AC 2012-4826: DESIGN OF A MOBILE ROBOT AND USE OF RFID FOR FAST WEREHOUSING

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Design of a Mobile Robot and use of RFID for Fast Warehousing

Abstract

Radio Frequency Identification technology (RFID) has been used in the past for several applications. Automatic identification technologies like RFID have valuable uses, especially for tracking and identification purposes such as inventory management. RFID is particularly useful where it can be embedded within an object, such as a shipping container. RFID can be used where human accessibility is limited or dangerous. The Self-Locomotive Inventory Management, or SLIM, System is a multi-faceted system to perform remote inventory of a warehouse, car lot, or other asset storage location. The system is comprised of a remote controlled vehicle equipped with a 400 MHz Active RFID reader with the associated Active RFID asset tags to gather the inventory data, a PC-based Human-Machine-Interface (HMI) control and interface station to control the vehicle, and a PC based database and web server to store and present the collected inventory data. This paper represents the result of a senior design project which is a done as pilot project in collaboration with industry. The students who participated in this project learned new hardware and software tools and applied the math and science principles learned in previous year. This project is a true example of experiential learning. A mobile robot with wireless control has been built. The robot has the capability of identifying RFID tags for each item and finding the dedicated location of the item in the warehouse. The robot uses a tracking system for the inventory. Tracking system can collect data on daily basis and perform routines operations. This information can be used both for quality control as well as improving processes and logistics.

This paper will describe: (1) Student participation (2) Construction of mobile robot, (3) the RFID technology used for identification of items, (4) tagging and storage strategy, (5) tracking system and (6) overall performance of the robot.

Introduction

Radio frequency identification (RFID) has been around for many years. In recent years RFID with improved capability and reduced cost, which become more attractive for inventory and tracking items in businesses and industry. A major push came when retailing giant Wal-Mart dramatically announced that it would require its top 100 suppliers to supply RFID-enabled shipments by January 2005 [1]. The use of RFID combined with the EPC promises to provide data about products never available before. Many items produced will eventually have their own unique ID numbers. All parts of the supply chain including manufactures, distributors and retailers will be able to have instant access to information about an individual product. RFID is not expected to replace bar codes simply because tags are still too expensive even though their prices have fallen to around 20 cents in volume versus 0.2 cents for a bar code label. Adoption is therefore likely to happen first at the Palette and Crate level, then as technology advances and costs reduce further, we can expect to see tags on more and higher value items. The wide adoption of RFID across the supply chain will bring significant benefits leading to reduced operational costs and hence increased profits. Many analysts suggest that this will happen in three primary areas [2].

- Reduced inventory and shrinkage
- Benefit from a reduction in store and warehouse labor expenses
- A reduction in out-of-stock items

The technology can be used to identify, track, sort or detect a wide variety of objects. Communication takes place between a reader and a transponder often called a tag. Tags can either be active or passive, or come in various forms including Smart cards, Tags, Labels, watches and even embedded in mobile phones. The communication frequencies used depends to a large extent on the application, and range from 125 KHz to 2.45 GHz.

Table-1
Most commonly used RFID frequencies for passive tags – Performance overview

	LF	HF	UHF	Microwave
Frequency Range	<135 KHz	13.56 MHz	860 - 930 MHz	2.45GHz
Typical Read Range	<0.5m	~ 1m	~4 –5 m	~ 1m

