MULTI-SENSOR FUSION FOR AUTOMATED GUIDED VEHICLE POSITIONING

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I hereby declare that the work in this project report is my own except for quotations and summaries, which have been duly acknowledged

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For my beloved mother, Huda
And my brother, Ahmed Elshayeb

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ABSTRACT

This thesis presents positioning system of Automated Guided Vehicles or AGV for short, *which is a mobile robot that follows wire or magnetic tape in the floor* to *navigate from point to another in workspace*. AGV serves in industrial fields to convey materials and products around the manufacturing facility or warehouse thus, time of manufacturing process and number of labors can be reduced accordingly. In contrast, the limitation of its movement specified by the guidance path considered as a main weakness. In order to make the AGV moves freely without guidance path, it is essential to know current position first before starts navigate to target place then, the position has to be updating during movement. For mobile robots positioning and path tracking, two basic techniques are usually used, *relative* and *absolute* positioning. Relative positioning techniques based on measuring travelled distance by the robot and accumulate it to its initial position to estimate current position, which lead to *drift error* over time. Digital compass, Global Positioning System (GPS), and landmarks based positioning are examples of absolute positioning techniques, in which robot position estimated from single reading. Absolute positioning does not have drift error but the system cost is high and has signal blockage inside buildings as in case of landmarks and GPS respectively. The developed positioning system based on odometry, accelerometer, and digital compass for path tracking. RFID landmarks installed in predefined positions and ultrasonic GPS used to eliminate drift error in position estimated from odometry and accelerometer. Radio frequency module is used to transfer sensors reading from the mobile robot to a host PC has software program written on LabVIEW, which has a positioning algorithm and graphical display for robot position. The experiments conducted have illustrated that the developed sensor fusion positioning system can be integrated with AGV to replace the ordinary guidance system. It will give AGV flexibility in task manipulation in industrial application.

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CHAPTER 1

INTRODUCTION

This thesis focuses on development and implementation of a positioning system for Automated Guided Vehicle (AGV) as a replacement of its ordinary guidance systems. The system consists of developing the positioning algorithm, module electronic board, and Graphical User Interface (GUI) program.

AGV is a mobile robot based on a fixed path *(e.g. magnetic tapes or colored line)* on its movement. This chapter begins with a brief introduction about mobile robots and AGVs usage in industrial applications. In order to make AGVs able to move freely without guiding path, the problem of positioning raised, which clarified afterward followed by research objectives and scopes of study.

1.1 Mobile robots

In 1920, Karel Capek introduced the word robot in the English language in his play Rossum's Universal Robots. In that play, Capek presents a future in which all workers are automated, and how this leads to the ultimate revolt when the automated workers get souls.

Even so, researchers have made big improvement in robots since the days of Capek and until today, robots are still far away from having souls. However, from static, non-autonomous robots in the beginning, now robots become mobile and autonomous. Mobile robots are able to travel throughout working place freely to carry out various tasks. Based on the movement ability of the mobile robots, two terms have to be defined here to differentiate between them, *mobility,* and *autonomy* of the robot.

1.1.1 Mobility

Mobility in general is the ability to move freely in working environment. Mobile robots have ability to do their tasks in various places in working environment unlike fixed robots or manipulators, which are widely used in car industries. Manipulators are programmed in such a way that they can repeat the same sequence of actions over and over again, faster, cheaper, and more accurate than humans.

Typically, manipulators consist of a movable arm fixed to a point on the ground, which can assemble or manufacture different parts. Besides moving around this fixed point, the robots are not able of moving freely and therefore they are not fully mobile. Robot can be categorized as fully mobile if it does not have limited range in movement. Therefore, if the robot has degree of mobility, it is called *mobile robots*, then mobile robot must have some kind of a control system or algorithm to determine and guide it during its movement. The type of that control system or algorithm of the mobile robot determines its *autonomy* (Negenborn, 2003).

1.1.2 Autonomy

General definition of autonomy is “self directing freedom”; for a mobile robot, it specifies to what extent a robot relies on prior information from the environment to achieve its tasks. Information from the environment can be a feedback from sensors used to sense the floor of the workspace or detecting obstacles in the way of the robot. Degree of importance of this information on control algorithm of the robot movement determines its degree of autonomy as well. Based on degree of autonomy mobile robots can be divided into non-autonomous, semi- autonomous and fully autonomous robots.

Non-autonomous mobile robots controlled manually by humans therefore, actions it manipulates is based on navigation commands received. In case of semi-autonomous robots, it either can be navigated by themselves or can be steered by humans. In contrast, fully autonomous robots are steered solely by the robots themselves, which means the robots do not require human interaction to fulfill their tasks. Semi or fully autonomous robots suitable to perform tasks in which each action to be taken is unknown. The robot has to determine by itself how to get to the goals to be achieved by it (Negenborn, 2003).

