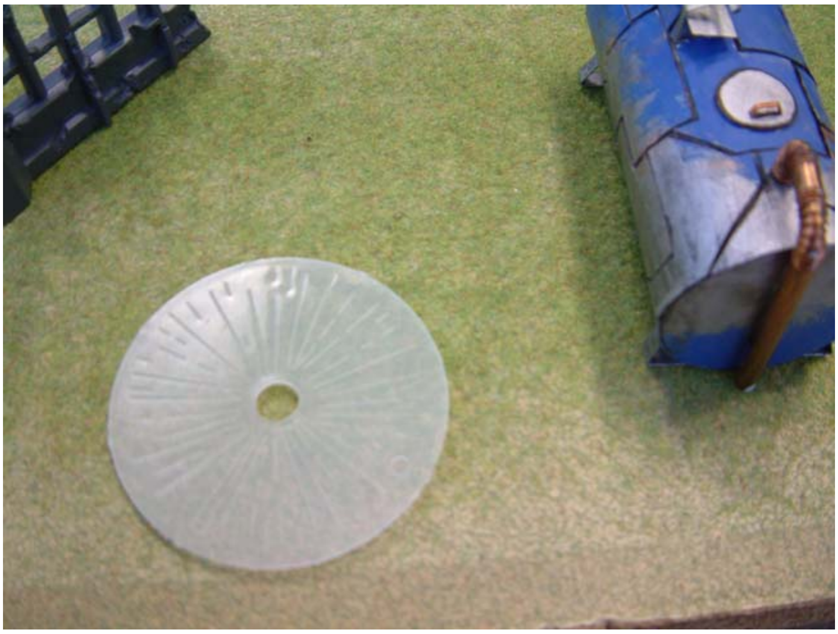


Fig. 4. A blast template for determining the blast radius of a grenade.

Besides measuring distances and angles, the players must consider the individual features and weapons of each game object. While, for example, game unit ‘A’ can only fire a weapon within a viewing angle of 150°, game unit ‘B’ has the ability to aim at targets in an 180° angle. In addition to that, the weapon of object A has a range of 15 centimetres, while object B's weapon has a range of 10 centimetres, but creates a blast radius of 2 centimetres in the target area (see Fig. 4). Apparently, such games can quickly become incredibly complex: Tens or hundreds of different game objects with distinct characteristics and equipment turn the game into an intricate and laborious episode of managing charts, sheets of paper, and measuring equipment.

Therefore, the goal is to take the burden off the player by generally displaying static, but essential information about individual game objects (e.g., individual firepower, life points, etc.) on the one hand, and, depending on the current context, by providing them with dynamic real-time information regarding the location and orientation (e.g., unit A is 12 centimetres away from unit B), on the other hand. In the next chapter, we will describe how we intend to realize this support.

3 RFID-based Determination of Position and Orientation

The idea of employing Radio Frequency Identification (RFID) technology for detecting tagged objects on surfaces such as shelves or tables has been investigated for many years now and has reached a certain level of maturity. In retailing, for example, there are already existing solutions available that keep track of goods placed on shelves in real-time (e.g., for replenishment and storage management; for example, cf. [7]). There are two central assumptions in such scenarios:

- For these applications it suffices to have one antenna to cover an area and read all goods within read range, and
- All objects are single-tagged (i.e., equipped with one single RFID tag that allows identification).

There are, however, other applications that do not only require knowing whether a given object is in read range, but furthermore where exactly the object is located. In addition to that, it might also be interesting (or sometimes even necessary) to know how the object is oriented in a 2- or 3-dimensional space, i.e., which direction a particular part of the object is pointed towards.

Before we present our approach, we discuss related work.

3.1 Related Work

We basically examine three categories of related work. First, we look into existing smart shelf applications, which are similar to our general idea of tracking objects on a surface such as a shelf of a table. Second, we specify other projects that concern themselves with multi-tagged objects and environments. This is essential for our intended enhancement of the conventional smart shelf. Third, we list other position and orientation technologies and compare them to our approach.

