LANDMARK GUIDED TRAJECTORY OF AN AUTOMATED GUIDED VEHICLE USING OMNIDIRECTIONAL VISION

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ABSTRACT

The omnidirectional camera is very useful in tracking a landmark for automated guided vehicle (AGV). The omnidirectional camera can sense object 360° around the AGV thus eliminating the need of camera panning or robotic reorientation. The image produced by the omnidirectional camera is usually highly distorted. However, one feature of the image captured by an omnidirectional camera is that the distortion only against the height of the object. Object with negligible height has negligible image distortion. With this feature in mind, this research investigates the trajectory generated from an AGV towards an identified and recognized landmark using omnidirectional camera without rectifying the distortion into perspective view. The research work involves landmark identification and recognition using image processing step. The landmark used, was enlarged to four different sizes, code-128 barcodes with cyan background and red orientation marker. The landmark identification and recognition is processed from the image captured by the omnidirectional camera. The camera was mounted on the AGV and remain as the sole range sensor for the AGV to sense its environment. Three fundamental trajectories used in robotics navigation namely straight, left turn, and right turn were experimented to present the trajectory of an AGV guided by a landmark. The AGV was modelled using Bicycle Model. The trajectory of the AGV is then simulated using MATLAB/Simulink. Next, the simulation work is validated with the experimental work. A proportional control is applied in the experimental work for the AGV move toward the landmark. All experiments were conducted in a laboratory environment with controlled illumination. The work thus demonstrate that the image captured using omnidirectional camera can be used to identify and recognize a landmark without going through any typical omnidirectional image unwarping process into a perspective view. The important navigational information for the vision-based-AGV can be extracted directly from the camera feed.

ABSTRAK

Kamera semua arah adalah amat berguna dalam mengesan suatu mercu tanda untuk kenderaan automatik terpandu (AGV). Kamera ini berupaya mengesan objek 360° di sekeliling kenderaan tersebut seterusnya menghapuskan keperluan pergerakan kamera atau orientasi semula robot. Imej yang terhasil daripada kemera semua arah ini bisasanya sangat herot-benyot. Walaubagaimanapun, satu ciri imej yang herotan terhasil oleh kamera semua arah ini hanya melibatkan ketinggian objek. Objek yang mempunyai ketinggian boleh abai mempunyai herotan yang boleh diabaikan juga. Oleh itu penyelidikan ini dijalankan bagi menyelidik trajektori AGV tersebut bagi pergerakan ke arah suatu mercu tanda yang telah dikenalpasti tanpa membetulkan herotan itu kepada perspective camera. Penyelidikan ini menggunakan langkah pemprosesan imej bagi mengenalpasti suatu mercu tanda. Mercu tanda yang digunakan adalah empat jenis saiz kod bar (code-128) yang telah dibesarkan. Mercu tanda ini menggunakan warna latar sian dan tanda orientasi merah. Proses pengenalpastian dilakukan melalui imej yang ditangkap oleh kamera semua arah. Kamera semua arah tersebut merupakan satu satunya sensor julat bagi AGV tersebut untuk mengecam persekitarannya. Tiga pergerakan trajektori asas dalam navigasi robot, gerakan lurus, belok kanan dan belok kiri, telah diujikaji. AGV tersebut mengunakan model basikal dan telah disimulasi melalui perisian MATLAB/Simulink. Kemudian, kerja kerja simulasi ini telah disahkan melalui kerja kerja ujikaji. Kawalan berkadaran digunakan dalam kerja-kerja ujikaji ini. Kesemua ujikaji dilakukan dalam persekitaran makmal dengan kawalan pencahayaan. Kerja penyelidikan ini berjaya menunjukkan bahawa imej yang diambil menggunakan kamera semua arah, walaupun mempunyai herotan, tetap masih boleh digunakan untuk proses pengenalpastian dan pengecaman mercu tanda tanpa pembetulan herotan tersebut.