As it can be seen from the Table-1, passive tags can be read at a distance of up to 4 - 5m using the UHF frequency band, whilst the other types of tags (semi-passive and active) can achieve much greater distances of up to 100m for semi-passive, and several kilometers for Active. This large difference in communication performance can be explained by the following; Passive tags use the reader field as a source of energy for the chip and for communication from and to the reader. The available power from the reader field, not only reduces very rapidly with distance, but is also controlled by strict regulations, resulting in a limited communication distance of 4 - 5m when using the UHF frequency band (860 MHz – 930 MHz). Semi-Passive tags have built in batteries and therefore do not require energy from the reader field to power the chip. This allows them to function with much lower signal power levels, resulting in greater distances of up to 100 meters. Distance is limited mainly due to the fact that tag does not have an integrated transmitter, and is still obliged to use the reader field to communicate back to the reader. Active tags are battery powered devices that have an active transmitter onboard. Unlike passive tags, active tags generate RF energy and apply it to the antenna. This autonomy from the reader means that they can communicate at distances of over several kilometers [3].
Robot has been used in warehousing and material handling for many years. Robot can systematically, accurately, and quickly moves and locate items. A revolution is underway in order to fulfill and automate warehousing and material handling. In response to competitive market pressures for shorter cycle times and greater accuracy, warehouses are increasingly using automation. Shorter cycle times are arising because retailers are asking for increasingly smaller and more frequent shipments. Robotic material handling, which has existed in production for quite some time, is finding an ever larger home in distribution. At a growing rate, vision-guided robots are moving into the warehouse, becoming indispensible instruments in the supply chain. And increasingly these robots are mobile, unlike material handling robots in production, which are primarily stationary. As robots move from production into distribution and become more mobile, new market opportunities are arising for automation companies [4]. Many manufacturers are tried to employ barcode technology in the robot to locate pallet or items. Bar code readers are very effective when the object is very close and faced on a certain angle. Dust, distance and slight change between bar code and the reader can provide erroneous result. Due to these reasons, barcode has not been utilized with robots in warehousing. On the other hand, RFID has much more capability and is more error proof. Inventory management is one of the most daunting tasks facing most commercial and industrial businesses today. The task is automated to some degree by hand-held RFID scanners, shipping tracking numbers, and even entry/exit count for highly electronic warehouses. However, the task of performing physical counts and actually locating items in a warehouse or other storage area is still done largely by hand. Exacerbating the situation is local and

federal regulations on most inventory-bearing industries regarding the storage of their items. Furthermore, these companies that store inventory pay annual taxes based on the inventory on hand at assessment time, so inaccurate counts can result in tax penalties or hefty overpayments. Typically, products enter the warehouse in bulk after completing their transit from production facilities. At the receiving point, products are identified and sorted by type and number and then moved to an assigned, recorded location in the warehouse where they are stored until ordered. A moving robot can travel through the isles in the warehouse and detect signal from a particular RFID tag which attached to the product. An on-board computer in the robot processes the data and sends the signal to the main computer in the warehouse.

Even if local inventory is maintained properly and accurately, the onus is on local warehouse managers to provide accurate reporting to senior management and, if applicable, corporate management regarding inventory count. This information often times is transmitted across hundreds or thousands of miles and must be presented in an "executive friendly" format. Senior management expects this data to be up-to-date, accurate, and available from anywhere their often highly transient business lifestyle takes them.

The Self-Locomotive Inventory Management (SLIM) System seeks to fill this gap in the logistics chain. SLIM is designed to operate as a fully autonomous inventory locator and count management tool. Consisting of an automated mobile vehicle and a Microsoft® Windows® enabled Human-Machine-Interface (HMI), SLIM handles the tasks of locating items; performing counts; storing data; and presenting data in a manner never before realized in a single system.

Student Participation

This paper represents the result of a senior design project at Electrical and Computer Engineering Technology. The students worked diligently to finish the required tasks within a timely fashion. The project incorporates mechanical, electrical, electronics, and computer skillsets and applications of theoretical principles into practice. The students managed to convince their industry partners to donate majority of the parts. The result of this project will be used to design a commercial version of the mobile robot. The following companies provided material or technical advice for this project.

- Advanced Motion Control – Camarillo, CA
- Elpro North America – Lenexa, KS
- JMI Controls – Highland, IN
- Kiser Controls – Burr Ridge, IL
- Robert McDonough
- Novaspect, Inc. – Elk Grove Village, IL
- RFID, Inc. – Aurora, CO
- Secure Technology Solutions – Douglasville, GA
- US Digital – Vancouver, WA

System Description

The SLIM System is comprised of two primary systems, a mobile vehicle and remote control station. Each system is further broken down into subordinate systems.