1.2 Automated guided vehicle (AGV)

AGV is a mobile robot that follows a specific path in the floor consequently; it is driverless vehicles which have been used widely on industrial field to move materials around a manufacturing facility or a warehouse. AGVs are employed in nearly every industry including, pulp, paper, metals, newspaper and general manufacturing. Transferring material or finished product and storing them on a bed is one example of AGV use in factories. Moreover, some AGVs use forklifts to lift objects for storage as the one shown in Figure 1.1.

AGV uses predefined path for guidance purpose in warehouse or factory. Two main technologies AGV uses for guidance, which are *magnetic wire* and *colored tapes*. In wire guidance, a wire emitting radio waves fixed in a slot cut in factory floor and a detecting sensor placed on the bottom of the robot facing the floor. The sensor detects the radio waves being transmit from the wire and follows it. Tape guidance technology can be in two types: magnetic or colored. AGV uses proper sensor to detect the tape as show in Figure 1.1, which uses colored tape. Using color or magnetic guidance has advantage over wired guidance, as it is easy in installation and can be relocate from place to another flexibly. Additionally, it is considered a "passive" system since it does not require the guide medium to be energized as wire does.

All AGVs in working environments linked through Radio Frequency (RF) module to a control unit. The control unit can be Personal Computer (PC) or Personal Digital Assistant (PDA) as long as it has windows mobile like PCs. AGV takes task manipulation orders from the control unit, and communicating to other AGVs in working area through it.

With all advantages AGVs have, it still has one main problem that is lack to be fully mobile. It is categorized under mobile robots since it can move through working place but in fact, the guidance path limits this movement to specific area in workspace.

Figure 1.1: TAW type AGV (HI-Tech Robotics Systemz LTD)

1.3 Problem statement

To make AGVs fully mobile it is important to find a way of guidance rather than ordinary wired or tape guidance technologies. If the AGV navigated, free of guidance paths thus finding its position in the factory or warehouse is essential information for navigation process. Two main techniques can be used for mobile robot positioning: *relative and absolute techniques*.

Relative positioning technique uses robot-heading angle and speed over time to calculate travelled distance, and by knowing robot initial position the current position of the robot can be determined. Mobile robots subjected to variation in speed and wheel slippage that leads to *drift errors* with time and long travelled distances (Liu et al., 2009).

In contrast, absolute positioning techniques do not rely on previous position to determine new position of the mobile robot; *e.g. Global Positioning System (GPS) or landmarks* so that; absolute techniques do not suffer from error drift problem. Absolute positioning using, GPS has low accuracy and signal blockage inside buildings so it cannot be used for mobile robot positioning (Jeehong & Lee, 2006).

Alternatively, landmarks widely using for indoor positioning, landmarks are features in the environment that a robot can detect. Landmarks installed in predefined position in working place so the robot can determine its position relative to landmark (Atif et al., 2008). However, cost of landmarks is high and difficult to install through all places in working environment especially, in case of factories or large warehouse.

Integration between relative and absolute techniques can overcome the shortcoming in each technique. Fusion of information from multiple sensors is important, since combined information from multiple sensors can be more accurate. In particular when not all sensors are able to sense the same; some features may be occluded for some sensors, while visible to others. Together the sensors can provide a more complete picture of the scene at a certain time. Multi-sensor fusion is also important since it can reduce the effects of errors in measurements.

1.4 Research objectives

This research intended to develop positioning system *(hardware and software)* to work as a replacement for AGVs ordinary guidance methods. Multi-sensor fusion used to get the advantages of both relative and absolute positioning techniques. Therefore, the objectives of this research are as following:

1. Design and fabricate of a positioning module electronic board with a wireless radio to communicate with the control unit.
2. Implementation of positioning algorithm based on multi-sensor fusion *(e.g. digital compass, odometry, accelerometer, RFID, and ultrasonic GPS).*
3. Enhancement AGV positioning by using RFID or ultrasonic GPS to eliminate drift error from relative positioning techniques.
4. Develop graphical user interface program on PC or PDA, which can be function as control unit for the AGV.

1.5 Scopes of the research

This research work focuses on developing sensor fusion system for AGV positioning. Different positioning sensors have been used to develop the positioning module electronic board such as, odometry, accelerometer, digital compass, ultrasonic GPS, and RFID to combine relative and absolute positioning techniques. Microcontroller used to acquire all sensor reading and send them to host PC via Radio Frequency (RF) module. The host PC run software program written in LabVIEW, sensor readings received from the microcontroller logged to positioning algorithm on the LabVIEW program to estimate AGV position. Communication between the positioning module electronic board and the PC established using Xbee RF module. In order to validate the positioning system experiment has been carried out to determine positioning accuracy and error value between actual and estimated position of the AGV.

1.6 Summary

Mobile robot position is essential knowledge the robot needs to know before start moving around in the environment. AGV as kind of mobile robots use wired or magnetic tapes guidance systems to solve positioning problem. Hence, AGV can only move based on the limits the guidance system gives to it. In order to make AGV move freely in workspace, relative and absolute positioning techniques can be used to as a replacement for ordinary guidance systems (wired or magnetic tapes guidance). The rest of the thesis is outlined as following:

Chapter 2 discusses review of literature on different positioning approaches. Advantages and disadvantages of relative and absolute positioning techniques highlighted to come out with the proposed sensor fusion system to overcome shortcoming of every technique.

