UNIVERSITI PUTRA MALAYSIA

# MOBILE ROBOT LOCALIZATION USING BAR CODES AS ARTIFICIAL LANDMARKS

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By

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Thesis Submitted in Fulfilment of the Requirements for the Degree of Master of Science in the Faculty of Engineering Universiti Putra Malaysia

May 2000

بسم الله الرحمن الرحيم

**Dedicated to**
**My parents, my wife, my son, and the rest of my family**

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science.

**MOBILE ROBOT LOCALIZATION USING BAR CODES AS ARTIFICIAL LANDMARKS**

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**May 2000**

**Chairman: Md. Mahmud Hasan, Ph.D.**

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"Where am I" is the central question in mobile robot navigation. Robust and reliable localization are of vital importance for an autonomous mobile robot because the ability to constantly monitor its position in an unpredictable, unstructured, and dynamic environment is the essential prerequisite to build up and/or maintain environmental maps consistently and to perform path planning. Thus, self-localization as precondition for goal-oriented behavior is a fundamental property an autonomous mobile robot needs to be equipped with.

Accurate, flexible and low-cost localization are important issues for achieving autonomous and cooperative motions of mobile robots. Mobile robots usually perform self-localization by combining position estimates obtained from odometry or inertial navigation with external sensor data.

The objective of the thesis is to present a pragmatic idea which utilizes a camera-based bar code recognition technique in order to support mobile robot localization in indoor environments. The idea is to further improve already existing localization capabilities, obtained from dead-reckoning, by furnishing relevant

environmental spots such as doors, stairs, etc. with semantic information. In order to facilitate the detection of these landmarks the employment of bar codes is proposed.

The important contribution of the thesis is the designing of two software programs. The first program is the bar code generation program which is able to generate five types of bar code labels that play a major role in the proposed localization method. The second program is the bar code recognition program that analyzes image files looking for a bar code label. If a label is found the program recognizes it and display both the information it contains and its coding type.

Results concerning the generation of five types of bar code labels which are code 2 of 5, code 3 of 9 , codabar code, code 128 and code 2 of 5 interleaved and the detection and identification of these labels from image files are obtained.

In conclusion the thesis proposes a solution to mobile robot self-localization problem, which is the central significant for implementing an autonomous mobile robot, by utilizing a camera-based bar code recognition technique to support the basic localization capabilities obtained from a dead-reckoning method in an indoor environment.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
Sebagai memenuhi keperluan untuk ijazah Master Sains

**LOKALISASI ROBOT BERGERAK MENGGUNAKAN KOD BAR SEBAGAI MERCUTANDA TIRUAN**

**Oleh**

**MAHMUD M. M. BEN-HAMID**

**Mei 2000**

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**Fakulti:** **Kejuruteraan**

"Di manakah saya" adalah soalan penting dalam pengemudian robot bergerak. Ketegapan dan lokalisasi yang boleh harap adalah perkara penting bagi sesebuah robot bergerak berautonomi kerana kebolehannya memantau secara seragam posisinya dalam suasana-suasana yang pelbagai seperti suasana yang tidak boleh diramalkan, tidak terstruktur dan dinamik adalah prakeperluan yang penting untuk membina dan/atau mengekalkan peta-peta alam sekitar secara konsisten dan terancang. Maka lokalisasi diri selaku prasyarat bagi sifat yang mementingkan matlamat adalah ciri asas suatu robot bergerak berautonomi.

Ciri-ciri ketepatan, kefleksibelan dan harga yang rendah bagi sesuatu lokalisasi adalah perkara penting bagi mencapai gerakan-gerakan robot bergerak yang berautonomi dan koperatif. Robot bergerak biasanya melaksanakan lokalisasi diri dengan menggabungkan nilai-nilai posisi yang diperolehi daripada odometri atau pengemudian inersia oleh data penderia luaran.

Matlamat tesis ini adalah untuk mengemukakan idea pragmatik yang memanfaatkan teknik pengenalan kod bar berdasarkan-kamera bagi menyokong

pemusatan setempat robot bergerak dalam persekitaran dalaman. Idea ini adalah untuk mempertingkatkan lagi keupayaan pemusatan setempat tersedia ada, diperolehi dari kaedah perhitungan-mutlak, dengan memperlengkapkan sasaran persekitaran yang relevan seperti pintu, tangga dsb., dengan maklumat semantik. Bagi memudahkan pengenalan perubahan-perubahan besar ini, penggunaan kod bar telah dicadangkan.