1. Mobile Vehicle

The mobile vehicle is a tracked vehicle running a number of sensors and sensor systems to accomplish the primary task of locating the desired item(s), moving to the item(s) location, providing verification methods of the item(s), and transmitting the item'(s) location back to the control station.

a. Drive System

The drive system is broken down into two identical halves, one for the port side and one for the starboard side. Each side operates completely independently of the other and is comprised of a signal conditioner, a DC drive, and a DC motor. The DeltaV PLC generates a 4-20 mA output proportional to the desired speed of the motors. The 4-20 mA is then converted by the signal conditioners into a 0-5 VDC signal which is fed into the DC drives. The DC drives use this speed reference signal to apply a proportional 0-24 VDC (from the power system) to the motors themselves.

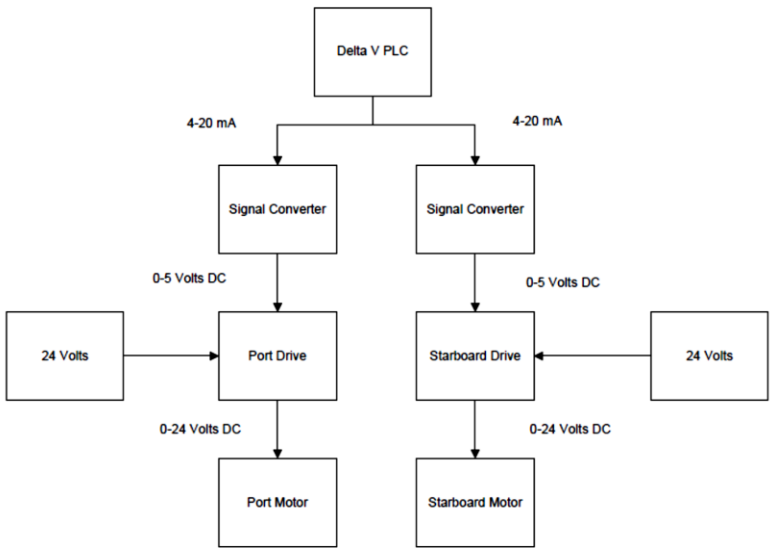

Figure 1 Block Diagram for SLIM Drive System

b. Navigation System

The navigation system utilizes a Dinsmore 1655 electronic compass to provide input to the DeltaV PLC regarding the vehicle's current heading. The RFID system provides a second input into the DeltaV PLC giving the item location's current heading and distance. Still a third input comes in from the encoders attached to the motors. The encoders provide data regarding linear displacement, or how far the vehicle has moved from its last waypoint. Finally, ultrasonic sensors are positioned along the physical edges of the vehicle to provide short range (appx. 3 ft) detection of any obstacles. All of these inputs are used by the DeltaV PLC to calculate an output to the drive system to actually move the vehicle.

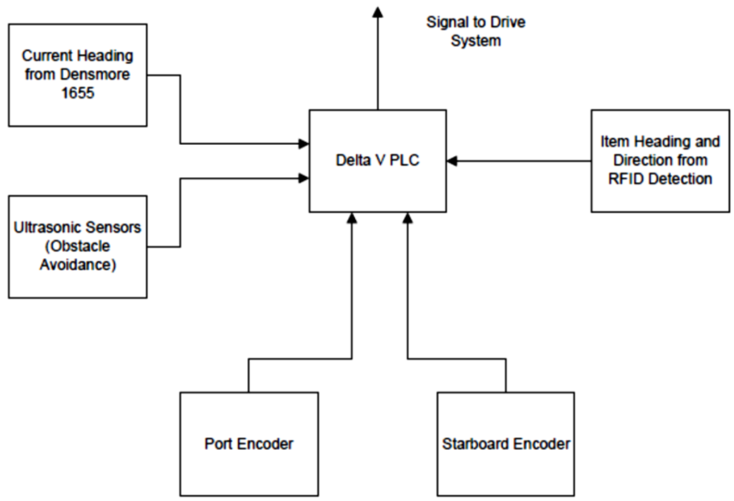

Figure 2 Navigation System Block Diagram

c. Power System

The Power System is a series of 6 and 12 VDC batteries combined to provide up to 24 VDC throughout the vehicle. The power system includes the wiring and the terminal blocks as well.