Chapter 3 provides an overview of the research methodology and steps taken to develop positioning system. It also covers briefly functions and theory of operation of the selected sensors. Finally, the positioning algorithm and use of LabVIEW are explained in details.

Chapter 4 discusses research outcomes and experimental results, which are carried out by installing the developed positioning module electronic board on a mobile robot to simulate AGV. Research conclusion and future work recommendations are covered in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

Different positioning techniques for mobile robot are covered in this chapter. The aim of the literature is to get a good understanding of theory of operation, advantages, and disadvantages of different mobile robots positioning approaches. From the literature it can be concluded that multi-sensors fusion as a new approach gives a better solution for positioning problem which can be used during this research.

2.1 Relative positioning techniques

Relative techniques estimate current position of mobile robot based on speed and heading angle of the robot and the time passed since the last known position. Mobile robots are subjected to variation on moving speed and wheel slippage, therefore small error in positioning will be accumulated and grow up unbounded with long time-periods and travelled distances (Liu et al., 2009). An example of relative positioning sensors is odometry and accelerometer.

2.1.1 Odometry

The word *odometry* originates from the Greek words *hodos* (meaning "travel", "journey") and *metron* (meaning "measure") on other words odometry is travelled distance measurement (Merriam-Webster, 2010). The odometry uses data from robot actuators to estimate change in position over time relative to initial position. Data from wheel encoders *(for wheeled mobile robots)* can be used to measure how far the wheels have rotated, and if it knows the circumference of its wheels, travelled distance then computed.

Since estimation of new position is based on the previous one, error in position estimation will be accumulated over time, which so-called *drift error*. Inequalities of wheel diameters, flatness of the road and wheel slippage are potential causes of odometry errors (Houshangi & Azizi, 2006). It is therefore necessary to augment the use of odometry by integrating it with another positioning sensor types. Vast studies have been made on odometry for error correction by utilizing another sensor along with odometry.

Houshangi and Azizi (2006) studied effect of using gyro with odometry for mobile robots position determination. Robot position and orientation calculated by integrating speed information from encoders and rotational rate from gyro, respectively. Houshangi and Azizi proposed two kinds of odometry errors: these errors are categorized as systematic (e.g. different wheel diameters), and nonsystematic (e.g. wheel slippage) errors. Position result by data integration of gyro with the odometry showed reduction of positioning error from 809 mm to 37 mm over 30-meter of travelled distance.

Odometry integrated with compass for navigation purpose of team of LEGO Robots (Pasztor et al., 2010). Pasztor *et al*, used odometry data to determine travelled distance of LEGO Robot however, error in position of the robot for 20-meter long was 11-meter which about 50% of the total travelled distance. The robot's direction differs so enormous from their original one thus, odometry alone as a solution for positioning not enough.

Pasztor *et al* combined digital compass to keep the robot in the specified path, in this method, the robot navigation program saved the starting angle (λ_b), and then by synchronizing wheels, the robot went towards the target position. When during walking the difference of actual direction (λa) reached 1^o degree from the original one, the robot suspended the synchronization between the wheels, and rotated the adequate wheel until (λ_b - λa = zero) obtained. Integrating the compass made enormous reduction in robot error for travelled distance 20-meter, which become 28 cm in final X position of the robot.

2.1.2 Accelerometer

Accelerometer is a sensor produce electric signal proportional to acceleration of the moving body *(i.e. mobile robot)*; the produced electric signal can be in form of voltage or current. Acceleration value of the mobile robot can be used to estimate position by integrating acceleration, once for obtaining the speed, twice for obtaining the travelled distance by the robot (Andres et al., 2006).

Position estimation is independent of external information sources. However, since measurements are made by integration, the position estimates *drift error* over time, and thus the errors increase without bound. Another source of error is sensitivity to bumpy ground, if there is a bump in the floor; the sensor will detect a component of the gravitational acceleration.

Andres *et al* (2006) carried experiment on using 2-axis accelerometer and two encoders as positioning sensors for dual drive mobile robot. The system based on fusion of data from the accelerometer and encoder then, log sensors information to *Kalman filter* for position estimation. Resultant position error in X and Y position of the robot was (5.5, 6.0) cm by using encoders data alone, (1.0, 25) cm by using data from accelerometer alone, and (2.0, 4.0) cm as result of data fusion of encoder and accelerometer. The error range from this system is accepted but, that study did not mention the travelled distance of the robot during the experiment, accelerometers are suitable as positioning sensors for short travelled distances. Another weakness of that study is Andres did not measure the acceleration of z-axis to give feedback about the floor flatness, which is source of error in encoder and accelerometer data as well.