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LIST OF SYMBOLS

α_f	Resultant front steering angle of the AGV.
α_r	Resultant rear steering angle of the AGV.
r	Turning radius of the AGV.
β	Heading angle of the AGV
X	Horizontal position of the AGV.
Y	Vertical position of the AGV.
w_e	The distance between AGV's longitudinal axis to left wheel.
w_g	The distance between AGV's longitudinal axis to right wheel.
γ_{fe}	Steering angle of the left front wheel.
γ_{fg}	Steering angle of the right front wheel.
γ_{re}	Steering angle of the left rear wheel.
γ_{rg}	Steering angle of the right rear wheel.
v	Actual speed of the AGV.
v_f	The front wheel velocity.
v_r	The rear wheel velocity.
δ	Side slip angle of the AGV.
l_f	Distance between the AGV's Centre of Gravity and front axle.
l_r	Distance between the AGV's Centre of Gravity and rear axle.
$\dot{X}$	Horizontal speed of the AGV.
$\dot{Y}$	Vertical speed of the AGV.
$\dot{\beta}$	Heading angular speed of the AGV.
v_t	Front and rear speed
ρ	Shortest distance between the AGV and the landmark.
τ	The angle between horizontal line and ρ.
σ	The angle of the AGV longitudinal axis and ρ.
θ	The angle of ρ to the AGV longitudinal axis at the final pose.
T_a	Transformation angle between the local coordinates system and the global coordinates system
τ_c	The angle between horizontal line and ρ, measured by camera.
X^*	Output of the X position proportional control

Y^*	Output of the Y position proportional control
TP_x	Target X-Position of the AGV
TP_y	Target Y-Position of the AGV
CP_x	Current X-Position of the AGV
CP_y	Current Y-Position of the AGV
K_p	Proportional Gain for ρ
σ^*	Output of the σ proportional control
θ^*	Output of the θ proportional control
TO_β	Target Orientation of the AGV
CO_β	Current Orientation of the AGV
K_θ	Proportional gain for θ
K_σ	Proportional gain for σ
RSE	Residual Sum Square Error
VAR	Statistical Variance
STDEV	Statistical Standard Deviation
n	Number of Data
Y_{exp}	Corresponding Y Position at an X Position in Experiment
Y_{sim}	Corresponding Y Position at an X Position in Simulation

LIST OF ABBREVIATIONS

1D	One Dimensional
2D	Two dimensional
AGV	Automated Guided Vehicle
CoG	Centre of Gravity
DC	Direct Current
ICR	Instantaneous Centre of Rotation
IO	Input / Output
PID	Proportional - Integral - Derivative
PWM	Pulse Width Modulation

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

On extra-large facilities such as ports, warehouses, or production factories, a conventional method (conveyor belts, trucks) of material handling system may not be practical. Automated guided vehicle (AGV) usually is a typical choice for the companies to manage the material handling system. AGVs can provide support in the form of material or product delivery from one station to another. The AGVs can drive directly to the designated station and skip the unnecessary stations.

AGV can be defined as an unmanned, autonomous vehicle that is a subset of mobile robots. The AGV may have on-board computer to store path planning and motion control system. A traditional AGV usually rely on either wired technology, guided tape, laser technology or inertial guidance systems that make use of the gyroscopes and wheel odometry for their path planning system (Kelly et al., 2007). These technologies have made the AGVs dependent on the infrastructure in order to navigate around the facilities where it was deployed. The dependency on the infrastructure demands every single AGV to be in operational state to avoid any disruption to the whole system. This system is, more or less, similar to a conveyor belt system.

Later generations of AGV are able to deviate significantly from their guide path. This type of AGV is usually known as a free ranging AGV and employs perception system on-board. The perception system, path planning and motion control are the common intelligent systems embedded in an AGV in order for it to carry out its assigned task in a manufacturing plant.

In a span of more than 50 years of AGV development, various sensors have been utilised in order to improve the AGV perception system. Among the sensors being used are optical sensor, sonar sensor, magnetic sensor, laser sensor, Global Positioning System (GPS) and camera based vision system (Xie, 1995). The perception system should provide the information for the AGV regarding the position of the target, current location of the AGV with respect to its origin and possible obstacles in its path. As an AGV's working environment becomes more complex, a reduction in perception process time is desired in order for the AGV to cope with its designated task.

Recent advancement in computer vision led to a rising interest on camera sensors for an AGV's perception system (Miljković et al., 2013). Apart from its economical reason, using camera for perception allows more information to be extracted within a single sensor. Obstacle avoidance, path planning, visual-servoing, and object recognition are among the navigation protocols executed from images acquired by the camera system.