d. PLC/DCS

The PLC/DCS used by the SLIM System is an Emerson Process Management™ DeltaV Process Control System. The DeltaV rack consists of an M5 Plus controller, a 12 VDC system power supply, an 8-channel 4-20 mA analog input card, an 8-channel 4-20 mA analog output card, an 8-channel discrete output card, an 8-channel discrete input card, and a 4-channel multifunction I/O card. The DeltaV PLC receives inputs from throughout the mobile vehicle and processes them in various ways unique to each system to produce outputs that in turn provide functionality to the various systems. In addition, the PLC communicates over wireless TCP/IP to the remote control station bi-directionally in order to read operator supplied inputs and provide feedback regarding the status and real-time operating parameters of the vehicle.

e. Camera Systems

The SLIM System takes advantage of a pair of cameras, one visible light and one infrared to provide visual verification of the item or items located in the warehouse or storage facility. Each camera communicates wirelessly to a station selector. The station selector is typically located near the remote control station as it is a USB device. The station selector then provides the camera image to the operator in real-time. By utilizing infrared cameras with infrared emitters, the SLIM System can be deployed in a “lights-out” or energy efficient installation. Figure 3 shows a block for the camera system.

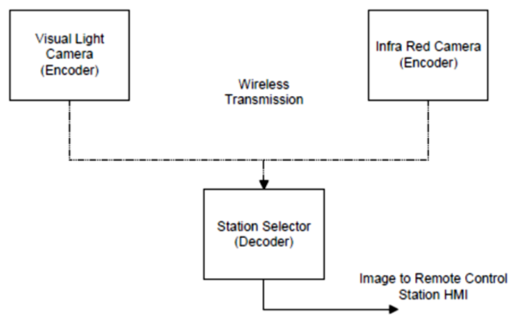

Figure 3 SLIM Camera System

f. RFID Detection System

The RFID detection system is the system most likely to change as development continues. In principle, each inventory item is tagged with a unique RFID tag. The onboard systems is comprised of a long-range, broad detector to locate the tagged item and provide heading and distance to the DeltaV PLC as well as a short-range precise detector to close in on the item once the distance has been reduced to a few feet. It may be possible to consolidate both detectors into a single device.

g. Network Communications

All DeltaV communications take place over TCP/IP. As such, network communications are required between the vehicle and the remote control station. This is accomplished through the use of a wireless access point on board the vehicle. The access point currently communicates directly to a wireless network interface card in the remote control station. However, in a large area deployment, the use of repeaters will be required.

2. Remote Control Station

The remote control station is a standard Microsoft® Windows® PC or server. This station runs several applications and services to accomplish its primary objective of providing a graphical user interface (GUI) to the system operator, storing operational and inventory management data from the mobile vehicle, and presenting the data in a user-friendly format to the World Wide Web. The basic Data Presentation flow is presented in Figure 4.