Smart Shelves. Smart shelves have been studied by several research groups, and a number of industrial initiatives already apply these technologies [5, 19, 27, 28]. These applications, however, focus on identifying single-tagged objects in range, i.e., retrieving information of what objects are on the shelf at any given time. Determining the exact position and orientation of the goods, however, is irrelevant. The main purpose of this research is the higher transparency and optimization of replenishment and storage management in retail stores.

Multi-tagged Objects. Although some research on multi-tagging has been conducted in the past, there is little or no overlap with our approach or goals. Bolotnyy and Robins investigate multi-tag systems and their benefits in [4]. They define three types of multi-tags:

- Redundant Tags (two or more independent tags carrying identical information),
- Dual-Tags (two tags connected to each other and having one or two antennas; they can further subdivided depending whether memory is in some way shared or not), and
- N-Tags (n tags connected to each other and having one or more antennas).

Their goal is the improvement of availability, reliability, and durability of RFID systems, especially in security-related applications. Our approach differs from this classification since we employ n tags per object, but each tag has a unique ID and they are not connected to each other in any way.

The approach of equipping objects with more than one tag has also been applied in [20]: they use multi-tagging to determine the direction in which a person is going. The usage of multiple tags in this case, however, is simply for the purpose of redundancy (i.e., guaranteeing that a person is tracked with a high probability).

Bohn [2, 3] also uses multiple tags, but instead of having reader in the environment scanning tagged objects, the environment is tagged with numerous tags and objects are equipped with mobile readers, thus, reversing the traditional concept of employing readers and tags.

Other Positioning and Orientation Technologies. There are other technologies that allow the determination of the position and orientation of an object in 2- or 3-dimensional space. These are briefly summarized. Ultra-wideband (UWB) technology is capable of tracking an object in a 3D space within tens of centimetres [32]. Though this level of preciseness might be good enough for other applications, it does not meet the requirement of our application. Besides, UWB tags are too big for our small game pieces. Furthermore, this technology requires installing and calibrating a (rather expensive) sensor infrastructure.

Another possible technology is Ultrasound, e.g. [24]. Systems such as Active Bat [29] allow the localization of an object within approx. three centimetres, which makes this system one of the most accurate currently available on the market. The bats are slightly smaller than UWB tags, but nonetheless still too big and thus not suitable for our purpose. Last but not least, the costs of the Ultrasound infrastructure are also very high.

Krohn et al. present a relative location system that also utilizes ultrasound [8, 12]. Their approach, however, does not require an infrastructure, but uses single devices equipped with transmitters that can determine the position and orientation autonomously. The crucial advantage of this approach (i.e., autonomy of devices, no infrastructure) is obviously also the biggest disadvantage: The devices are relatively big, require an energy source, and they have to be maintained.

Schmidt et al. present a load sensing system that allows 2D-positioning on a table [25, 26]. However, using this system does not work in our scenario for two reasons: On the one hand, the objects might be too lightweight for the table to sense them (e.g., plastic figures); on the other hand, the surface might not be totally flat, i.e., it might be covered with several decoration components on which the objects are placed. This is an essential requirement that has two implications: The aforementioned uneven surface due to decoration elements and the resulting possible interruption of the line-of-sight between an object and the sensor (see Fig. 5). For this reason, we also do not consider infrared technology (e.g., [18]) which depends on line-of-sight, nor other approaches that require a rather flat table, e.g. [23].

Magerkurth et al. developed STARS, a tabletop game that allows identifying game objects as well as their position and orientation on a table based on visual recognition [15, 16, 17]. With regard to the collected information (i.e., identity, position, and orientation), this approach comes closest to ours. This system, however, requires the installation and calibration of the video equipment, and the game objects must be significantly distinctive in their shape in order to avoid erroneous detection. The system has moreover not been tested with decoration elements (i.e., it only operates on a flat table), which might reduce the visual recognition capabilities (see Fig. 5).

Fig. 5. Landscape elements (left) do not work with sensing techniques that require a flat surface and/or line-of-sight. Video recognition does not work with many objects that look very similar, i.e., objects that do not have distinctive shapes (right).

Lee et al. present TARBoard, an "a tangible augmented reality system designed for table-top game environment" [13]. The system allows video-based tracking of tangible objects on a glass table. TARBoard shares the common problems of video analysis: The camera must get a clear picture of the scenery at all times, and it requires calibration of the video equipment, which by the way is usually noticeable by the players and thus hardly unobtrusively.