Better results from accelerometer can be obtained by extracting the acceleration of gravity from accelerometer output (Oh Chul & Kiheon, 2009). If the robot at rest the accelerometer output is, gravity acceleration once start accelerates the output will be combination of body acceleration and acceleration of gravity. Chul and Kiheon (2009) aimed to develop attitude reference system using 3-axis accelerometer, they developed algorithm to extract acceleration of gravity from accelerometer output data. The developed system by Chul and Kiheon can be used to control the attitude of robots and integrate it with odometry positioning technique to enhance odometry positioning by giving feedback about floor flatness as discussed in previous section.

Wong *et al* (2008) proposed a novel for using accelerometer as a balance sensor for humanoid robots to measure Zero Moment Point (ZMP) of the robot body. A 3-axis accelerometer sensor is mounted on the robot for determining the rotate angle velocity of the humanoid robot. Fuzzy controller is used to control the motions of the robot to adjust the posture of the robot for static balancing using acceleration value. Experiments results showed that accelerometer integration with fuzzy control able to adjust the posture of the robot to change its center of gravity for different standing environment so that the humanoid robot can balance and stand on an inclined plane by itself.

2.2 Absolute positioning techniques

In contrast with relative positioning; absolute positioning techniques estimates robot position independent of the previous location. Position estimation is not derived from integration of sampled sensor measurement. Robot position been computed in the global coordinates using the distances from some reference positions in the working environment (Hwang et al., 2006). This technique has the advantage that the error in robot position does not grow increasingly. Absolute positioning has many categories but the following will be taken into consideration:

I. Magnetic compasses

II. Landmark based positioning

2.2.1 Magnetic compass

Robot position in global co-ordinate system denote by its location relative to Cartesian coordinate system and heading angle, (x, y, θ). Magnetic compass is a sensor provide absolute heading of the mobile robot. The type of handheld compass used in orienteering is illustrated in Figure 2.1. The user rotates the compass housing until the desired direction is aligned with the direction of travel arrow, and then orients himself so that; the compass needle is aligned with North in the compass housing.

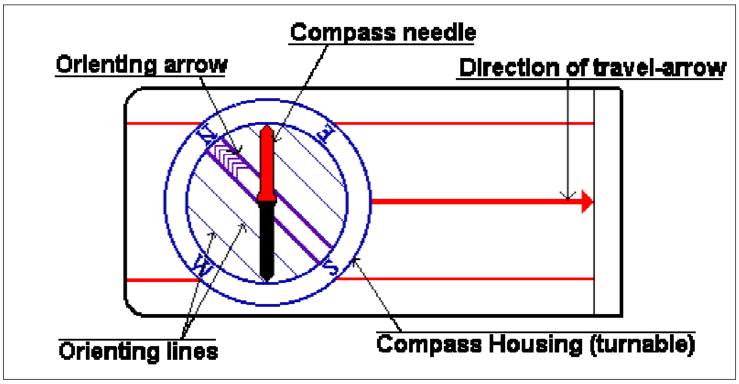

Figure 2.1: Compass used in orienteering (Kjernsmo, 2003)

Electronic compasses use vector magnetometer techniques and sensors. For example, two-axis magnetic compasses measure the horizontal vector components of the Earth's magnetic field using two sensor elements in the horizontal plane but orthogonal to each other. Called the X and Y-axis sensors, each sensor on an electronic compass assembly measures the magnetic field in its sensitive axis and the arc tangent Y/X provides the heading of the compass with respect to the X-axis.

A two-axis compass can remain accurate as long as the sensors remain horizontal, or orthogonal to the gravitational (downward) vector. In moving platform applications, two axis compasses are mechanically "gimbaled" to remain flat and accurate (Honeywell, 2010).

Three-axis magnetic compasses contain magnetic sensors in three orthogonal directions to capture the horizontal and vertical components of the Earth's magnetic field. To gimbal the compass electronically, the three magnetic sensors are complemented by a tilt-sensing element to measure the gravitational direction. The tilt sensor provides two-axis measurement of compass assembly tilt, known as pitch and roll axis. The five sensor inputs are combined to create a "tilt-compensated" version of the X and Y-axis magnetic vectors, and then computed into a tilt compensated heading (Honeywell, 2010).

One disadvantage of any magnetic compass, however, is that the earth's magnetic field is often distorted near power lines or steel structures. This makes the straightforward use of geomagnetic sensors difficult for indoor applications (Borenstein et al., 1997).

Experimental study on KVH C-100 Fluxgate shows that when compasses are used on mobile robots, carefully tuned digital low pass filters are very effective in minimizing errors produced by vibration (which can produce errors up to 10°). The study concludes that electronic compasses have good potential to be useful in mobile robot positioning, especially as part of a multi-sensor system, in which other sensor modalities can take over when needed (Ojeda & Borenstein, 2000).

Another study on using compass reading inside structured area as a magnetic signature detector to specify the current location in the environment based on magnetic field value of the location has been carried out by Suksakulchai (Suksakulchai et al., 2000). The experiment was successful and the robot was able to recognize all places while travelling to the goal. The computation time was very rapid, and memory space used in consumption is very small. This technique can be used with a topological map or odometry itself as an external reference.

