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Algorithm for an indoor automatic vehicular system based on active RFIDs☆

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Abstract

An algorithm for helping the routing of heavy vehicles within an industrial setting is proposed. The system makes use of active RFID tags placed all over the industrial area. The algorithm aims to minimize shifts and loads of heavy vehicles in order to reduce production times and costs. Results are encouraging and the system is particularly adaptable to different scenarios. For example, it could be used by companies producing concrete to drive trucks to efficiently collect the materials needed for the product recipe.

Keywords: Active RFIDs; Indoor localization; Vehicular system

1. Introduction

A location sensing algorithm that uses Radio Frequency Identification (RFID) technology [1,2] for locating objects inside buildings is presented. It improves the overall accuracy of locating objects by utilizing the concept of reference tags. Based on experimental analysis, active RFIDs are considered viable and cost-effective candidates for indoor location sensing.

Although the use of Wi-Fi systems could be the best choice for this type of application [3] they can result in a high cost when it becomes necessary to cover the entire area. Furthermore, if indoor location sensing inside metal sheds is considered, the use of GPS systems (which guarantee a high degree of accuracy) is not possible.

At present, owing to their limited cost and dimensions, passive RFID tags are widely used, while active tags are still less common. However, active RFID tags can function as "beacons" to aid, for example, in navigation [4] and localization [5].

Here, an accurate positioning technology which can identify the movement and location of vehicles and goods and provide real time information, is presented. The RFID signals from an object attached with an active tag is automatically detected and recorded in the database for location detection.

The research methodology of this study has three phases: analyze the design specifications and deal with the most important implementation details, analyze the production cycle, which is the part of the project that involves vehicular aid and finally develop an algorithm to discriminate among the different RFID-tagged areas, in order to aid in handling the vehicle.

2. The problem

The problem of indoor location sensing using active RFIDs is not completely new, and some works and algorithms can be found in literature. Some of them have been discussed and summarized in review papers [6–8]. Some of the others works, in particular, the original LANDMARC [9] and VIRE [10] algorithms, and some of the more recent and enhanced versions [11–15], are worth citing. Furthermore, the recent advances in indoor localization techniques, which are mainly based on passive RFID can be found in [16,17] and [18].

Many of these methods assume that the emitted signal is almost omni-directional and are dependent on the signal strength received by the tag reader. These assumptions could be almost valid in free space, where the power of the received

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signal can be measured to a certain degree of accuracy, since it decreases with distance according to the well-known Friis law [19]. Some models that account for the antenna height, path loss, delay, etc. in non-free-space environments have also been developed [20–22]. Theoretically, such models can be used to correct the free-space assumption and estimate the distance from the reader to a tag, based on the received signal strength. However, the major limitation of such models is that most of them assume a propagation scenario with a limited number of reflections and obstacles. However, according to [23], in which a study was conducted in a simple but real office building, the metal window frames and pipes passing through rooms are obstacles to RF signals that cannot be neglected. Furthermore, cabinets, timber walls, and people can cause extra path loss as well as multiple scattering when the signals penetrate through them.

Hence, in a real, complex operating environment similar to that considered in the present paper, where many reflections and multiple paths are present which are also time-varying, it is almost impossible to discriminate according to the signal strength. In addition, it must be noted that, because of production tolerances, the power of active tags can vary from one another, despite the fact that they are all tuned at the same output value. Furthermore, the use of a regular grid of passive tags for localization, which is suggested in many of the cited papers, is very difficult to implement in a real, harsh environment.

In the algorithm developed in the present work, one important design decision was to design a system that, rather than not reading, might give rise to false positives, which can be filtered out later. This choice was dictated by the environmental characteristics. While it is almost impossible to avoid false readings, it is also true that, under certain conditions, RFID tags will be unreadable and this would make the system "blind". Therefore, it was decided to operate with more power, at the cost of an increased number of false positives.

