A Passive RFID Location Sensing

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ABSTRACT
This paper proposes a location sensing model based on passive RFID systems. The proposed model is useful for identifying the location of moving nodes relative to existing anchor nodes, i.e., nodes with known coordinates, which has applications in logistics, yard and warehouse management. The study explores algorithms for estimating location coordinates. These algorithms are much simpler to implement than other techniques such as signal attenuation that have been suggested by others. The proposed model does not require special hardware and control software that is needed by other approaches. It only requires basic passive RFID readers and tags. The study also demonstrates the implementation of a prototype in a laboratory environment along with the experimental results.

Keywords: RTLS, localization, location sensing, location identification, positioning, passive RFID.

1. INTRODUCTION
Monitoring and the control of physical environment has always been a subject of interest in ubiquitous computing. Such ability has vast applications in numerous areas most notably in warehousing and logistics. Order picking in warehouses, positioning a container in a shipyard, tracking a fork truck or a robot are some examples. In particular, identifying and monitoring the location of a moving node such as a fork or lift truck within a facility in real-time increases visibility, enhances managerial decision making, reduces costs and improves delivery and service.

Light frequency identification (LFID), [8], or bar coding technology has been used in grocery and other industries since 1974 with the advent of the UPC bar code standards and numbering system to manage and identify items. It was one of the most cost effective technologies that have ever been utilized in the supply chain. The technology improved inventory accuracy and visibility throughout the supply network, thus improving service while reducing inventory levels, overproduction, and cost. LFID or bar coding has a few shortcomings. It operates at the visible light or infrared frequencies, needs line-of-sight scanning, labels are not rewritable, symbols should be scanned one at a time and scanning needs human intervention in the majority of applications. Nevertheless, LFID has been used for location identification in some warehouse environments.

Radio frequency identification (RFID) technology, on the other hand, does not have those shortcomings and has been successfully used in a variety of closed-loop applications since the 1980s. In the past few years, the development of an open-loop RFID-enabled supply chain management system known as the EPCglobal network has created considerable momentum for research and development in a variety of IT industries. This lead to the rapid development of new technologies, hardware and software leading to a considerable reduction in RFID technology deployment costs.

One novel closed-loop application of RFID technology is for location identification in real time. These solutions are known as real-time location sensing or RTLS. RTLS employ a variety of tag types such as active transmitter, passive backscatter or semi passive (battery-assisted passive backscatter or BAP). One advantage of BAP and active over passive tags is that they have longer read range than passive tags, can be integrated with various sensors and log sensor generated data for transmission. The manufacturing cost of passive, BAP, and active tags differ substantially with passive tags being the cheapest by a wide margin. Therefore, passive RTLS systems are in general much less costly than the BAP or active RTLS. Some companies such as Alien have discontinued their BAP product line as a result of Gen 2’s superb performance and their substantial lower cost.

In this paper, I propose a passive backscatter RTLS system, primarily for indoor applications that differs from the existing passive RTLS systems and is much simpler and less costly to implement.

2. LOCATION SENSING SYSTEMS
We define location sensing as systems or methods that automatically discover spatial association among objects. This definition is consistent with the current literature for example, [9], [11], and [5]. If such a system is able to provide the location information instantly as the position of the object of interest changes, then it is referred to as a
real-time location sensing (RTLS). Other terminologies such as localization, positioning and location identification have also cited in the literature. This paper employs these terminologies interchangeably.

Location sensing systems may be classified and studied from a variety of perspectives and attributes. Cost is a major factor to be considered in any such study. Suitability of the system for indoor or outdoor implementation is another major factor. Other important attributes [6] include signal technology, location assessment methodology, and location estimation algorithm. A rather comprehensive classification of locating systems can be found in [5] and [11]. Some of the major attributes of various location sensing systems are explained below.

**Decentralized versus centralized location computation**
In decentralized location identification, each node calculates its position locally. The most prominent example is the Global Positioning System (GPS), which the location of the node or GPS receiver is computed by the node based on the signals directly received from some of the more than 24 special satellites orbiting the earth.

In centralized or network-based location identification, various nodes usually propagate some signals or information. The signals are then processed by another (usually centralized) processing unit to estimate the location of each node. Most commercially available active RFID location systems employ such approach. It is also possible to have a hybrid system, which the node and the centralized processing unit cooperatively calculate the location to improve accuracy, for example, the Assisted GPS [1].