Sumbangan penting dari tesis ini adalah rekabentuk dua program perisian. Program pertama adalah program penghasilan kod bar, yang mana ia mampu menghasilkan lima jenis label-label kod bar yang memainkan peranan utama dalam kaedah pemusatan setempat yang disarankan. Program kedua adalah program pengesahan kod bar yang menganalisa fail-fail imej bagi mengesan label kod bar. Jika label ditemui, program berkenaan akan mengesan dan memaparkan kedua-dua maklumat yang dikandunginya serta jenis mengkodnya.

Hasil keputusan berkaitan dengan penghasilan lima jenis label kod bar iaitu sisipan kod 2 antara 5, kod 3 antara 9, kod barpenutup, kod 128 dan kod 2 antara 5 serta pengesanan dan pengenalan label-label ini dari fail-fail imej akan diperolehi.

Sebagai kesimpulan, tesis ini mencadangkan penyelesaian pada masalah pemusatan setempat-sendiri bagi robot bergerak yang merupakan pusat paling penting bagi melaksanakan robot bergerak autonomi, dengan memanfaatkan teknik pengenalan kod bar berdasarkan-kamera bagi menyokong asas pemusatan setempat yang diperolehi dari kaedah perhitungan mutlak dalam persekitaran dalaman.

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# LIST OF SYMBOLS AND ABBREVIATIONS

| | | |
|---|---|---|
| AGV | : | Automated Guided Vehicles. |
| UMBmark | : | University of Michigan Benchmark. |
| TRC | : | Transition Research Corporation. |
| INS | : | Inertial Navigation System. |
| GPS | : | Global Positioning System. |
| ARK | : | Autonomous Robot for a Known Environment. |
| AECL | : | Atomic Energy of Canada Ltd. |
| MDARS | : | Mobile Detection Assessment and Response. |
| SLNM | : | Short-Lived Navigational Marker. |
| CAD | : | Computer Aided Design. |
| X | : | The Width of the Narrowest Element of the Bar Code. |
| LSB | : | Least Significant Bit. |
| MSB | : | Most Significant Bit. |
| AIM | : | Automatic Identification Manufacturers. |
| ASCII | : | American Standard Code for Information Interchange. |
| CCD | : | Charge-Coupled Device. |
| mil | : | One Thousand of the Inch. |
| LED | : | Light Emitting Diode. |
| IR | : | Infrared. |
| UPC | : | Universal Product Code. |
| EAN | : | European Article Numbering. |
| MFC | : | Microsoft Foundation Class. |
| PLD | : | Programmable Logic Device. |
| I | : | Intercharacter Gap. |
| N | : | Wide to Narrow Ratio. |
| C | : | Number of Elements. |
| OCR | : | Optical Character Recognition. |
| $\vartheta$ | : | The Mean Value of the Gray Scale. |

# CHAPTER I

# INTRODUCTION

In order for a mobile robot to perform its assigned tasks, it often requires a representation of its environment, a knowledge of how to navigate in its environment, and a method for determining its position in the environment.

The most important result from surveying the literature on mobile robot positioning is that to date there is no truly elegant solution for the problem. The many partial solutions can roughly be categorized into two groups: relative and absolute position measurements. Because of the lack of a single, generally good method, developers of automated guided vehicles (AGVs) and mobile robots usually combine two methods, one from each category.

A naive approach to robot localization is to use odometers to measure the displacements of a robot. This approach, known also as dead-reckoning, is subject to errors due to external factors beyond robot's control, such as wheel slippage, or collisions. More importantly, dead reckoning error increases without bound unless the robot employs sensor feedback in order to recalibrate its position estimate.

A key issue in developing a solution to the localization problem is that of domain dependence. The majority of localization methods are constructed based on explicit and/or implicit assumptions about the environment. In the context of machine vision, for example, many techniques extract domain-dependent features from the image, such as straight lines or corners - features which may not be present or stable outside of structured office or industrial environments. Hence, a goal of the method presented here is to achieve domain independence.