Furthermore, video analysis requires much computational power and it is rather error-prone, depending on the concrete video data to be analyzed: A game set consisting of tens or hundreds of small, much alike-looking figures is a serious challenge. If, however, a video analysis application is powerful enough to cope with the aforementioned scenario, it should also be capable of determining the orientation of game objects. Therefore, video analysis certainly is one of the most promising techniques for years to come.

In [30, 31] Tse et al. present a multimodal multiplayer tabletop that uses speech recognition and a multi-user touch technology as input as well as a projector for displaying the game surface. Though the system works quite well, it still suffers from the drawbacks of calibrating the projector as well as the touch system based on capacitive coupling through the human body. Moreover, the equipment is very expensive.

Another category of augmented tabletop applications are games that employ head-mounted or similar devices (HMD) to project a virtual layer over the real world, e.g., False Prophets [18], Tankwar [22], Hybrid AR Worms [21], and Battleboard 3D [1]. These games aim at exploiting the advantages of virtuality without neglecting the social component, which is inherently the case when playing virtual games (i.e., sitting isolated in front of a computer).

Although this hybrid approach certainly will play a major role in the gaming industry in the future, there are nonetheless three disadvantages to it: First, since the game is mostly, if not totally, simulated, the players do not experience the sensation that comes with tangible objects and user interfaces. Second, the social component is not as strong as in traditional tabletop games since the players' focus is rather on the projected virtual objects and effects than on interacting with the other players. Third, the players are required to wear the devices that create the virtual world. Even if these devices become handier and smaller, the gaming experience yet differs from traditional gaming with respect to the degree of physical freedom.

3.2 RFID technology

RFID technology offers great possibilities for detecting and identifying objects. In the context of gaming applications, the major benefits are:

- The technology can be hidden and thus works unobtrusively,
- The objects are almost maintenance-free (except for exchanging damaged RFID tags),
- The players do not have to calibrate the equipment,
- Each game object is uniquely and unambiguously identifiable,
- No line-of-sight is required, and
- The game still works even if the technology is switched off or malfunctioning.

Since the antennas induce a 3-dimensional field, it is also possible to have game elements on the table that make the game map uneven or even represent taller buildings (e.g., hills, houses, etc), see Fig. 6.

Fig. 6. Objects that are not directly on the ground make it difficult for some position recognition techniques to work.

In order to provide players with the information where each object is currently located, we have to be able to track single RFID tags on the battlefield. In the case of RFID technology, this can be done in several ways, i.e., using different techniques that will be discussed now.

Varying the Power Level of the RFID Reader. The first approach is to vary the power level of the RFID reader. The basic idea is to first start with the maximum power level and detect all RFID tags in range. Then, the power level is reduced and again all tags in range are read. This step of reducing the power level can be repeated several times until the reader reads with minimum power. Given that the reader or the application can differentiate between the different radii induced by the different power levels, it is possible to determine where the tags must be approximately located. This approach, however, requires readers that can vary the power level which is not standard yet. Furthermore, this technique is very time-consuming since every reader has to do numerous read cycles to determine the position of the tags, which in turn might turn out to be obstructive to the dynamic nature of the game.

Reading the Signal Strength. The next approach is based on measuring the strength of the signal returned by the induced RFID tags. It is possible to estimate the distance between a tag and the antenna given the received signal strength. This feature, however, is not supported by most available readers. In addition to this, this approach is rather error-prone since we have to deal with distortion due to reflections, multipath, etc.

Trilateration / Multilateration. Trilateration describes the technique of determining the position of a tag by calculating the *time of arrival* from at least three different locations (i.e., readers). Multilateration, also known as *hyperbolic positioning*, is the process of locating an object by accurately computing the *time difference of arrival* of a signal emitted from the object to three or more receivers. It also refers to the case of locating a receiver by measuring the time difference of arrival of a signal transmitted from three or more synchronized transmitters.