**Outdoor versus indoor**
One of the pioneering locating system, Global Positioning System (GPS), has traditionally been used for outdoor localization [7]. GPS signals cannot penetrate many structures and thus becomes ineffective when indoor localization is needed. Technologies such as RFID, ultrasound, and infrared have been employed to primarily address indoor localization.

**Accuracy and precision**
Accuracy relates to the grain size. In other words, how close the estimated location coordinates on average are to the true location. For example, a system that returns estimates of location that are on average within a foot of the true location is more accurate than a system that returns an estimate that is within 10 feet. Precision (or reliability), on the other hand, relates to the consistency of location estimates. In other words accuracy corresponds to the mean of location estimates but precision relates to the variance of location estimates. For example, two systems may on average estimate the location with accuracy of one foot but the system that produces estimates with smaller variance has more precision.

Drawing from the field of statistical process control, high-precision low-accuracy systems are easier to bring to perfection than high-accuracy low-precision.

**Signal technology**
Automatic location identification systems have generally employed some physical phenomena as reference beacons such as the electromagnetic energy (light or radio) as well as mechanical energy (ultrasound). Some systems employ more than one signaling technology, in combination, to achieve their goals. Various implementation have used a variety of signal type and frequency from ultrasound to infrared.

**Location assessment method**
Some method should be used in order to assess the location of an unknown node relative to the known position of some other nodes. Two general approaches have been used with signal technologies mentioned above [5]: Triangulation, and Proximity. These approaches can be used individually or in combination. Other researchers refer to these two broad approaches as range-based and range-free, respectively [6].

**Triangulation - range based**
Location assessment approaches employing triangulation or range-based methods rely on the geometric properties of triangles and signal characteristics to assess object locations. They translate signal characteristics into absolute measures of distance. The techniques can further be divided into subcategories of lateration -- measuring distances, and angulation -- measuring angles.

**Lateration:** The position of a node in lateration approach is computed based on measuring its distance from multiple non-collinear reference points. In general, at least \( n+1 \) distinct reference measurements are required to compute the location in \( n \) dimensions.

Two signal characteristics have been used in practice for calculating distance, time-of-flight and attenuation. In time-of-flight approach, the time it takes for a particular signal to travel from point A to point B is used to calculate the distance between the two points on the basis of the known speed of the signal (light). The implementation of time-of-flight approach includes time-of-arrival (TOA) and time-difference-of-arrival (TDOA).

Attenuation approach, on the other hand, relies on measuring the strength of the signal, knowing that the signal loses its intensity as it travels farther away from the emitting source. Therefore, the distance between point A and B is calculated by comparing the strength of the signal at the two points. For example, the strength of a radio signal in free space is reduced or attenuated by a factor of \( \frac{1}{d^2} \) after traveling a distance equal to \( d \).
Angulation: In angulation method, multiple phased antennas with known separation measure TOA of a signal. This information along with geometry of the receiving array are used to measure the angles of the signals arriving (AOA) at the known nodes. This information is combined with at least one known length such as the known distance between two reference points to assess the location [5].

Proximity - range free
The principle in proximity or range-free approach to location sensing is to estimate the location of a node by determining its nearness or connectivity to some reference points with known locations. For example, when a wireless laptop detects an access point, the information can be used to infer the proximity to the access point. As another example, when an RFID reader detects a UHF tag and reads its ID number then the tag should be within a few feet of the antenna. As the examples show, the accuracy of this approach varies greatly and depends on the underlying infrastructure used.

The approach in general produce coarse location information but their results are less sensitive to noise than the range-based techniques [10]. The technique can offer relatively good accuracy if sufficient infrastructure is in place otherwise a coarse and potentially ineffective estimate of the location will result.

Physical and semantic location
The location sensing systems may provide two types of information: physical and semantic (or symbolic). Physical information corresponds to the position of a node on the physical coordinates. For example, the GPS system provides the global coordinate of a GPS device. As another example, the position of a node or a forklift truck in a warehouse can be expressed in terms of its Euclidian $x$, $y$ coordinates with respect to an origin. The origin can be in or out of the warehouse. An advantage of physical location information is that one may infer about the spatial relationship (e.g., Euclidian distance) of two nodes based on their physical location information.