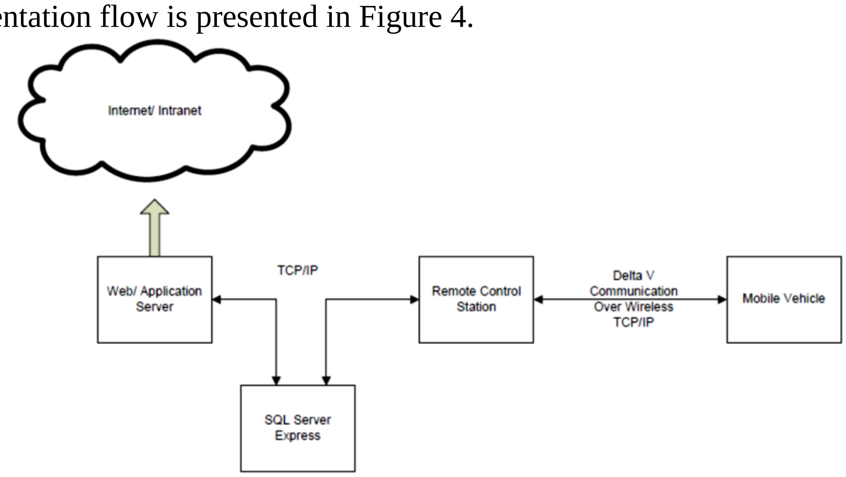

Figure 4 Data Flow Block Diagram

a. OPC Server

OPC (OLE for Process Control) is a process control standard for communicating process data in a number of methods. The SLIM System utilizes both real-time (OPC-DA, or OPC-Data Access) and historical (OPC-HDA, or OPC-Historical Data Access) data. The OPC Server is provided as part of the DeltaV system and is installed on the remote control station.

b. Human-Machine Interface including OPC Client

The Human-Machine Interface (HMI) is a custom developed application deployed on the remote control station. The HMI is developed using Microsoft® Visual Basic.NET®. In addition to the .NET™ libraries, the HMI takes advantage of add-ins from Data Layer's® OPCWare Client Developer ® to make the HMI an OPC Server. This is the mechanism by which the HMI communicates with the DeltaV system to send and receive data. Furthermore, the HMI is responsible for communicating with the SQL Server database for storage of application critical data.

c. SQL Server 2005 Express Edition® database (referred to as SQL Server)

SQL Server is a relational database that provides the data repository for the SLIM System. It receives data from the HMI and, if necessary for trends or other historical data access, provides data back to the HMI. It also provides all of the data to the Web Application for presentation to the data consumers.

d. Web Application

The web application is developed using Microsoft® ASP.NET®. It is accessible from the Internet/Intranet, network security permitting, and takes the inventory data stored in SQL Server and present it to the end users in a variety of formats, many of which will allow a degree of user customization as to the data presented.

e. System Autonomy

The robot is equipped with a microprocessor to perform computation, adjustment of parameters, acquiring information, modifying and updating values of required parameters. This capability gives the robot learning capability about its surrounding environment without direct human interface. The robot communicates with a computer in warehouse. There are two large batteries on board that provide sufficient power for four hours of operation without interruption. The microprocessor on board as well as communication links with main computer assures sustainability of the robot operation. The computer checks the parameters as well as environmental condition and sends a corrective command to the robot if needed. The sensors installed on the robot provide speed, coordinate, distance and pictures to main computer. The sensors provide information which is processed to make sure the robot does not harm people or property. The robot requires a command from main computer to start or stop operation. The Figure 5.