As a part of sensor fusion compass is widely used for heading measurement since it cannot be used as the only tool for robot positioning and navigation. A compass and two IR sensors oriented at 90◦ to sense the environment used in (Peasgood et al., 2005). Another study using digital compass as heading sensor in biomimetic legged robot the sensor shows sensitivity and error in reading due to change in tilt of the robot relative to horizontal. Accelerometer was used together with the compass as tilt sensor which shows improvement in heading angle reading (Anđelković et al., 2003).

2.2.2 Landmarks based positioning

Landmarks refer to feature or object in the environment around the robot that can be recognized by it. Each landmark has prior information in the robot memory; this information is landmark position in Cartesian coordinate. Thus, once the robot detects three or more landmarks it can calculate it position using triangulation or trilateration (Ozawa et al., 2007). Triangulation techniques use distances and angles between the robot and the landmark; trilateration techniques only use distances. The angles and/or distances are then used to calculate the position and orientation of the robot (Singhal, 1997). Landmarks can be categorized as following:

I. Active landmarks

II. Passive landmarks

  a. Passive natural landmarks

  b. Passive artificial landmarks

If the landmarks actively send out signals for the robot to discover that it exists, the landmark is so-called *active landmarks*. These signals can be inform of infrared, RF (Radio Frequency) signal from satellite like GPS, ultrasonic, or RFID (Radio Frequency Identification) signal from active RFID tag (Lee & Song, 2007).

In contrast, *passive landmarks* do not actively send signals therefore; the robot has to look for the landmarks and estimate its position relative to the landmarks. Passive landmarks either can be part of the workspace such as doors and windows, which is called *natural landmarks* or landmarks designed to be recognized by robots, which is called *artificial landmarks*. Artificial landmarks such as bar codes, passive RFID tags, or colored geometric figures, like squares and circles.

Use of landmarks in mobile robot positioning has various styles based on type of landmark and sensor used to detect it. For example, a color artificial landmark system proposed by Guo and Xu (2006) in which the red number patterns installed in predefined positions. The robot equipped with camera to detect landmarks. By detecting, recognizing, and locating an artificial landmark, the mobile robot can calculate its own position and heading with respect to the landmark frame.

Ozawa *et al* (2007) used vision system to for mobile robot positioning by recognizing visual natural landmarks. The developed algorithm by Ozawa applied on RoboCup soccer game, the landmark was the target and the ball. Average positioning error from the algorithm 21 cm, indeed accuracy of using vision system for landmarks recognition depends on distance between the landmark and the vision sensor. The further away a landmark is from a robot, the less accurate position estimation.

In the methods using natural landmarks, robust extraction of natural landmarks is a difficult task (Guo & Xu, 2006). However, artificial landmarks are very simple and powerful for accurate localization. RFID is an example of artificial landmarks; RFID can be active or passive landmarks depend on tag type as will be explained in detail in section 2.5.

2.3 Global positioning system (GPS)

GPS has been developed by United States to be used by the Department of Defense in order to provide a positioning service for US military. Nowadays, GPS is also used for commercial purposes such as nautical, aeronautical, ground based navigation, and land surveying. The current US based GPS satellite constellation system consists of a 24-satellite system as shown in Figure 2.2.

The number of satellites for this system can vary due to satellites being taken in and out of service. Other countries are leading efforts to develop alternative satellite systems for their own GPS systems. A similar GPS system is the GLONASS constructed by Russia. Each satellite maintains its own specific orbit and circumnavigates earth once every 12 hours. The orbit of each satellite is timed and coordinated so that five to eight satellites are above the horizon of any location on the surface of earth at any time (Dana, 2001).

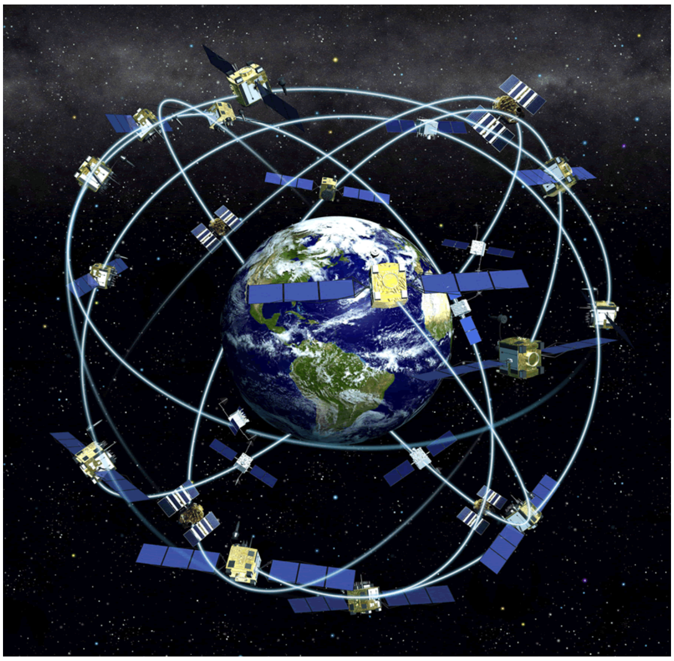

Figure 2.2: Global Positioning System

A GPS receiver calculates position by first receiving the microwave RF signals broadcast by each visible satellite. The signals broadcasted by the satellites are complex high frequency signals with encoded binary information. The encoded binary data contains a large amount of information but mainly contains information about the time that the data was sent and location of the satellite in orbit. The GPS receiver processes this information to solve for its position and current time.