Triangulation. Triangulation, also called *angle of arrival*, is the process of finding the coordinates and the distance to a point by calculating the length of one side of a triangle (which is formed by that point and two other known reference points), based on measurements of the angles and other triangle sides, using the law of sinus. This requires the antenna to be able to measure the angle of incoming and outgoing signals, which most currently available antennas do not support. It would, however, be possible to equip each receiver station (i.e., reader) with several antennas, but this in turn would significantly increase the reading time and the costs of the infrastructure.

Our Approach: Antenna Grid. Since none of the aforementioned techniques satisfies our requirements or is too expensive in terms of time or monetary costs, we followed a different idea. Our approach is to increase the number of antennas in order to exploit the information we gain from the overlapping read ranges of the antennas. The general principle is shown in Fig. 7. The circles around the antennas symbolize their read range given a specific tag (the read range inter alia varies with the tag model). Therefore, we use a modified version of the *cell of origin* approach.

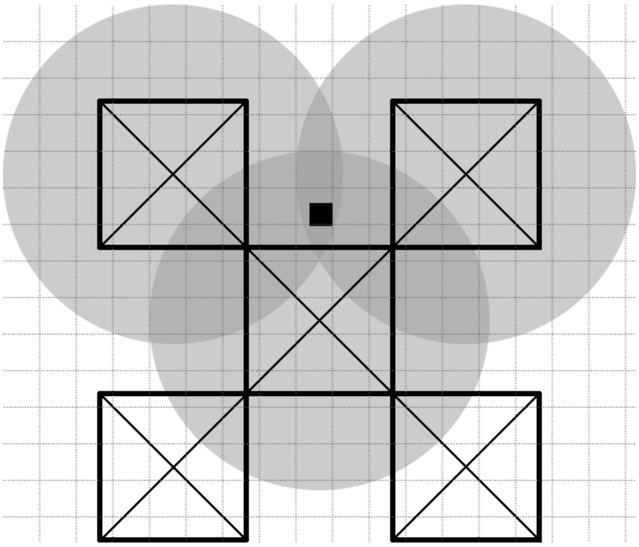


Fig. 7. The principle of our approach: We use multiple antennas and determine the position of a tag by using an antenna grid (big squares with thick black lines) that allows measuring the overlapping areas of the read ranges (grey circles) and thus the approximate location of the tag.

When an antenna reads a given tag, the grid increases an internal counter for each section (the small grey squares in Fig. 7) that is range of this particular antenna. After completing the read cycles, the tag is most likely in (one of) the sections with the highest counters. In Fig. 1, the dark area in the centre marks the area where the tag, represented by the small black square, must be located. It is not possible to determine where exactly it is within this area. Therefore, the goal is to minimize this area of uncertainty. It is obvious that the size of the "uncertainty area" depends on the number and size of the read range circles (i.e., the antennas), and on the layout of the antenna grid. The smaller the read range circles, the more antennas there are and the denser the grid, the better.

However, due to numerous technical deficiencies of the currently available equipment and the general problem of interference that RFID technology has to cope with (e.g., tags are not read in a cycle, metallic environments, etc), the reality differs very much from any theoretical assumptions. For this reason, we experiment with several constellations of RFID tags and antennas and vary the following components:

- The layout of how the antennas are placed (design of the antenna grid),
- The RFID antenna model,
- The RFID tag, and
- The read range of the employed reader.

This is done to achieve two goals: On the one hand, as a result we intend to find the best solution given the employed equipment, and, on the other hand, we want to get a general understanding of how, and to what extent, antenna grids as well as different RFID antenna and tag models influence the outcome.

4 Discussion

We developed a test environment to investigate how the variation of these components influences the preciseness of the readings. So far, we used one antenna model (FEIG ID ISC.ANT 100/100) and two different antenna grid layouts. We experimented with two different RFID tags and measured the range in which each tag can be read by the reader.

We arranged eight antennas in a chessboard pattern (see Fig. 8). Since each antenna is 10x10 centimetres, we cover a total area of 40x40 centimetres. We tagged a couple of objects with several RFID tags and placed them on the field. The software developed by us controls the reader (FEIG ID ISC.MR 101-A), which is connected to the antennas via a multiplexer (FEIG ISC.ANT.MUX 8). The sequentially energized antennas return the read tags in range. After several read cycles (one read cycle takes approximately 2-3 seconds), which is done to avoid erroneous read data, the software determines the highest probability for each scanned tag on the board. Based on this data and the known shape and size of the object, the estimated position and orientation of is then calculated and displayed (see Fig. 9).