Domain independence has been achieved by using bar code labels as artificial landmarks. The advantage of using the bar code labels are: (1) easy to identify, (2) inexpensive, (3) easy to set up, and (4) inconspicuous to human. These landmarks are useful for the particular domain, while moving to a new domain will not require much alternation. The method presented here are general in the sense that the same off-line attaching of the bar code labels in an indoor environment and on-line position estimation of a mobile robot can be employed in a new domain with little or no alteration.

## Objective of the Thesis

Our aim is to navigate a mobile robot in an indoor environment, especially in an office building, not in a factory environment. The objective of the thesis is to present a pragmatic idea which utilizes a camera-based bar code recognition techniques in order to support mobile robot localization in an indoor environment. The main idea is to further improve already existing basic localization capabilities, obtained from dead-reckoning method, by furnishing relevant environmental spots such as doors, stairs, etc. with semantic information. In order to facilitate the detection and the recognition of these artificial landmarks the employment of bar code labels has been proposed.

## Thesis Organization

The thesis proposes a method for mobile robot self-localization using bar codes as artificial landmarks. The theoretical aspect of the localization problem in general and our specific solution are considered. Chapter 2 surveys the state-of-the-art in sensors, systems, methods, and technologies that aim at determining the robot's position in its environment. The general overview over bar codes, including various bar code labels and their structure, the different types of bar code readers, and the usage of bar code labels in mobile robot applications is presented in Chapter 3. Chapter 4 presents our localization method that uses bar code labels as artificial landmarks to support basic localization capabilities obtained from dead-reckoning method, along with the description of two software programs: one for the generating and the other one for the recognition of five types of bar code labels. Chapter 5 presents the results obtained from the generation and the recognition software programs with a discussion. Finally, the conclusion is presented in Chapter 6.

# CHAPTER II

# LITERATURE REVIEW

Exact knowledge of the position of a vehicle is a fundamental problem in mobile robot applications. In search for a solution, researchers and engineers have developed a variety of systems, sensors, and techniques for mobile robot positioning. This chapter provides a review of relevant mobile robot positioning technologies. The review defines seven categories for positioning systems: Odometry, Inertial navigation, Magnetic compasses, Active beacons, Global positioning systems, Landmark navigation, and Model matching. The characteristics of each category are discussed and examples of existing technologies are given for each category. The field of mobile robot navigation is active and vibrant, with more great systems and ideas being developed continuously.

This section surveys the state-of-the-art in sensors, systems, methods, and technologies that aim at finding a mobile robot's position in its environment. The survey are not considering Automated Guided Vehicles (AGVs). Because AGVs use magnetic tape, buried guide wires, or painted stripes on the ground for guidance. These vehicles are thus not freely programmable and they can not alter their path in response to external sensory input (for example, obstacle avoidance).

The most important result from surveying the literature on mobile robot positioning is that, to date, there is no truly elegant solution for the problem. The many partial solutions can roughly be categorized into two groups: relative and absolute position measurements. The two groups can be further divided into the following seven categories:

(I) Relative Position Measurements (also called Dead reckoning):

(1)Odometry.
(2)Inertial Navigation.

(II) Absolute Position Measurements (Reference-based systems):

(3)Magnetic Compasses.
(4)Active Beacons.
(5)Global Positioning Systems.
(6)Landmark Navigation.
(7)Model Matching.

Because of the lack of a single good method, developers of mobile robots usually combine two methods, one from each group.

## Relative Positioning Measurements

### Odometry

Odometry is the most widely used navigation method for mobile robot positioning; it provides good short-term accuracy, inexpensive, and allows very high sampling rates. However, the fundamental idea of odometry is the integration of incremental motion information over time, which leads inevitably to the unbounded accumulation of errors. Specifically, orientation errors will cause large lateral position errors, which increase proportionally with the distance traveled by the robot.

Despite these limitations, most researchers agree that odometry is an important part of a robot navigation system and that navigation tasks will be simplified if odometric accuracy can be improved. For example Cox (1991), Byrne et al. (1992), and Chenavier and Crowley (1992), propose methods for fusing odometric data with absolute position measurements to obtain more reliable position estimation. Odometry is based on simple equations (Borenstein et al., 1996), which hold true when wheel revolutions can be translated accurately into linear displacement relative to the floor.