The accuracy of a commercial GPS system without any augmentation is approximately 15 meters (Macarthur, 2003). Differential GPS (DGPS) can provide higher positioning accuracy by installing receiver in a known position; the fixed receiver calculates its position based on the received satellites signals. The amount of positioning error is then calculated by extracting the estimated position of the fixed receiver and actual position value. Other moving *receivers (i.e. moving car or mobile robot)* can estimate its position more accurately by broadcast data with the stationary receiver (Dana, 2001).

Recently a new type of GPS correction system has been integrated so that a land based correction signal is not required to improve position solutions. The Wide Area Augmentation System sends localized correction signals from orbiting satellites (Administration, 2010). Currently this system only covers most of North America.

GPS has poor accuracy to be used as positioning technique for mobile robot applications specially, if the robot is being used for manipulation tasks. Another limitation is signal blockage problem inside buildings or in cloudy days since GPS positioning rely on received signal from satellites. Therefore, ultrasonic GPS themes seem to be a good solution for mobile robot absolute positioning indoors.

2.4 Ultrasonic indoor GPS

To date several methods proposed to estimate the position of a mobile robot using ultrasonic sensors, one of them is using two artificial landmarks to determine the mobile robot's current position and orientation. In (Feng-ji et al., 1997), sixteen sonar sensors mounted around the mobile robot are used to detect obstacles. The purpose was to provide an estimation of the robot's absolute position and orientation in its working space. Using map matching from sonar sensors and matches it to the real working place map. Error in position and orientation from this system was 10cm and 10 deg.

Ghidary (1999) developed home robot localization system; the localization method utilizes ultrasonic and infrared signals simultaneously. The transmitter, which is mounted on the mobile robot, transmits both ultrasonic and infrared signals at the same time. The receivers are located at fix points in the ceiling of the room use the received infrared signal as a trigger to measure The Time Of Flight (TOF) of ultrasonic waves. The location of robot is computed by measuring its distance from three receivers. The heading of the robot is computed by measuring its position in two successive points while the robot moves from one point to the other. The performance and validity of this system are evaluated using one transmitter and six receivers located in a 6m x 4m room. Error in positioning was less than 5 cm in X and Y position.

Shoval (1999) used ultrasonic sensors for the measurement of angular position of a mobile robot relative to a known ultrasonic source. In this work proposed using of phase difference measurement to determine a mobile robot's angular position relative to a known ultrasonic source. Two ultrasonic sensors attached to the sides of the robot, and serve as receivers. A third sensor is positioned at an off-board location. This sensor only transmits signals at a rate controlled by the mobile robot (control and synchronization can be achieved by radio link but in our bench top set-up a wired link was used). When the transmitting sonar fires an ultrasonic wave, the two receivers are set for “listening mode” ready to receive the signals. A fast measurement system calculates the phase difference between the received signals in both sonar, where the magnitude of the phase difference is proportional to the difference of the Euclidean distance between the receivers and the transmitter.

Based on ultrasonic sensory information, an approach is proposed for localization of autonomous mobile robot (AMRs). In the proposed method, it is proven that the combination of three ultrasonic transmitters and two receivers can determine both the position and the orientation of an AMR with respect to a reference frame uniquely. In this manner, since only ultrasonic sensors are used, the proposed method will be highly cost-effective and easy to implement (Wu & Tsai, 2001). Such localization system not possible to be used in real applications because; the transmitters installed very near to each other only 20 cm apart which mean small coverage area. The experiment done in static mode the robot was not moving and that is not the case in mobile robot applications.

Shoval (2001) presented a method for measuring the relative position and orientation between two mobile robots using a dual binaural ultrasonic sensor system. Each robot is equipped with a sonar transmitter that sends signals to two receivers mounted on the other robot. It is assumed (but not implemented in this system) that the two robots can synchronize events with an infrared or radio link. The receivers measure the distance to the transmitter on the other robot, and a geometric model determines the relative position and orientation of the two robots based on a combination of the data from all four receivers.

In Shoval (2001), experimental results show the accuracy and operational limitations of the technique. The described method can assist multi-robot systems where cooperation is required in terms of relative position and orientation. In addition, the system can be implemented in tasks where a single robot is required to position itself accurately against other point. For example, a stationary transmitter/receiver setup can be installed in docking stations, doorways or narrow passageways to guide the robot to the desired position and orientation regardless of the accuracy of its other positioning systems. The simplicity of operation and the low cost for the obtained accuracy make the system advantageous for implementation is multi-robot system or in industrial environments.

