Design and Implementation of a RFID Based Real-Time Location-aware System in Clean Room

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Abstract—Application of Automated Material Handling System (AMHS) to the semiconductor manufacturing factories is one of the most important steps in the automation process of semiconductor business. All cassettes in the vehicle of the transportation facility can send their positioning information through this system. Nevertheless, some positioning information may still be interfered or get lost if there is any relocation of the cassette inside the effective ranges of AMHS by operators. In order to retrieve these lost cassettes only manpower is possible, and the relocation process is time wasting and inefficient. In this paper, we have implemented a Clean Room Real-Time Location-aware System (CRRLS) that is based on the technology of RFID (Radio Frequency Identification). The proposed system can reveal the positioning information of the cassette in the clean room by analyzing the received radio frequency energy information. Moreover, we establish a transmitting model of radio signal, and used this model to estimate distance between RFID tag and readers. A triangular positioning algorithm is developed to estimate the location and its 2-dimensional coordinate of the cassette. Furthermore, reusable RFID tags can save additional information sent by the transceivers and data of parameters for the production process to reduce the possibility of severe damage because of wrong parameters setting. As a result, competitive advantage of the semiconductor business can herewith greatly increase.

Keywords—semiconductor manufacture; automated material handling system (AMHS); RFID; infrared; LANDMARC.

I. INTRODUCTION

Semiconductor industry is one of the most important high-tech industries in Taiwan and has spent a lot of manpower and material resources in every respect. Time saving in this industry is the most important issues. Engineers are doing their utmost best to reduce unnecessary time consuming from all possibilities and to lift percentage of yield rate. However, in a broad area such as clean room, varieties of machines equipments and pipelines are all over the places. It may happen some important products were misplaced by operators in a temporary storage area from time to time and eventually were lost because of human negligence. It takes even longer to reallocate this misplaced product than to reproduce it. No matter what, it is an immense damage of this business, and is something we are trying to overcome in this study.

In this paper, we present an effective indoor positioning system by the RFID architecture that allows users to keep tracking location of product. Staff is no longer required to leave their jobs to look for missing products caused by some personal negligence. It can cut the time waste and extra financial expense owing to machine idling and reduce the possibility of casualties during searching by manpower. On the other hand, many parameters and information sent by the rewritable electronic tags can be received by the RFID readers that are mounted on the machine platform [9]. Engineers can accurately read and correctly implement parameters on the production. In addition, they can pay necessary attention, so that it can not only reduce the low wafer production settings due to human error caused by lost reference data but also reduce paper consuming by the engineers or operators in the clean room to mark notice. This technology can make the entire clean room toward a paperless (Paperless FAB) environment [4].

The production machines in most semiconductor factories in Taiwan read product-related information by bar codes readers at present. Due to possibilities of pollution error, detachment or fading of the bar code reader because of long time operation, the percentage of correct reading is greatly reduced. If the automated material handling system [2] can cope with the RFID technology and to change the original code reader into RFID reader, it can not only improve the accuracy of product positioning but also avoid errors listed above.

A similar system of implementing RFID as an aid for inventory management was successfully installed in one semiconductor manufacturing company in Taiwan. It actually save many man-hours in case of searching for lost products by loading some wafer boxes and Probe Cards [7] that are equipped with RFID tags. These boxes accurately control and save correct records whenever there are import
or export events happening. The moving records are accurately controlled, and indeed save many man-hours searching for lost and cut machine idle time. However the above application of RFID is more about the field of warehouse logistics management system. Compared with the front-end semiconductor wafer manufacturing business, the interior of clean room is so large that there are lots of temporary storage places for products or experimental half-products. It is not easy to build up an effective logistics tracking management system suitable for clean room. In order to solve this issue, this paper has applied useful characters of RFID to create an effective indoor positioning system for clean room environment.

The organization of this paper is as follows: Section 2 gives some background and related technologies for indoor positioning. Our proposal of CRRLS is explained in Section 3. A prototyping and experiment simulation result is given in Section 4. Some remarks of the system are given in Section 5, and Section 6 draws on conclusions.

