Determining the Position and Orientation of Multi-Tagged Objects Using RFID Technology

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Abstract

The idea of smart shelves or tables equipped with RFID technology has been around for some time now. There already are commercial products available, especially for retailing. All presented solutions, however, are designed to only identify objects currently in range. While this may be sufficient for some applications, there are others that do not only require identification, but furthermore the exact position and orientation of the objects.

In this paper, we present an approach to determine the position and orientation of multi-tagged objects. We introduce the general idea, then our developed system, and finally our preliminary findings. We also summarize our next steps and describe a planned test series.

1. Introduction

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).

There are two central assumptions in this scenario:

- For these applications it suffices to have one antenna to cover an area and read all goods within read range.
- 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).

One application that we are currently investigating is a table-top game where game pieces of two or more parties are moved over a game board to engage in battle. To do so, it must be determined which adversary game objects are within the visual angle of a given game piece and what the distance is between them. Currently, this is realized manually with rulers and goniometers. Our aim is to support the players by automatically capturing this information and providing it to them.

To achieve this, we increase the number of antennas covering the surface (i.e., an antenna array covering the game board) and the number of tags assigned to each game piece (i.e., multi-tagged game pieces). The goal is to find an optimal combination and configuration of antennas and tags to achieve the best possible accuracy of determining position and orientation of the objects.

This paper describes our approach, the current status of the project, and future steps.

2. 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 shelf or 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 and compare other position and orientation technologies to our approach.

2.1 Smart Shelves

Smart shelves have been studied by several research groups and there already are industrial initiatives that apply these technologies [4, 8, 14, 15].

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.

2.2 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 [3]. 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 [11]: 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 [1, 2] 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.

2.3 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 centimeters [17]. Though this level of preciseness might be good enough for other applications, it does not meet the requirement of our application. Besides, the 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 [10, 16]. Systems such as Active Bat allow the localization of an object within approx. 3 centimeters, 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.

Schmidt et al. present a load sensing system that allows 2D-positioning on a table [12, 13]. 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. For this reason, we also do not consider infrared technology (e.g., [7]), which depends on line-of-sight, nor other approaches that require a rather flat table, e.g. [9].

Magerkurth et al. developed STARS, a table-top game that allows identifying game objects and their position and orientation on a table based on visual recognition [5, 6]. 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.

3. Our Approach

The RFID-based calculation of the position and orientation of a multi-tagged object can be rephrased to locating each single tag with as little deviation as possible. Based on the preferably exact position determination of every tag and detailed information of the multi-tagged object (i.e., shape and size), we can estimate where the object is located and how it is angled with a certain probability.

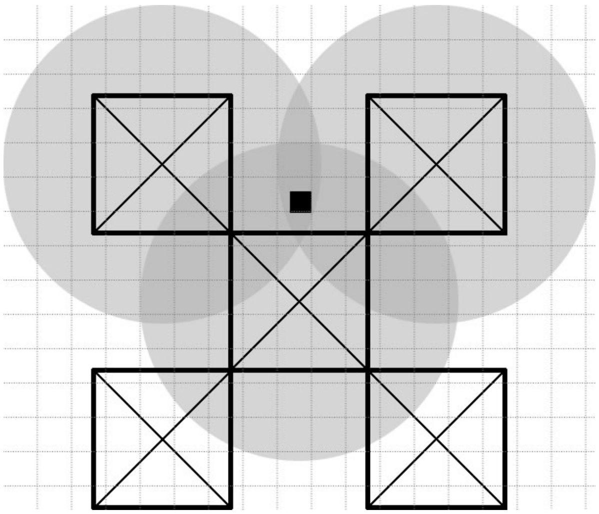

Figure 1: Determining the position of a single tag using trilateration

We use trilateration to estimate the exact location of a tag. The general principle is shown in Figure 1. The circles around the antennas symbolize their read range given a specific tag (read range inter alia varies with the tag model). The dark area in the center marks the area on which the tag, represented by the 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 array. The smaller the read range circles, the more antennas there are and the denser the grid, the better.

Theoretically, it is sufficient to have the exact location of two of the n tags an object is equipped with. But due to numerous technical deficiencies of the currently available equipment and the general problems with 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 factors/components:

- Layout of how the antennas are placed (antenna array design),
- RFID antenna model,
- RFID tag, and
- 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 used equipment, and, on the other hand, we want to get a general understanding on how and to what extend different antenna arrays, RFID antennas and tag models influence the outcome.

4. Current Status and Next Steps

So far, we have used one antenna model (FEIG ID ISC.ANT 100/100) and one antenna array layout. We experimented with several different RFID tags and measured the range in which each tag can be read by the reader.