The technology allows more researches being conducted in order to understand the robotics perception from a simple range sensor to self-localization and mapping. Furthermore, the camera configuration, such as monocular (Sabikan et al., 2010) binocular, (Xu and Tian, 2011) trinocular (Xie, 1995) or omnidirectional camera (Weijia et al., 2008), also contributes to the application of camera systems in robotics.

1.1 RESEARCH BACKGROUND

In order to develop a free ranging AGV, the AGV needs to have at least an algorithm to localize itself within its environment. The localization can be achieved by several methods such as Simultaneous Localization and Mapping, range laser or sonar and triangulation, map building, or landmarks. Navigation by using landmarks can be useful in manufacturing warehouses. The landmarks can simultaneously be treated as machine or station identification for the company asset management. The landmarks should be placed in a global coordinate system, thus giving the AGV the localization needed to complete its required navigation. Navigation by known landmarks permits the AGV to directly approach the landmarks instead of having to follow a specific line around the facilities.

Adopting a camera in an AGV system allows the AGV to identify landmarks placed in a manufacturing environment through image processing. Camera has been extensively used as part of AGV perception due to its flexibility and superior image quality. However, a frontal camera has certain limitation mainly a small view angle. In order to provide a full 360° view around the AGV, a frontal camera system have to be panned or tilted. Panning and tilting mechanism adds extra weight to the AGV and will cause a slight delay in identifying the location of the landmarks. These limitations will in turn limit the capability of the AGV to interact with its environment.

In order to get a full 360° view around the AGV, an omnidirectional camera is usually used. The omnidirectional camera view can be achieved by using fisheye lens, or catadioptric camera system. Catadioptric camera system is a camera with spherical, conical, hyperboloidal or parabolical mirror system with the main purpose of extending their field of view. However, the images captured by omnidirectional camera are usually highly distorted.

1.2 PROBLEM STATEMENT

The current issue on the AGV's vision system is the narrow field of view (Taha et al., 2010). The narrow field of views present a limitation to the infrastructure-free AGV to manage its path trajectory, landmark recognition and obstacle identification especially when the landmarks are frequently out of the camera field of view.

Weijia et al used a fisheye lens to detect coloured landmark beacon for their AGV navigation (Weijia et al., 2008). Before the recognition is made, they ran an image rectification process in order to get a correlation between the fisheye image points and the real images. The image rectification process refers to the step of unwarping omnidirectional image into a perspective image view before any other image processing steps to extract usable information from the image are applied.

Yingjie et al utilised a catadioptric omnidirectional camera system in a highly dynamic environment for their mobile robot (Yingjie et al., 2004). They tracked landmarks in the form of a goal post or corner post for the mobile robot localization. They rectified the image through a process named cylindrical projection to eliminate the robot and the ceiling from the view. This rectification process causes significant reduction in image data for navigational approach. In both, the approaches rectification of the image is necessary thus slowing down the navigation process.

Taha et al discovered that image captured by catadioptric omnidirectional camera only distort significantly against the height of an object. The object length and width on the ground distortion, when viewed from the camera system, is negligible. (Taha et al., 2010)

Thus, the rectification of the image captured by the omnidirectional camera leads toward reduction of data, longer image processing time, and consumed more computing power. However, there exists certain parts on the image where the distortion is negligible.

1.3 RESEARCH OBJECTIVES

It is hypothesized that the AGV can identify and recognize a landmark and navigate to approach the landmark using omnidirectional camera without going through any image rectification process. Therefore, the aim of this research is to develop an AGV navigation system using catadioptric omnidirectional camera without any image rectification. The navigation system should include landmark recognition and identification, and trajectory generation.

In order to achieve the research aim, three objectives are set namely:

(i) To develop a system using catadioptric omnidirectional camera as the range sensor for an AGV

(ii) To identify and recognize landmarks for navigation using the developed system.

(iii) To generate the trajectory for the AGV to align and position itself with a landmark using the developed system.