However, in case of wheel slippage and some other more subtle causes, wheel rotations may not translate proportionally into linear motion. The resulting errors can be categorized into one of two groups: systematic errors and non-systematic errors (Borenstein and Feng, 1996). Systematic errors are those resulting from kinematic imperfections of the robot, e.g., unequal wheel diameters or uncertainty about the exact wheel-base. Non-systematic errors are those that result from the interaction of the floor with the wheels, e.g., wheel slippage or bumps and cracks. Typically, when a mobile robot system is installed with a hybrid odometry/landmark navigation system, the density in which the landmarks must be placed in the environment is determined empirically and is based on the worst-case systematic errors.

Borenstein (1995), developed a method for detecting and rejecting non-systematic odometry errors in mobile robots. With this method, two collaborating platforms continuously and mutually correct their non-systematic (and certain systematic) odometry errors even while both platforms are in motion. A commercial version of this robot, shown in Figure 2.1, is available from TRC under the name "OmniMate."

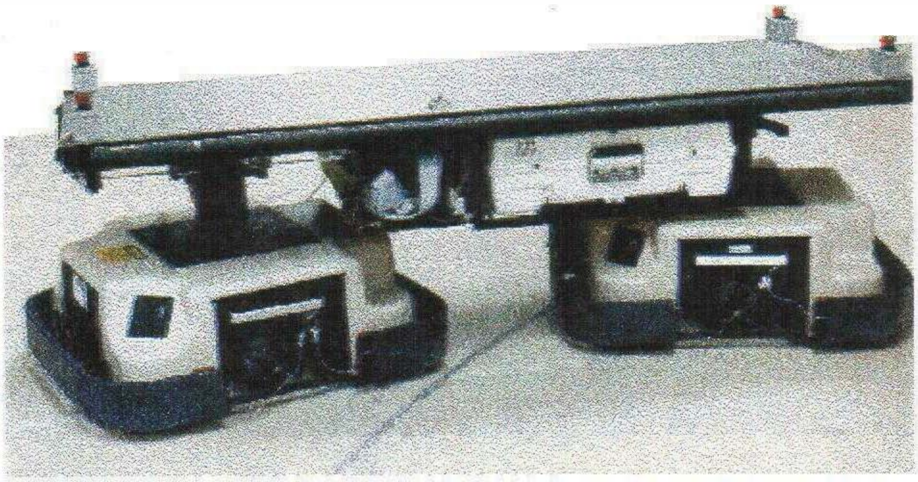

**Figure 2.1: The OmniMate is a Commercially Available Fully Omnidirectional Platform.**
(http://www-personal.engin.umich.edu/~johannb/OmniMate.htm)

**Inertial Navigation**

Inertial navigation uses gyroscopes and accelerometers to measure rate of rotation and acceleration, respectively. Measurements are integrated once (or twice, for accelerometers) to yield position. Inertial navigation systems have the advantage that they are self-contained, that is, they don't need external references. However, inertial sensor data drift with time because of the need to integrate rate data to yield position; any small constant error increases without bound after integration. Inertial sensors are thus mostly unsuitable for accurate positioning over an extended period of time.

**Accelerometers**

Test results from the use of accelerometers for mobile robot navigation have been generally poor (Borenstein et al., 1996). Accelerometers also suffer from extensive drift, and they are sensitive to uneven ground because any disturbance from a perfectly horizontal position will cause the sensor to detect a component of the gravitational acceleration. One low cost inertial navigation system aimed at overcoming the latter problem included a tilt sensor (Barshan and Durrant-Whyte, 1993; 1995). The tilt information provided by the tilt sensor was supplied to the accelerometer to cancel the gravity component projecting on each axis of the accelerometer.

**Gyroscopes**

Gyroscopes, also known as rate gyros or just gyros, are of particular importance to mobile robot positioning because they can help compensate for the foremost weakness of odometry: in an odometry-based positioning method, any small momentary orientation error will cause a constantly growing lateral position error. For this reason it would be of great benefit if orientation errors could be detected and corrected immediately. Until recently, highly accurate gyros were too expensive for mobile robot applications. For example, a high-quality Inertial Navigation System (INS) such as those found in a commercial airliner would have a typical drift of about 1850 meters (1 nautical mile) per hour of operation, and cost between $50K to $70K (Byrne et al., 1992).

However, very recently fiber-optic gyros, also called laser gyros, which are known to be very accurate, have fallen dramatically in price and have become a very attractive solution for mobile robot navigation. One commercially available laser gyro is the Autogyro Navigator from Andrew Corp. ANDREW, shown in Figure 2.2.