The numbers at the edges of the object shown in Fig. 3 correspond to the last four digits of the read RFID tag ID (e.g., “1126” in the right upper corner corresponds to the tag attached to the nose of the airplane). The underlying grid is a real-world mapping with each grid square representing 1x1 centimetres. The bigger squares named “a1” to “a8” display the antennas in the chessboard layout.

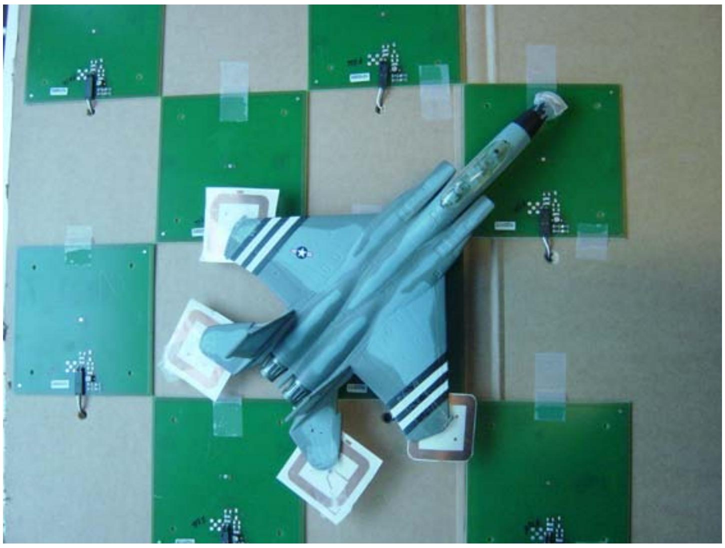
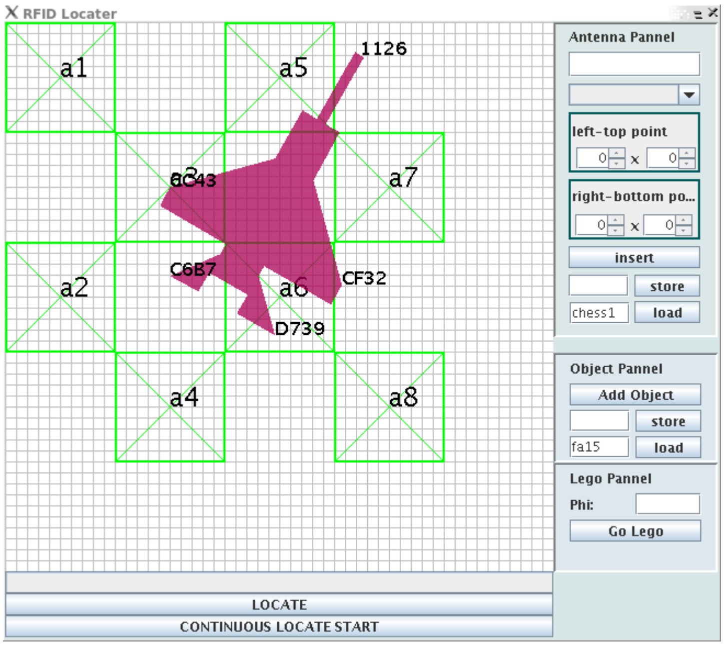


Fig. 8. Preliminary test with a multi-tagged object (using 4x4 centimetres RFID tags) and an antenna grid with 8 FEIG ID ISC.ANT 100/100.



left-top point 0 x 0

right-bottom po... 0 x 0

chess1

fa15

Fig. 9. A screenshot of the application displaying the estimated position and orientation of the multi-tagged object (cf. Fig. 8).

We conducted a preliminary test series with a multi-tagged object in order to get initial idea of how accurate this localization technique really is. The goal was to measure the position of each individual tag, the position of the object (based on the measured locations of the individual tags) as well as the angle of the object with respect to the y-axis. In our initial test series, we tested the following parameters:

Table 1. The parameters of the preliminary conducted test series.