Moreover, another important constraint that was taken into account in implementing the algorithm was the processing speed capability of the system. Indeed the system is simultaneously engaged in the identification of the right container as well as in reading the necessary components for the recipe in progress, weighing, etc., while the vehicle is moving around at a more or less "random" speed and also along a path that is chosen by the human operator that cannot be predicted easily.

3. The production cycle

The following is a simplified, but typical production cycle of heavy industries. The main actions carried out by heavy vehicles are:

1. Select the order to be processed.
2. Retrieve the recipe related to that order.
3. For each material in the recipe,
    (a) Retrieve the warehouse containing the material
    (b) Collect the material
    (c) Select the proper area where the material must be unloaded
    (d) Unload the material at the specified area
4. If any warehouse or any other place is no longer needed, remove it from the recipe.

The processing phases described in point no: 3 can be repeated until the required quantity of materials is not collected.

It is possible to work in parallel with multiple production orders, switching from one production order to another.

During the process of material collection, it is checked whether the quantity of retrieved materials is sufficient to meet the production requirements. If something goes wrong during the collection process, the system must signal this with an error code.

All the operations are usually recorded in the log and the order status is updated each time an operation is completed.

It is possible to record the operations manually, since manual operation is required when handling materials without RFID tags, in cases when materials from other containers are to be used, and when operations mistakes have to be corrected.

When the total quantity of raw materials retrieved from the warehouses or manually recorded is equal to the quantity to be produced, a loading completion message is displayed by the system.

4. The driving algorithm

Warehouse trucks are practical equipment for lifting and moving goods in warehouses. The working scenario of warehouse trucks is complicated. In industrial environments, it may be very useful to utilize control algorithms for driving vehicles during the stages of collecting materials from different containers or warehouses.

The basic idea is to have a single RFID reader that moves with the vehicle, and many fixed active RFID beacons, which are placed without following any regular disposition and that are used to tag the various regions of interest. This scheme is also referred to as *reverse RFID*, since it reverses the usual implementation of RFID subsystems by locating the RFID tags at fixed, known locations.

Due to the characteristics of the working environment, it is possible to have false readings of RFID tags and cases in which the tags are not read even if they are correctly transmitting a signal. However, due to the nature of the problem, it is necessary to implement a system that is more sensitive to false positives than to missed readings. In fact, false positives are not a big problem as the proposed algorithm eliminates them.

A key element that has to be taken into account when developing the algorithm is the processing speed capability of the system.

The system simultaneously performs an analysis to identify the correct area and read the list of necessary materials for the order in progress, while the truck is moving along a specific path, which needs to be predicted for the handling operations.

The proposed algorithm is based on the arrival times and repeated readings of the same identifier, which is sent from a specific area that is equipped with active RFID tags. The system matches each area with the following information:

- RFID code
- Area (container) description
- Type of container (e.g. warehouses, waste dump, other areas)
- Location
- Capacity.

Specific areas can be labeled with one or more RFID tags to enable automatic recognition by the vehicle.

The objective of the algorithm is to identify the container in which the vehicle is present and to decide if it is the correct place for the current recipe. In particular, the readings are counted and ordered by the arrival time and put in an *item* list. Another list is associated with the containers placed in that area. The tag identifiers (tag-id) that are received are asynchronously processed, according to the flowchart shown in Fig. 1, while the item and container lists are updated at regular intervals. In particular, the item list is processed and any tag-id that has an arrival time exceeding a preset constant is removed from the list. The remaining tags are processed and the container list is updated accordingly. As for the recipe, during the production cycle, an in-memory copy is kept up to date with the operations, and the containers that are no longer valid are removed from the recipe table and marked as bad. These steps are summarized in the flowcharts shown in Fig. 2. A decision is taken at regular intervals. At each clock tick, the container with the larger number of readings and with the more recent arrival time is selected.

The operator can also manually record any kind of operation. This is necessary because there may be areas without tags in the warehouse, from which materials need to be collected.