II. SOME BACKGROUND AND RELATED RESEARCHES

For the consideration of different objects and various environments, many positioning technologies have been developed, and they were applied to solve many practical military and civilian problems. However, when the object located in indoor environment, the accuracy is not comparable with outdoors. As a result, a new indoor positioning technology needs to be studied and to make up the GPS (Global Positioning System) deficiencies. At present, the common technology in the indoor positioning application includes infrared, IEEE 802.11, ultrasound and RFID technologies, and these technologies will be shortly introduced in the following paragraphs. More information can look into references.

A. Infrared Indoor Positioning Technology

Infrared indoor positioning sensing was first developed by Olivetti Research Laboratory (Now known as AT&T Cambridge) [6], also known as Active Badge. It implemented diffuse infrared technology to realize indoor location positioning. The system is required to set up infrared receivers and every infrared was connected to a central server. By continuous emission signals from the portable infrared transmitter carried by the user, and the received signals will be delivered to the control server to estimate location of the user. While the line-of-sight requirement and short-range signal transmission are two major limitations that suggest it to be less than effective in practice for indoor positioning sensing [8].

B. Ultrasonic Positioning Technology

The Active Badge location system [11] is the primary example that uses ultrasonic positioning technology, while Active Bat system is developed by AT & T Cambridge Research Laboratory to improve disadvantage of lower accuracy of this early infrared systems [4].

C. Wireless Local Area Network Positioning Technology

RADAR is a radio frequency based system for location and tracking users inside building. It uses a standard 802.11 network adapter to measure frequency energy at multiple base station locations to provide overlapping coverage in a given area [1]. It combines empirical measurement and signal propagation modeling to determine the specific location of objects [12]. The difficulty is that the object being tracked must be supported by a Wave LAN NIC, which may be impractical on small or power constrained building [8].

D. RFID Positioning Technology

RFID is a means of storing and retrieving data through electromagnetic transmission to an RF compatible integrated circuit and is now being seen as a radical means of enhancing data handling processes [10]. A RFID system has several components including a number of RFID readers, RFID electronic tags, and the communication between these devices, and the architecture was shown in Figure 1. The communication mechanism is explained in the following. If the application system needs to do product identification, the main computer will send a command to RFID readers. Radio frequency wave energy by internal controller through built-in RF transceiver (Transceiver) will be sent out by readers. If antenna of the electronic tag received the radio wave, the internal transponder mechanism will transform this radio wave into power and a new radio wave will be sent out to the main computer to do product identification and management [7]. The communication diagram can refer to Figure 1.

Figure 1. RFID architecture diagram

At present, there are some well-known RFID indoor positioning technologies; for example, LANDMARC system [8] and SpotON system [5]. The LANDMARC system employs the idea of having extra fixed location reference tags with SSI (frequency energy information) and transmit power (Power Level) to help location calibration. These reference tags serve as reference points in the system. At the time LANDMARC was just developed, RFID did not
provide the frequency energy of tags to readers. Readers can only report the power from smallest level 1 to 8 of the tag detected and to determine the distance. Those received tags ID from readers will be used to match with the existed reference tags and the range of their position can be estimated. The main advantage of this approach is less expensive. The SpotON system [5] sets up a three-dimensional model by the received information from RF tags and to determine product’s location. The positioning algorithm did not undergo by a central controller, but with some reference sensors with the same hardware architecture. Sensors were scattered in the environment to collect and return the frequency energy information. The result will be computed by some distributed computation technology.

In conclusion, from the above information, only application of RFID-based technology can simultaneously take into account of high positioning accuracy and low cost system considerations and is the best option for indoor positioning technology for our study.

III. SYSTEM STRUCTURE

Due to LANDMARC system must be deployed many active electronic tags in the environment to determine the position of unknown object, but because of elevated floor often be turned, so it isn’t suitable for the clean room environment[8]. Nevertheless the SpotON system doesn’t set up a central control system, it need calculation of all scattered points to get the position of the unknown object, in addition, it must be equipped with specific hardware devices of RFID, and additional cost is needed. None of these are suitable for our study. In this paper, we will implement technology of RFID, in accordance with the special character of clean rooms to set up CRRLS. This technology uses RFID readers which were deployed or mounted on the equipments to collect frequency energy information from different electronic RFID tags and to estimate the reliable distance and signal [7]. According to the relationship of the estimated distance and frequency energy, position of the unknown tag can be calculated by a triangular positioning algorithm; as a result, it can achieve location – awareness.