Parameter	***Variations***
Antenna Grid (cf. Fig. 12)	2
Tag Types (cf. Fig. 11 and 13)	2
Positions X-Axis (intervals of 4 centimeters)	10
Positions Y-Axis (intervals of 4 centimeters)	10
Angles (0.0°, 30.0°, and 45.0°)	3
Read cycles	3

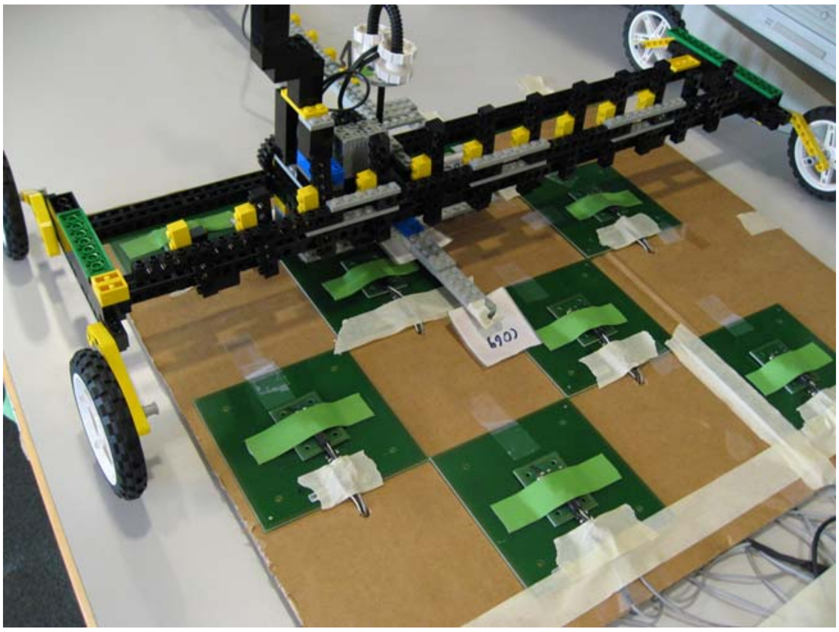


Fig. 10. The test environment consisting of a LEGO Mindstorms robot, the test object attached to it (in the center of the figure), and the antenna grid.

The evaluation was technically realized as follows: We attached four tags of one tag type to an object (see Fig. 11) and attached this object in a certain angle to a robot that automatically moved this object over an antenna grid (see Fig. 10). With total size of the field being approx. 40 x 40 centimetres, the robot stopped in intervals of 4 centimetres, and empowered each antenna 3 times (to avoid not reading tags that are actually there). Given the parameters in Tab. 1, the test series resulted in a total of 3600 measurements.

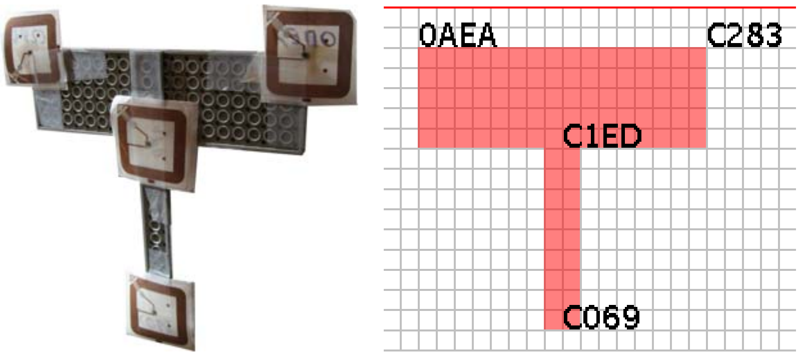


Fig. 11. The test object that we used to conduct the prelimary test series. The object has a distinctive shape with four tags (of the big RFID tag type) attached to the extremities (left). On the right side is the virtual representation of this object as it is used by our test application.