1.4 SCOPE OF THE STUDY

The main focus of this study is landmark recognition and the AGV navigation toward the landmark. Contributing factors for AGV navigation using landmark are identified and described in this research. These factors include modelling of four-wheel steering with a four-wheel drive AGV, omnidirectional catadioptric camera as a sole sensor on board the platform, target recognition and detection and target approach by the AGV. In this research several requirements are identified for the design of the landmarks.

The landmarks are easily reproduced from off-the-shelf material with minimal modification.

However, the study is conducted in a controlled environment. The experimental test did not run in a real factory warehouse. The experiment did not take into account the integration between the AGV and the material handling system in a manufacturing environment. The AGV used in this research is only applicable to AGV locomotive as it does not tow any material behind the platform.

Furthermore, the study only focuses on the algorithm for landmark recognition and the AGV's navigation towards the landmark. No obstacle avoidance algorithm, or battery management algorithm were embedded into the algorithm used in this research. The landmark used in this study was artificial landmark and specific to the code-128 only.

In addition, the camera used to identify and recognition of the landmark was an omnidirectional camera which consist of a perspective camera pointing upward and a parabolical mirror on top of the camera at the focal point. The experiment also assumes that the landmarks are clearly visible to the AGV camera system and there are no obstructions, partially or otherwise, between the AGV's camera and the landmark.

In order to control the AGV autonomously from its current position towards the landmark, proportional control is applied to the AGV microcontroller. The error is generated from the difference of the landmark position (set point) and the current AGV position. The tuning of the proportional gains was by the trial and error method. Only proportional control is used because the primary concern was to generate the trajectory for the AGV to align and position itself with a landmark. Then, only three trajectories were examined in this study namely straight trajectory, right turn trajectory, and left turn trajectory.

1.5 METHODOLOGY OF THE STUDY

The research work was conducted in four phases, namely modelling, assembly, manual test, and autonomous test phase. Following a waterfall model concept, each phase must be satisfactorily conducted before moving on to the next phase. Figure 1.1 shows an overview of the research activities using a Waterfall model for the projects implementation.