In this study, we adopted the approach similar to RADAR [1]. The architecture of CRRLS is composed by three major components, including the Signal Receiving Processing Component, the Signal Pattern Matching Component, and the Manufacturing Execution System Integration Component; the diagram is shown in Figure 2. Function of each component will be explained in the following subsections.

A. Signal Receiving Processing Component

The Signal Receiving Processing Component (SRPC) was mainly composed by the RFID readers and electronic tags. The main function of the system is to process the information detected and received by the pre-mounted RFID readers. This component contains an application program that can receive and display all electronic tags that RFID reader has detected. Before production was on line, SRPC tested and collected information from different positions along the path measured by equal distance from various routes through electronic tags mounted in a self-moving vehicle, and save these information into a back-end database. A model of the ratio wave frequency energy and the distances can be established and to be referred by the positioning application module. In this paper, we have established a reliable model of signal transfer prediction through the database and the system will effectively calculate the result without frequently access to the database. By the relationship function of the radio wave frequency energy and the distances, performance of the system can be greatly increased.

B. Signal Pattern Matching Component

The main function of Signal Pattern Matching System (SPMS) is to detect signal and to estimate the position of the unknown electronic tag, in addition, to display the position of the tag by comparing data with signal pattern data base. It began by receiving signal from various electronic tags by readers and to estimate distance through the positioning application module. Results will be shown in a monitor and will be saved into a positioning database. The responding speed will be greatly affected by the transfer prediction model of frequency energy database built by signal pattern prediction model which is constructed by SRPC.

The Signal Receiving Processing Component (SRPC) transmits the information collected at offline stage by TCP/IP protocol to Signal Pattern Matching Component and to estimate absolute coordinate of the electronic tag by a triangular positioning algorithm. The idea of this triangular positioning algorithm is to estimate distance between this electronic tags and three other reference readers. In this paper, we try to build the transfer prediction model of radio waves to estimate the distance of electronic tags and RFID readers, moreover, because clean room of semiconductor wafer manufacturing factories has less partition walls, it reduce the possibility of frequency energy decay caused by penetration of electromagnetic wave through partition walls. In addition, sponges were laid out on the walls to absorb reflection magnetic wave that is why the triangular positioning algorithm can be successfully implemented in
this study.

SRPC will select the strongest three signals from the RFID readers according to their frequency energy to the same electronic tag. The location of the tag and three readers will be rendered by their plane coordinate. The system applies the concept of vectors to calculate the distance between electronic tag and three RFID readers. Three RFID readers are modeled as centers of different circles and the distance between reader and tag is their radius respectively, and the diagram is sketched in Figure 3. Ideally the position of the unknown tag will be the position of the intersection of three circles. But due to measurement error, an overlap area shown in Figure 3 is the dark area that the tag may locate. Points inside this area to any center of circle must be less than their radius. For this reason, we estimate the most appropriate position by averaging all points inside this area. In this study, we begin by forming a smallest external polygon around this overlap area, and to find their incenter (or intersection of bisectors of three internal angles in a triangle) of each triangle inside this polygon, and eventually, the average coordinate of these incenters is defined as the position of unknown RFID tag.

![Figure 3. Schematic diagram of the triangular positioning algorithm](image)

C. Manufacturing Execution System Integration Component

One of the main functions of Manufacturing Execution System Integration Component (MESIC) is to integrate the information obtained from the positioning algorithm given by SRPC, in addition, to execute Manufacturing Execution Management System (MEMS). Though, MEMS is the core step of the whole semiconductor production, in usual situation, MEMS always applied different protocols, includes TIBCO, CORBA and so on, so it is important to integrate diversities between these different protocols into an effective one. Due to complex procedures for manufacturing, it usually takes more than 600 steps for one complete cycle. AMHS is designed to allow products quickly and effectively sent to the next workstation and the operators can quickly and accurately get what they need during the process, as a result, the AMHS in MEMS plays an extremely important role during the production. This system in semiconductor factory is on top of aisles and the machine. OHS (Over-head Hoist Shuttle), OHT (Over-head Hoist Transportation) and RGV (Rail Guided Vehicles) are the three main vehicles responsible for the wafer delivering and handling, and they served as a transportation vehicle from warehouse or station to next process [8]. In addition, there is a temporary storage area called Stoker, it is set up between every production line as the Automated Inventory Systems. Figure 4 shows a wafer handling system.