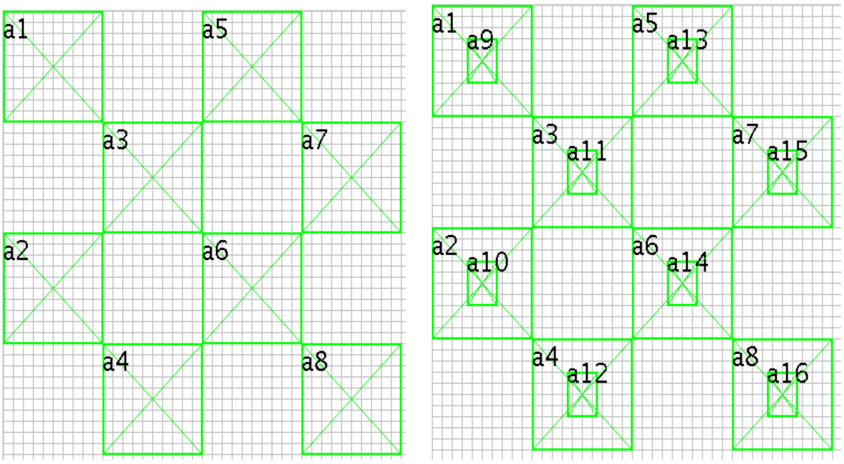


Fig. 12. The two different antenna grid layouts used for our preliminary test series. The grid on the left consists of eight 10x10 centimetres antennas, while the one on the right uses eight additional antennas that are considerably smaller (3x4 centimetres) and placed on top of the bigger antennas. Of course, the antennas are not operated simultaneously since this would result in totally biased read results.

Tab. 2 and Tab. 3 summarize the results we received by our initial test series. As we expected, using the big RFID tags yielded in rather poor results: with deviations of approx. 5 centimetres, the big RFID tags are not suitable for applications such as miniature war games since they require very fine granularity. The smaller RFID tags in yielded in better results: The average deviation was approx. 3.5 centimetres. Though this is significantly better, it is not good enough yet.

To our surprise, adding the smaller antennas to our setting did not improve the results. On the contrary: In three out of four cases the results were even worse.

Table 2. The mean deviation of the position of the multi-tagged object. The values are listed in millimetres (e.g., a value of 33.89 mm means the estimated position of the object is wrong by 3.4 centimetres compared to the actual position).

Setting	*X-Axis*	*Y-Axis*
Antenna Grid with 8 big antennas Big RFID Tags (4 x 4 centimeters)	49.84 mm	52.13 mm
Antenna Grid with 8 big and 8 small antennas Big RFID Tags (4 x 4 centimeters)	47.63 mm	52.57 mm
Antenna Grid with 8 big antennas Small RFID Tags (1.5 x 1.5 centimeters)	33.86 mm	37.85 mm
Antenna Grid with 8 big and 8 small antennas Small RFID Tags (1.5 x 1.5 centimeters)	35.34 mm	41.56 mm

Regarding the angles, the initial results were also not very satisfying: The bigger the tested angle, the higher the deviation; i.e., the more we rotated the object with respect to the y-axis, the worse the results became. In this case, using the smaller tags did not significantly improve the results and adding the smaller antennas sometimes yielded in better, sometimes in worse results. This certainly inquires further investigation.

Table 3. The mean deviation of the orientation (angle) of the multi-tagged objects. The results are displayed in degrees (e.g., 27.47° means the estimated orientation is wrong by 27.47° compared to the actual orientation).

Setting	*0°*	*30°*	*45°*
Antenna Grid with 8 big antennas Big RFID Tags (4 x 4 centimeters)	27.47°	40.53°	48.90°
Antenna Grid with 8 big and 8 small antennas Big RFID Tags (4 x 4 centimeters)	37.91°	36.44°	38.11°
Antenna Grid with 8 big antennas Small RFID Tags (1.5 x 1.5 centimeters)	17.82°	44.67°	51.16°
Antenna Grid with 8 big and 8 small antennas Small RFID Tags (1.5 x 1.5 centimeters)	30.84°	45.55°	47.86°

Our preliminary tests showed that the best estimates of the scanned tags are within a deviation of 3-4 centimetres. Although this is insufficient for real world applications like miniature war games, which require a resolution of less than one centimetre, this is a rather fair result considering it was our very first test series. Therefore, we intend to further vary the layout of the antenna grid, the types of RFID antennas and tag models, as well as the read range of the RFID reader. The usage of smaller antennas instead of the 10x10 centimetres antennas should help increase the precision. Increasing the number of tags while simultaneously using smaller tags should also result in a higher accuracy.