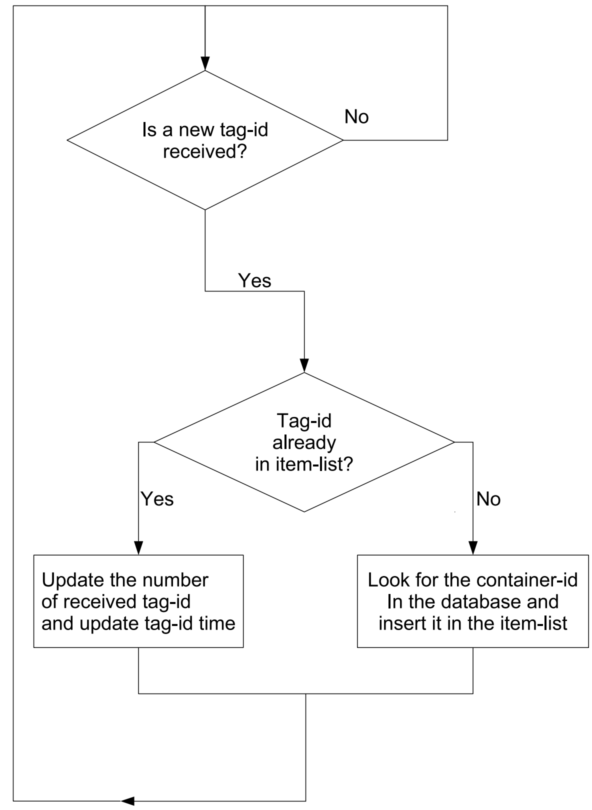

Fig. 1. Flowchart for processing the received tag identifiers.

5. Results and discussion

Although a theoretical assessment of the capabilities of the algorithm, and, in turn, of the entire cycle, was not carried out, this algorithm was implemented in a real production line [24].

For this, a radio-frequency identification subsystem featuring a reader and several tags in the 2.4 GHz band were used.

Active tags, working in beacon mode, were selected, ensuring that the system will properly work even in case of longer tag/reader distances, for example in warehouses. The batteries can last up to 5 years. The tags are encased in a rugged shell, for working in harsh environmental conditions and for protecting the RFID tags from dust (which is the main unwanted element in this case), extreme temperatures, and moisture.

The tags are placed near the warehouses to ensure unhindered operation and movements of the vehicle and good tag/receiver communication.

The output power of each tag can be adjusted for proper reading distance tuning. For example, when the vehicle enters very small tagged-areas, less power will be required for higher reading selectivity, since the tags will be very close to the reader.

The reader is enclosed (both the transceiver and the antenna) inside an IP65 box and is installed inside the vehicle cabin, just beyond the windshield.

The identification information that the RFID tags transmits to the reader is typically a unique serial number. Although the tags are read-writable, the algorithm proposed in this paper does not require rewriting the tags or storing further information, because the unique tag identification number is sufficient to identify the area. The material-tag matching, which is the precise identification of the material available in that specific site, can be carried out via software using the information stored in a central database.

After a long testing period, the new system is now perfectly integrated in the production cycle, and has considerably enhanced the production quality.

6. Conclusions

In this paper, an algorithm for indoor automatic vehicular systems based on active RFIDs was introduced. The algorithm helps in driving a heavy vehicle inside an industrial area to efficiently collect materials needed for a specific production order from different warehouses. This system can be used (for example, by companies that produce concrete) to drive trucks for the efficient collection of materials needed for the product recipe. In such environments, the materials are stored in containers placed in different areas; each area is equipped with one or more tags in order to drive the truck to collect sand, cement, and lime.