The semantic information, on the other hand, employs description or symbolic characterization of the position. For example, Arkansas State University is located in Jonesboro, Arkansas or the forklift truck is in isle number three or dock door number five. The advantage of symbolic information is that it can readily be interpreted by human. On the other hand, one cannot directly infer about the spatial relationship (e.g., nearness) of two nodes based on their symbolic position information.

3. THE MODEL AND METHODOLOGY

Based on the above taxonomy, our proposed model is a range-free or proximity location sensing, employs physical position information, and can be implemented in a centralized and/or decentralized applications i.e. the location coordinate calculation can happen at the moving node or at a centralized control computer. The proposed model consists of passive RFID tags that are positioned at known locations within a facility. These are called anchor or reference tags. Each anchor tag has in its memory the absolute coordinates of its location with respect to a known reference point (origin). One or more moving nodes, each containing an RFID reader, can identify their positions within the facility by reading the coordinates of the nearby anchor tags. A node can resemble an automobile, a forklift truck, a robot, a cart, a person or any device, whose unknown or changing position within the facility is of interest.

The accuracy of this technique depends on the population density of the reference tags. In other words, the closer the reference tags are to each other, the higher the resulting accuracy. However, when anchor tags are too close to each other, the reader may read multiple tags simultaneously. This complicates the location estimation because it is not clear which tag’s coordinates is a more accurate estimate of the node’s location.

One technique suggested in the literature is tag isolation. [3] (U.S. Patent) suggested the use of signal attenuation to isolate tags. In this method, the intensity of reader’s radio signal is decreased iteratively in order to decrease the read range. As a result, tags that are farther away become unreadable. The iteration continues until all but one tag fall outside the reading range. It is assumed that the last tag remaining in the read field is the closest tag to the node and thus its location is the most accurate estimate of the location of the node. This method has several shortcomings. For example, the iterative process may not result in an isolated tag. In other words, the last two or more tags may become unreadable simultaneously in the last iteration. As another example, manufactured tags may not have uniform sensitivity and responsiveness. Some tags might be louder than others. In this case, the isolated tag may not be the closest tag to the reader.

It should be pointed out that [2] (Patent application) suggested a system with some similarity to what suggested in this paper. However, the major difference is that in their proposal, the tags physical location is found in a lookup table. However, our system reads the reference location information directly off the tag.

Infrastructure requirements
Sufficient passive UHF Gen 2 RFID reference tags are properly positioned to form a grid structure on the floor, ceiling, walls, or under carpet, tile, concrete, sub floor, etc. The memory module of these tags will be programmed to contain location coordinates information. Various tag frequencies may be used. However, UHF band with Gen 2 tags is preferred due to range, performance and implementation costs.
In a two-dimensional implementation, the Euclidian plane may resemble the ceiling, floor, wall etc. of a warehouse facility. The two perpendicular sides of a warehouse may be used as the x and y axes and to determine the origin. It is also possible to use imaginary perpendicular lines within or outside the facility as the axes.

Once the origin is determined, we may mark off a number scale on the x and y axes starting at the origin using a reasonable unit length (let say one meter or one foot). While not necessary, applying uniform grid lines on the x and y axes to form square grids simplifies computation.

Tags are placed at the (real or perceived) intersection of the grid lines (Figure 1). Each tag stores in its memory its x, y coordinates. It is recommended that a tag be affixed at the intersection of all gridlines. However, this is not necessary in our proposed methodology. For example, there is no need to place tags in areas that the node cannot access or get close such an enclosed office space in a warehouse.

It is assumed that the moving nodes, whose location information within the facility is of interest, such as fork or clamp trucks can move within the facility, on or parallel to the Euclidian plane, and are equipped with an RFID reader and one or more patch antennas. The antenna’s radiation surface is parallel to the surface of the grid. The reader can communicate with the host application through the Wi-Fi (or other wireless protocols) network.