![Figure 4. Schematic diagram of the Handling system](image)

By MESIC, products related information, including its location and status can be controlled by MEMS. Even though, product may be misplaced or out of range from AMHS, it still can be retrieved by the positioning system. Users are also capable to input important data to the electronic tag of RFID and it is one of the important parts of avoiding human error in MEMS.

IV. SYSTEM IMPLEMENTATION AND EXPERIMENTAL SIMULATION

In order to experiment the RFID Indoor Positioning system, we made a temporary workplace where RFID readers were set up. The possibility and efficiency of this system will be verified by the setting of this workspace. The workspace is a rectangular indoor space, length is 15 meters, and width is about 10 meters. We consider SYRD245-1N readers and SYTAG245-2C-B10-G RFID tags operating in the UHF frequency with range between 2.40~2.48 GHz were properly set up to fit for a real wafer clean room workspace.

A. Signal Reception

Signal reception and processing components are composed by two modules which are the signal detection module and the signal pattern matching database. The main function of signal detection module is receiving and storing electronic tag signals detected by the RFID readers. There are two main purposes of this function; the first object is to collect signal pattern information of each training point reader at offline stage in order to deduce the prediction
model of radio signals to be used in the experimental transmission environment. We use an average value of every measurement receiving between each training point reader and electronic tags to carry out the reader frequency energy sampling and set up the database by the frequency energy. By the data receiving from the signal reception system provided by RFID reader, information such as electronic tag identifier (Tag ID), frequency energy (RSSI) and signal quality-related data can be saved to the signal pattern database. By the information collected by the signal pattern database, we can set up a prediction curve models by Regression statistics. Once the prediction model is verified, a radio wave propagation model of our experimental workplace can be derived by giving several signal frequency energy collected from those training points. The second objective of this function is to provide an interface of operation when it is on line. Users can select signal detected from one specific reader or from all readers to be analyzed by the real time positioning system and to display result.

In this experiment, the distance between two training points is 60 cm and is the same as the width of every piece of the floor tile in the clean room. Each training point will be measured repetitively 10 times for the reliability of the measurement data. In the radio frequency energy collection process, signals sent from the passive electronic tag mounted in a small self moving-car with the speed close to human walking is traveling to each training point reader. We found that when the electronic tag distance is more than 1080 cm from readers we mounted, there is difficulty for reader to effectively detect signal sent from RFID tag. Therefore, in this experiment, abnormal signal receiving from reader points which is over 10.8 meters will be removed from information list collected from measurement points.

B. Signal Analysis

Model analysis is implemented to analyze function between two variables, which are distance and frequency energy received from RFID readers. The special character of electromagnetic wave which has frequency energy proportional to the reciprocal of distance to the square, therefore, a natural logarithmic regression analysis model is used and the equation is given as:

\[ Y_i = \beta_0 + \beta_1 \ln(x_i) + \epsilon_i \]  \hspace{1cm} (1)

Where \( Y_i \) is the detected frequency energy, \( x_i \) is the distance between electronic tag and the reader (in meters), \( \beta_0 \) is the y-intercept, \( \beta_1 \) is slope, and \( \epsilon_i \) is some random error or noise term. A frequency energy model is derived as,

\[ Y_i = 13.47 \ln\left(\frac{1}{x_i^2}\right) + 162.94 \]  \hspace{1cm} (2)

In order to see if the model is correctly reflecting the experimental data, implementation of Equation 2 and our receiving signal data were sketched and were given at Figure 5.

In the experiment, if there is an unknown RFID tag entering the path, the received frequency energy will be taken into the prediction model of Equation 2 to calculate the possible distance between RFID reader and this tag. A residual plot between original experimental data and the model estimation has shown irregular pattern, it means the hypothesis of variance of error is true. Figure 6 gives the residual plot in this experiment; it shows that there is not any particular pattern, nor any special trend of these residuals.