Experimental analysis has demonstrated that the algorithm significantly enhances production, and therefore active RFID

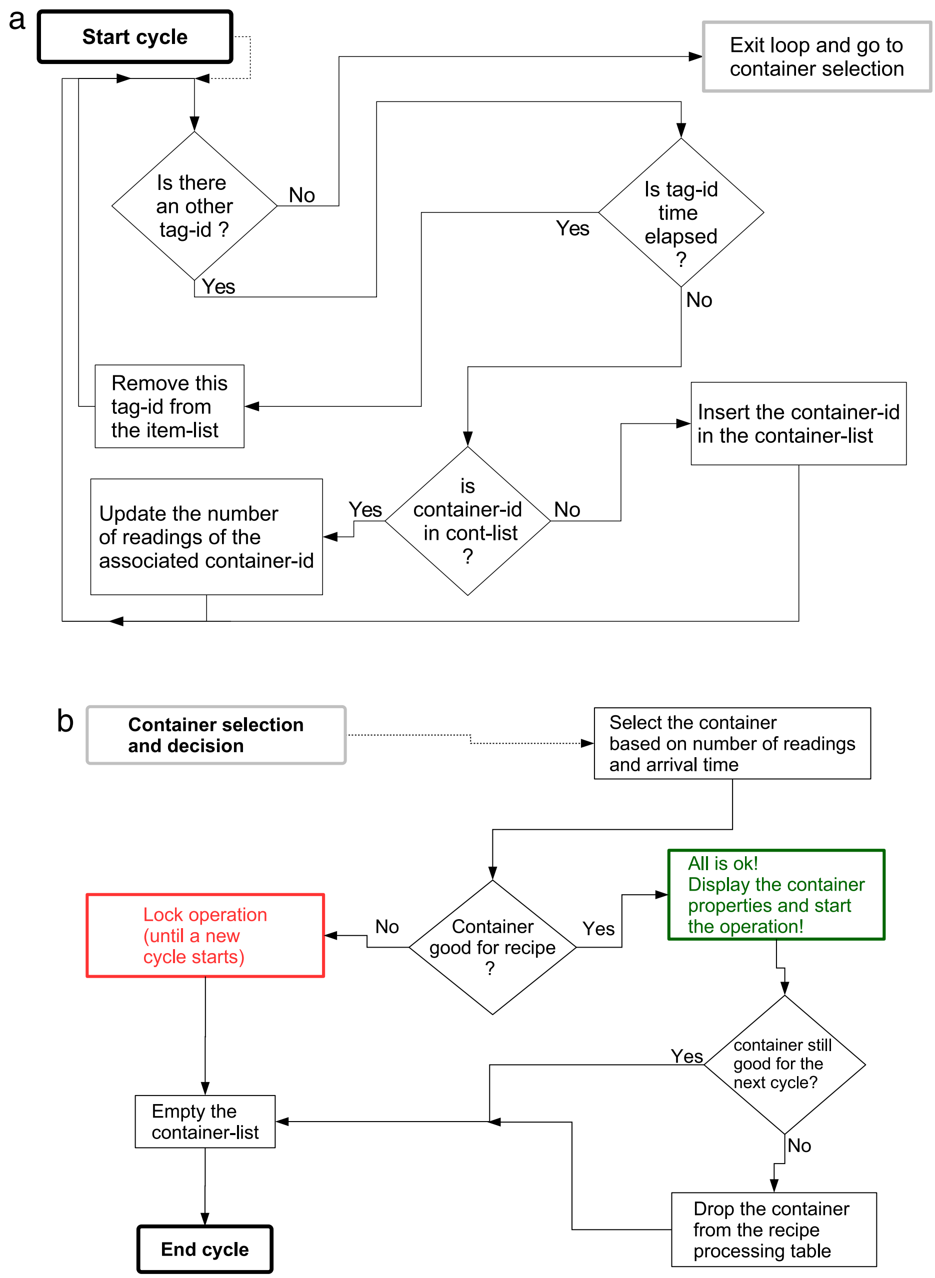

Fig. 2. Tag list processing (a) and container selection (b) flowcharts.

technique is a viable and cost-effective candidate for indoor location sensing.

Future developments would be focused on defining some metrics to access the capabilities and limitations of the system from a more quantitative perspective. For this, the customers could be asked to provide more relevant data for statistics, the decision algorithm could be studied from a theoretical perspective, and a simulation framework could be defined to quantify the dependence on various important parameters (e.g. vehicle speed, RFID location, area, dimensions, etc.).

Conflict of interest

The authors declare that there is no conflict of interest.

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