![Figure 1: A conceptual two-dimensional implementation](image)

**Location computation methodology**

Our methodology is based on simple algorithmic computations that can be implemented through software. Various algorithms are needed because each may produce solutions with higher accuracy and/or precision depending on the design and the state of the underlying grid infrastructure such as reference tags density, the electromagnetic field, and the impact of multipath radio reflection or signal absorption. All or select algorithms can be applied for location estimation simultaneously. A higher level of precision may be assured when various algorithms lead to the same or similar coordinate estimates. In cases when the estimated location coordinates are not identical, simple rules such as the average of those solutions may be applied to arrive at a unique estimate. Such adaptability is not warranted under the attenuation method [3].

In this paper, we explain the centroid method. The following notations are used in the analysis. Given the set of all reference points (tags), $R$, with coordinates $(X_i, Y_i), i \in R, j \in R$. Let’s assume that at time, $t$, the reader reads a subset of the reference points, $r$, containing a set of tags with coordinates $(X_j, Y_j), i \in r, j \in r$. The center of gravity or centroid $\overrightarrow{C} = (\overrightarrow{X}, \overrightarrow{Y})$ is calculated by Eq. (1):

$$\overrightarrow{C} = (\overrightarrow{X}, \overrightarrow{Y}) = \left( \frac{\sum_{i \in r} X_i}{k}, \frac{\sum_{j \in r} Y_j}{k} \right),$$

Where $k$ is the number of points or tags in $r$.

The point $\overrightarrow{C}$ is considered an estimate of the current location of the node. An interesting result of the proposed approach, i.e. the use of Euclidian coordinates, is that the current location estimates at various consecutive points in time, for example $\overrightarrow{C}(t=1), \overrightarrow{C}(t=2),...$, can be used to monitor the direction of the movement of the node.

**4. EXPERIMENTAL RESULTS**

Figure 2 depicts the reference tags grid with the origin $(0,0)$ in the center of the grid. Therefore, the plane spans all four quadrants. The grid lines are not uniform in distance and include one-foot and 2-foot separation both horizontally and vertically. A tag containing the coordinate information is placed at the intersection of all vertical and horizontal grid lines. Visual information about the coordinates has also been provided at each intersection.

We exhibit the result of one pilot run to demonstrate the viability of the method. In this run, the patch antenna, supposedly installed on a fork truck, was placed parallel to the plane, four feet away, and at the position with coordinates $(3, -2.3)$. On the Figure, this location is represented by a heart symbol. This location was estimated visually by projecting the center of the patch antenna onto the plane. Figure 2 also shows those tags.
that are detected by the RFID reader (triangles), and the centroid estimate of the location (2.5, -2.7) depicted by a star. The centroid estimate is calculated based on the coordinates of the detected tags as follows:

\[
\text{\textbf{r}} = \left\{ (0,0), (-2,-4), (2,-5), (5,-5), (5,0), (0,-2), (2,0), (4,-4), \\
(4,-2), (2,-2), (4,0), (2,-4), (0,-4), (4,-5), (5,-4) \right\}
\]

\[
\tilde{C} = (\bar{X}, \bar{Y}) = (2.5, -2.7)
\]

The x-coordinate and y-coordinate of the centroid solution is the average of all x coordinates and y coordinates of all detected tags, respectively. The result shows the subjective accuracy of the method.

Figure 2: A conceptual representation of the grid, detected tags (triangles), true location (heart) and estimated location using centroid (star).

5. CONCLUSION

This study presented the viability of using passive RFID tags in location sensing through the use of Euclidian coordinates or physical location information instead of symbolic location information. We proposed one simple algorithm, centroid, to estimate location by using the coordinate information. The centroid approach has been suggested by [2]. However, that study used the centroid method in a different scenario and under different radio technology. First, they were dealing with outdoor localization. Second, the reference points were active radio transmitters that broadcasted their location coordinates. The implication of our research is different than [2] in that our research is focusing on: (1) Indoor location sensing, (2) passive RFID tags, and (3) the nodes that should interrogate the reference points in order to determine its position.

We are currently exploring various other heuristic algorithms. A battery of various methods is required because each method may perform better in a different environment and RF conditions. These may include density of tags, health of the infrastructure, whether or not all reference tags are operational, electromagnetic interference and electromagnetic field distortion. Another extension of this research that we are considering includes the use of multiple patch antennas with various radiation angles. Extension of the research should also include experimenting under more realistic conditions to determine the accuracy and reliability of various algorithms.

6. REFERENCES