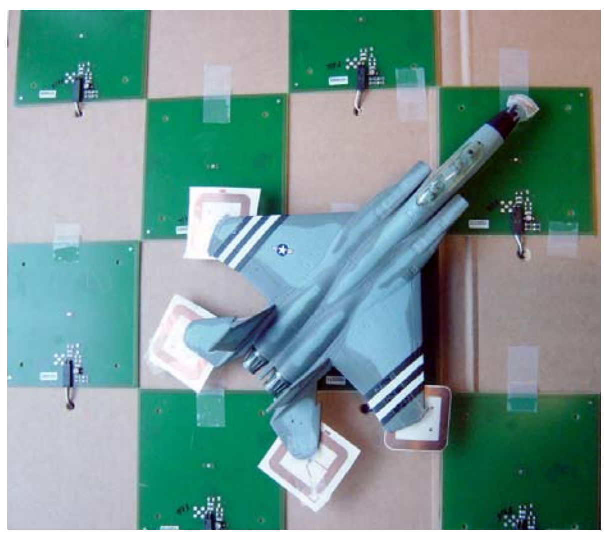

Figure 2: Antenna Array with a multi-tagged object placed on it

We arranged eight antennas in a chessboard pattern (see Figure 2). Since each antenna has dimensions of 10x10 centimeters we cover a total area of 40x40 centimeters. 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 (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 Figure 3).

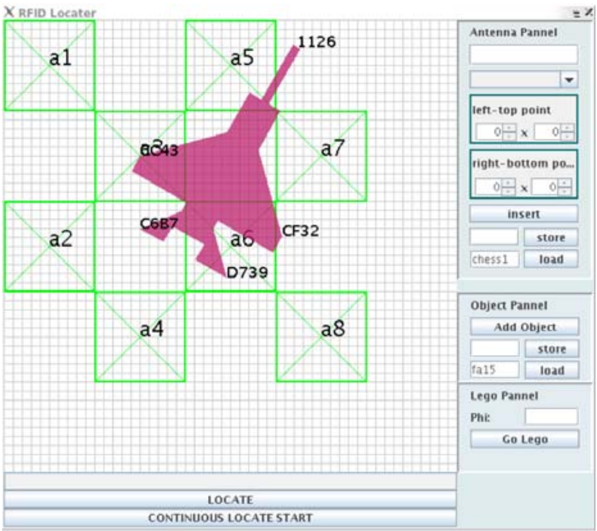

Figure 3: Screenshot of the GUI, displaying the estimated position and orientation of the object

The numbers at the edges of the object correspond to the last four digits of the ID of the read RFID tag (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 centimeters. The bigger squares named “a1” to “a8” display the antennas in the chessboard layout.

Our preliminary tests showed that the estimates of the scanned tags are within a few centimeters. This is a rather good result for the position, but not yet sufficient for the orientation: given a deviation of only 3 centimeters, for example, the visual angle is biased significantly (the exact bias depends on the size and shape of the object, i.e., the smaller the object the bigger the deviation).

Therefore, we intend to further vary the layout of the antenna array, 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 (or even in addition to) the 10x10 centimeter antennas should increase the preciseness distinctively. Increasing the number of tags while simultaneously using smaller tags should also result in a higher accuracy.

We are planning to conduct a test series that evaluates each combination. Three real-world objects are equipped with several RFID tags and then placed on the antenna array, varying position and orientation using a test system developed by us.

In addition to this empirical approach, we also intend to come up with a mathematical model, if possible. The factors influencing the result of the presented approach are diverse: besides the aforementioned hardware components and the layout of the antenna array, the accuracy also depends on environmental factors (e.g., metallic elements). For this reason, a first approach would initially only include the hardware components and the layout of the antenna array.

5. Conclusions

In this paper we presented a novel approach to calculating the position and orientation of objects using RFID technology.

We demonstrated the idea of equipping a surface with an antenna array and placing multi-tagged objects on it. Determining the position of each single tag allows us to estimate where the object, that the tags are attached to, is positioned and how it is angled.

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 antenna array is installed under a table and the RFID tags are invisibly embedded into the objects), and can thus unobtrusively support the players’ actions. Furthermore, RFID technology is comparably inexpensive compared to other technologies such as UWB or ultrasonic, which also require a fixed infrastructure.

Our future work will specifically concentrate on improving the estimates (achieving a higher resolution of the scanned area) by employing smaller antennas and tags on the one hand, and by optimizing our estimate algorithm on the other hand.

By attending this workshop, we hope to receive valuable feedback through discussions and comments.

6. Acknowledgements

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