In Hwang *et al* (2006) indoor GPS system using ultrasonic sensor has been built, this system consists of one transmitter having ultrasonic and RF and two receivers. The transmitter irradiates RF and ultrasonic, and the receivers calculate corresponding distance with reference to the RF signal. The two distance values are used for determining the location of the transmitter by trigonometrical functions. Due to the characteristics of ultrasonic sensors, noise occurs in sensor values by surrounding temperature or obstacle. Location error is minimized by prediction and correction of the noise with Linear Kalman Filter. In order to prove the effectiveness of this system, experiments were carried out in a room dimensioned by 3.5m*2.2m, wherein the location error showed 2cm max in x and y position.

Ultrasonic GPS has high positioning accuracy for indoor applications with the fact that, reflection of ultrasonic wave in case of dynamic environment leads to error in positioning. Moreover, coverage area for most ultrasonic transducers is only 2-meter; as a result, ultrasonic GPS to be used in factories or large warehouses need to spread large number of ultrasonic transmitter modules as well. Using large number of ultrasonic transmitters has health drawback on labors in the place and increasing the positioning system cost.

2.5 Radio Frequency IDentification (RFID)

RFID is a term referring to a type of system where communication between the constituent components *(e.g. RFID reader and tag)* is realized using Radio Frequency (RF) or magnetic field variations. Every RFID tag has a unique identification number so that, the tag usually attached to the object that is being identified.

The reader is the device that can detect the presence of tags, and read information stored on the tags. After a successful read, the reader can then notify some other system about the presence of a tag, and forward fetched data for further processing. Tags often incorporate a so-called UID, an abbreviation for Unique IDentifier. In this context, each tag uniquely identify by data bits located in the memory areas. More advanced tags also offer a general-purpose, non-volatile, user-programmable memory, so that information about the attached object can be stored in the tag itself, and not in a separate storage system.

In a separate storage system, the information about attached objects are stored in database (DB). It should be emphasized that a tag works as both a transmitter and a receiver; a tag intercepts an RF signal, and then transmit a response. This also applies to the reader. Moreover, both readers and tags make use of antennas to manage communication. However, RFID tags are usually seen as a way of doing identification, there is nothing that says it must be used for this purpose only. RFID tag can be seen as a general purpose, wireless-accessed storage device, usable for many more applications than just identification.

2.5.1 Types of RFID tags

A common way of categorizing different types of RFID tags is by how they obtain power. This characteristic is actually a major factor for the size, cost, and longevity of a tag; passive tags obtain their power by means of utilizing the RF signal sent out from the reader; active tags use an internal power source in the form of a battery cell. Traditionally, tags that make use of an on-board power source for some of its function, and the RF signal of the reader for other functions, have been referred to as active as well. A more recent term for this type of tags is semi-passive. This section will only focus on passive and active tags (Johansson, 2008).

2.5.1.1 Passive RFID tags

The most notable feature of passive tags is that they completely lack an internal power source; they are powered solely by an electric current induced in the antenna of the tag by the reader's RF signal. Often, this induced current is just enough to power up the tag, calculate the response, and finally transmit the response back to the reader. This is the reason why passive tags have limited capabilities compared to active tags.

Passive tags obtain power from the reader's RF signal by a phenomenon known as the near field. It occurs when the magnetic part of the RF signal is powerful enough to induce a current in a coil. Induction is based on the property that when a coil is placed in an alternating magnetic field, energy is drawn from the field, resulting in a voltage in the coil. This means that in a system of passive tags, both readers and tags use coils, and not conventional radio antennas. As suggested by the name, the near field is only available in vicinity close to the reader's antenna; the strength of the magnetic field decline very fast.

The advantage of passive tags (compared the active tags) are generally low price, small size, and a simpler manufacturing process. Apparent disadvantages include a small memory capacity, and limited calculation abilities. Usually, the limited range is also considered as a disadvantage. In this project, the limited range of passive tags has actually been an advantage (Johansson, 2008).

2.5.1.2 Active RFID tags

The major characteristic of active tags is that they use an internal power source, i.e., batteries, and with these follow larger possibilities in almost every respect compared to passive tags. For example, since a battery is used to power the circuitry, it is possible to transmit and receive without having to be powered by the near field of the reader's antenna. More importantly, the limited communication range imposed by the near field does not apply.

The advantages of active tags (compared the passive tags) are generally higher memory capacity and higher calculation abilities (perhaps encryption of transmitted data to prevent eavesdropping). Moreover, communication is often more reliable, due to the more reliable power source. Disadvantages are generally higher price, and larger in size (Johansson, 2008).