C. Development of Real-time Location Module

An interface for the Real-time Location-aware Modules (RLM) is developed by Microsoft Visual Studio 2008 and the back-end database structure is built by Microsoft SQL Server. Figure 7 gives the interface.
The purpose of developing this system is to provide users some simplified and accurate positioning information. In the indoor environment, RLM will display a floor plan of deployed environment in the monitor. When the system initiated, the application module will scan signals from RFID tags in this environment. When the signal detection module sent and stored information to a specified catalogue, RLM will begin to analyze this data with the assistance of the signal transmission prediction model given in Equation 2, result contains Tag ID, frequency energy, and the distance between RFID tag with all the readers will be displayed. If at the same time there are three or more than three readers simultaneously detected from the same electronic tag, RLM will apply a triangulation positioning algorithms in SPMS to mark a possible location of this electronic tag, including its coordinates. Based on the result given by previous analysis, the optimal approximated location of this electron tag will be shown in the monitor by a small red dot for attention, as the red dot shown in Figure 8.

If the same electronic tag was repetitively detected in different time, RLM will display the electronics tag with serial number saved in the positioning database. Based on the orders, users will be able to know their coordinates and the time of appearance of these electronic tags respectively; at the same time the program will mark a solid line to connect these different locations according to the order of sequential appearance. As a result, the system can not only achieve the purpose of position-aware but also has a function of tracing specific RFID tag. The real-time location system and real-time tracing diagram is shown in Figure 9.

D. Integrated Manufacturing Execution System

RLM can be accessed with different approaches; one way is through protocol architectures, such as TIBCO, CORBA. Given order by MESIC, positioning information saved in the back-end data base can be accessed. To access by this way owns the advantage of high security and confidentiality. Users do not own the right to access freely and in turns the possibility due to wrong operation cause data lost or data base damage was reduced. In another way, the disadvantage is a relatively low information response speed. The alternative way to access is to allow users to access location results to the database directly. Compared with the first way, the database system security and confidentiality is reduced, but of course the response speed of query result will be greatly improved. In this experiment, we allow users to have the ability to direct fetch the database.
V. RESULTS AND DISCUSSION

According to a report from a semiconductor company in Taiwan, in general, it takes about 11 minutes to search for a lost cassette by man power, and at the same time, the production line was forced to be idled. It causes damages not only the low production rate but also the financial burden for these expensive production equipments idling. We expect a great amount of time will be saved if CRRLS can be set up. In our experiment, it takes about 1 minute to allocate the lost item. Though, a RFID application was already equipped to a very accurate inventory management system in Taiwan, and the function of correct allocation of products are constrained by the conditions as manpower delivery to some certain areas, and following along certain routes. But, in this paper, we have designed a system which RFID readers were attached to machine platform or were set up at some area that were not on the path of transportation. The expense of setting up RFID in CRRLS can therefore be greatly reduced. In addition, we take radio frequency energy to estimate distance and apply a triangular positioning algorithm to calculate accurate location of electronic tags. No matter how products were delivered to any unknown area by accident or random path, CRRLS still can allocate that wafer-box immediately. In general, it saves about 90% of time to reallocate and machine idle of the whole production line. CRRLS can certainly bring more efficiency and productivity to the business.

VI. CONCLUSIONS AND FUTURE WORK

Taiwan's semiconductor industry came from scratch until now has become one of the Taiwan's core industrial business. Techniques in this industry are mostly a combination of the latest technology and methodologies. To implement an effective positioning system and to use in the manufacturing execution management system can help the crews in the clean room to control and manage locations of their product and related information. This study has set up a signal patterns database in the offline phase; on execution, a correct location of product will be revealed quickly by our design. The system has brought an effective platform to the clean room logistic management. It not only can significantly reduce the manpower cost of search time, but also may reduce the labor casualties. In addition, the related hardware cost is greatly reduced compared with a similar RFID application system. Because of the RFID readers can be attached to the machine equipment. In the future, this system can not only set up in the clean room, if we can solve the problem of electronic tags mounting, much of the production of auxiliary equipment such as masks, removable shelves and so on, all those industries can use our positioning system. On the other hand, we can import the system from upstream and downstream of semiconductor business as long as the cost is reasonable. The purpose of this study is to try to exclude the loss of products and enhance their reallocation problem. It not only can effectively reduce the product cycle time (Cycle Time), but also our country can still continue maintaining such a high-tech industries advantage in the international competitive edge.

REFERENCES