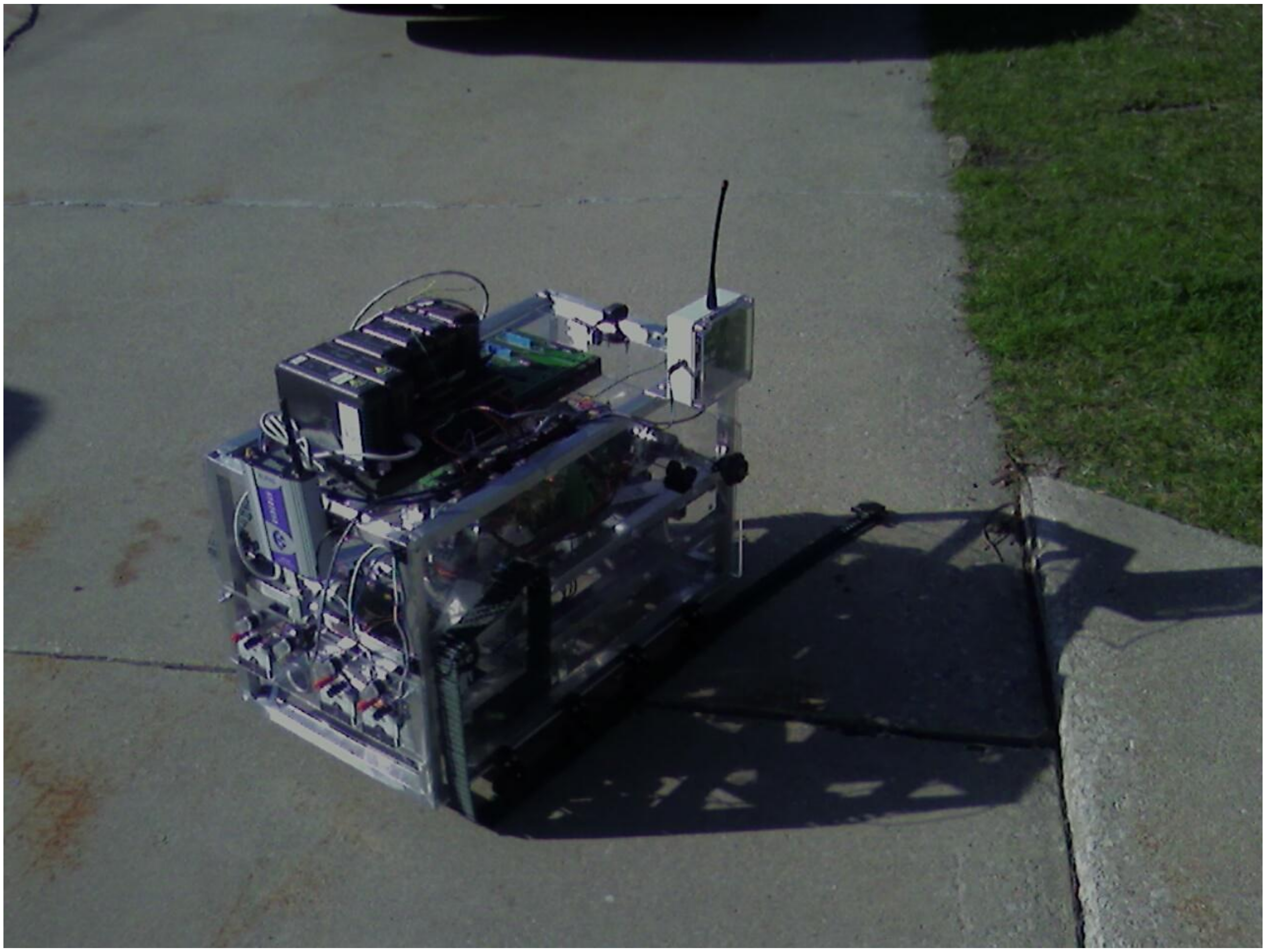

Figure 5 The actual robot

Conclusion

A robot with vision and RFID detection capability is built. The mobile vehicle is a tracked vehicle running a number of sensors and sensor systems to accomplish the primary task of locating the desired item(s), moving to the item(s) location, providing verification of the item(s), and transmitting the item'(s) location back to the control station. The SLIM System utilizes both real-time (OPC-DA, and OPC-Data Access) and historical (OPC-HDA, or OPC-Historical Data Access) data. The HMI is developed using Microsoft® Visual Basic.NET®. In addition to the .NET™ libraries, the HMI takes advantage of add-ins from Data Layer's® OPCWare Client Developer ® to make the HMI an OPC Server. SQL Server is a relational database that provides the data repository for the SLIM System. SLIM receives data from the HMI and, if necessary for trends or other historical data access, provides data back to the HMI. It also provides all of the data to the Web Application for presentation to the data consumers. The web application is developed using Microsoft® ASP.NET®. It is accessible from the Internet/Intranet, network security permitting, and takes the inventory data stored in SQL Server and present it to the end users in a variety of formats, many of which will allow a degree of user customization as to the data presented.
The moving robot uses a secure computer protocol for communication. The SLIM System was an extremely aggressive project involving mechanical, electrical and software engineering. The students during this project learned how to apply math and science principles into practice. During

the course of study, several industries assisted the student in donating equipment, hardware and software set ups. The students experienced a true partnership between industry and university in the process of completing the project.

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