2.5.2 RFID frequency bands

RFID tags fall into three regions in respect to frequency:

- Low frequency (LF, 30 - 500 kHz)
- High frequency (HF, 10 - 15MHz)
- Ultra high frequency (UHF, 850 - 950MHz, 2.4 - 2.5GHz, 5.8GHz)

Low frequency tags are cheaper high frequency tags. They are fast enough for most applications, however for larger amounts of data the time a tag has to stay in a readers range will increase. Another advantage is that low frequency tags are least affected by the presence of fluids or metal. The disadvantage of such tags is their short reading range. The most common frequencies used for low frequency tags are 125 - 134.2 kHz and 140 - 148.5 kHz.

High frequency tags have higher transmission rates and ranges but also cost more than LF tags. Smart tags are the most common member of this group and they work at 13.56MHz. UHF tags have the highest range of all tags. It ranges from three to six meters for passive tags and 30- meters for active tags. In addition, the transmission rate is also very high, which allows to read a single tag in a very short time. This feature is important where tagged entities are moving with a high speed and remain only for a short time in a readers range. UHF tags are also more expensive than any other tag and are severely affected by fluids and metal. Those properties make UHF mostly useful in automated toll collection systems. Typical frequencies are 868MHz (Europe), 915MHz (USA), 950MHz (Japan), and 2.45GHz. Frequencies for LF and HF tags are license exempt and can be used worldwide; however, frequencies for UHF tags differ from country to country and require a permit.

2.5.3 RFID for mobile robots positioning

In recent years, RFID has attracted economic, public, and scientific interest. RFID has found its way into robotics, it promises improvements in self-localization, mapping, and navigation in general. Among the various interesting properties of RFID, the probably most important is that objects equipped with RFID tags can be identified uniquely (Schneegans et al., 2007). One of the first surveys into how to localize a mobile robot via RFID is the one presented by Hahnel *et al* (2004).

In Hahnel *et al* (2004) a probabilistic sensor model for their RFID reader was proposed, which associates the probability of detecting an RFID tag with the relative position of that tag with respect to the antenna. This model was used to map the positions of passive RFID tags in an office environment, given a previously computed map learned via a laser-based SLAM (Simultaneous Localization and Mapping) algorithm. The position of each tag was represented by a number of particles, whose weights were updated after each position reading of the tag. Monte Carlo localization was then used to estimate the position of the robot in the map, using another set of particles to represent the robot pose. Hahnel proposed system achieve robust self-localization based on RFID data and odometry alone.

Furthermore, self-localization was greatly accelerated, and the required number of particles could be reduced if the data of laser scanner and RFID reader were combined as compared to localization with a laser scanner only. A somewhat similar work, originally intended to locate nomadic objects, is the one by (Liu et al., 2006). They demonstrated a system for passive UHF (Ultra-High Frequency) tags, which exploits the directionality of RFID readers. Beliefs of the positions of tagged objects are formed from varying robot poses over time. Successfully examined how support vector machines could learn robot locations In (Yamano et al., 2004). They generated feature vectors out of signal strength information gained from active RFID tags. Djugash utilized active RFID tags in an outdoor environment (Djugash et al., 2005). They used time-of-flight measurements both for pure self-localization and for simultaneous localization and mapping based on Kalman and particle filters. In the context of passive high frequency (HF) tags operating at 13.56 MHz, Bohn has furthermore examined how tags densely spread on the floor allow for location estimation (Bohn, 2007).

Tsukiyama explored a simple navigation mechanism based on vision for free space detection and RFID tags as labels within a topological map of an indoor environment (Tsukiyama, 2003). Kulyukin et al (2006) have also studied navigation based on passive RFID tags. Their robotic guide was able to assist visually impaired people in way finding in indoor environments. Kleiner (2006) studied the use of RFID labels for the coordination of robot teams in exploration, during which the labels were autonomously deployed. Recently, Zhou proposed a vision-based indoor localization method in which they used modified active RFID tags as landmarks (Zhou et al., 2007). The tags were equipped with bright LEDs to be recognized. An additional laser diode allowed for the selective activation via a laser beam emitted by the robot. A prototype system, which lacked the ability of autonomously point a laser at visually recognized RFID labels, promised accurate localization. Note that the laser activation step requires line-of-sight, which is generally not the case for other RFID-based localization approaches.

Chon *et al* (2004) presented RFID localization system to replace GPS in tunnels and structured areas in which GPS signal become weak of blocked. The method presented in that research suggested to be used for outdoor applications to localizes city cars by the same way GPS can do. The idea is to install RFID tags in predefined positions and store tags ID and location on database system. Every car has to have RFID reader Fixed on it. The cost is low and easy to implement for mobile robot applications for indoor and outdoor localization.

2.6 Summary

Dead reckoning provides location data by accumulating the travelled distance from a known initial position. The moving distance and direction of a robot can be detected with sensors such those based on the vehicle’s an odometer with optical encoders, and magnetic compass. On the rough of the ground the travelled distance, produce a high-accumulated error. This error is caused mainly by wheel slip. Therefore, it cannot be used as a unique method for attaining a precise position of the vehicle during a large period.

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