5 Conclusions

In this paper we presented a novel approach to determine the position and orientation of objects using RFID technology. Based on the example of a miniature war game, we demonstrated the idea of equipping a surface with an antenna grid and placing tagged and multi-tagged objects on it. Calculating the position of each single tag using the overlapping read ranges of the employed antennas allows us to estimate where the object is approximately positioned, and thus, in the case of multi-tagging, how it is oriented.

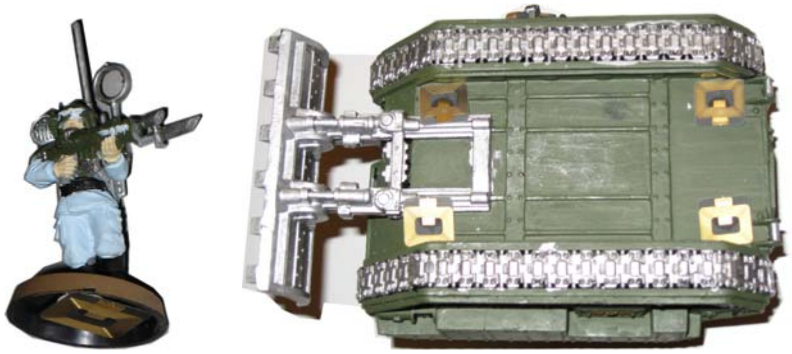


Fig. 13. Warhammer 40k objects equipped with unobtrusive and almost invisible RFID tags as it could be realized in a real game setting.

There are several advantages to this approach. The objects can be moved freely on the surface, even if there are decoration elements. The technology is completely disguised (i.e., the RFID tags are invisibly embedded into the objects and the antenna grid is installed under a table (although the test environment is set up on a table, we assume that installing the antennas under a non-metallic and rather thin table does not influence the results significantly), and can thus unobtrusively support the players' actions (see Fig. 13). Furthermore, RFID technology is comparably inexpensive compared to other technologies such as UWB or ultrasonic.

Furthermore, the infrastructure is almost maintenance-free as we do not need to calibrate the antenna grid (in contrast to a camera, for example), the RFID tags do not need to be maintained or replaced (in contrast to active modules with batteries), and the calculation can be done by a computer with average computational power, which in turn means that the computer employed can be rather small and thus also be integrated in the environment. Additionally, we can scan many figures simultaneously and unambiguously identify them, which is not as easily possible with other localization techniques; and, in the case of miniature war games, the number of game objects is quite often rather high (see Fig. 14).

There are only two disadvantages we encountered so far: First, the selection of the individual components (RFID readers, antennas, and tags) as well as the design of the antenna grid is very crucial: If we substitute only one component (e.g., one reader model with another reader model), the results are at least distorted, if not totally different. Second, some miniature war game figures are tin soldiers; usually, metal biases the read rate of readers and tags. So far, the problems arising from metallic figures were not very critical since they are placed on top of plastic trays, so called slottabasses, which in most cases provide enough space between the tag and the metal.

Fig. 14. A battlefield with many different game objects. This figure demonstrates how complex such a game might become in terms of number of game figures.

Obviously, the feasibility of our approach absolutely depends on the accuracy of the infrastructure. As we pointed out before, there several factors that more or less significantly influence how accurate the location of a tag can be determined:

- The layout of how the antennas are placed (design of the antenna grid),
- The RFID antenna model,
- The RFID tag, and
- The read range of the employed reader.

Depending on various factors that can be influenced by the setting, the read accuracy can be rather precise. Currently, we investigate how we can maximize the accuracy by varying these factors. Our future work will specifically concentrate on improving the estimates (achieving a higher resolution of the scanned area) by employing smaller antennas and tags.

The idea of supporting the players by providing them with relevant information based on the current state of the game holds great potential: The players are not only disburden with acquiring this information manually, which can be cumbersome and annoying; but, in doing these tasks automatically, they can fully concentrate on the actual game events and the social interaction. It is also possible to support the players even more by, for example, automatically capturing the results of the dice, cf. [10].

And, by doing this in a totally unobtrusive way, pervasive computing technologies such as RFID technology can highly contribute to closing the remaining gap between the physical and virtual world and thus to bringing a new level of entertainment and fun to the players.

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