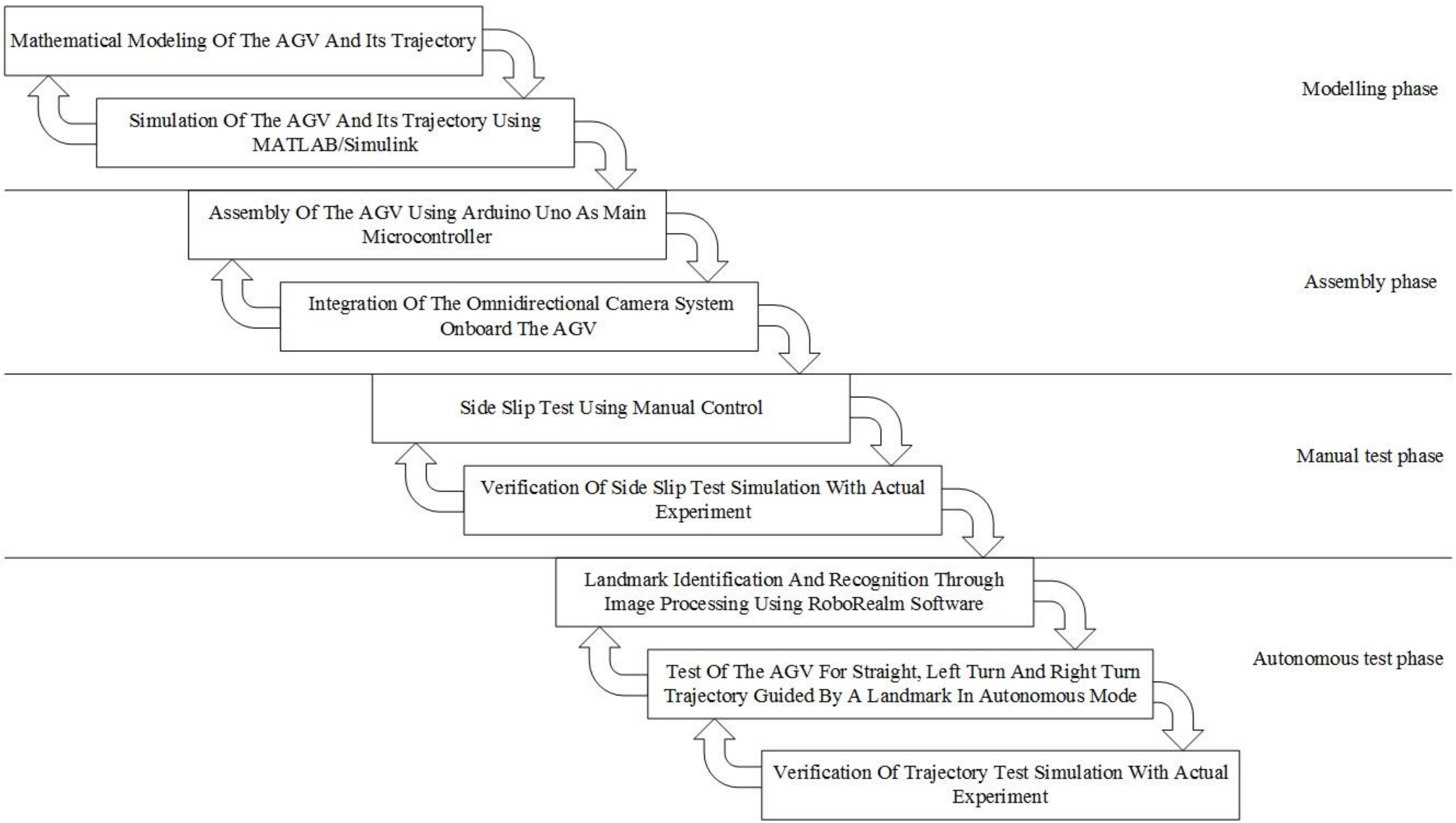

Figure 1.1: Overview of the research methodology using Waterfall model.

The modelling phase focused on the simulation of the derived mathematical model using MATLAB/Simulink while in the assembly phase the main focus was on establishing a wireless radio frequency connection signal between the AGV's on board camera system and the workstation so that the image feed from the camera can be processed on the workstation. Results from the image processing provided the control signals for the AGV on board microcontroller to move the AGV using Bluetooth connection.

In the manual test phase, the AGV was controlled manually to evaluate the AGV behaviour and validate the mathematical model simulation. After that, the research continued by identifying and recognizing the proposed landmark and run experiments for the straight, left turn and right turn trajectories. Then, the simulation results for the three trajectories were validated against the experimental results.

1.6 CONCEPT DEFINITION AND RESEARCH TERMINOLOGY

This section will explain several terms that are used throughout this thesis which may have ambiguous definitions to the reader. Among the term used are:

(i) Vision-based automated guided vehicle (AGV)

Vision-based AGV refers to an autonomous mobile robot that incorporate camera as a sensor to scan its environment. The camera system can either be active or passive, single or multiple configurations. The information extracted from the camera vision plays a significant role in the AGV operation.

(ii) Omnidirectional camera or omnidirectional image

Omnidirectional camera used in this research refers to a camera system that consists of an ordinary perspective camera and a parabolical mirror. Objects are reflected on the mirror before being captured by the ordinary perspective camera. The image generated from this camera system is called an omnidirectional image.

(iii) Natural or artificial landmark

Landmarks are distinctive feature discovered from the images captured by the camera to help the AGV navigation process. If the landmark is gathered from the environment without purposely placed in the surrounding, the landmark is considered a natural landmark, whereas if the feature is purposely placed in the surrounding, the landmark is called an artificial landmark.

(iv) Localization

Localization is a technique for determining the AGV position in global coordinate reference frame. Global coordinate reference frame is a reference frame given by the Cartesian axes for the entire environment where the AGV operates whereas the local coordinate reference frame may refer to the Cartesian axes with respect to the specific moving object such as AGV local coordinate system or camera local coordinate system

(v) Trajectory

Trajectory refers to a path taken by the AGV to move towards a landmark either by mathematical calculation or visual clues gathered by the AGV's range sensor.

(vi) Station

Station is a theoretical place, where the landmark is placed and the AGV make a good transfer from or to the AGV.

1.7 ORGANIZATION OF THE THESIS

This thesis is arranged as follows:

Chapter 1 presents the background of the study, problem statement, research objectives, scope of the study and clarification of terms used in this thesis.

Chapter 2 describes a review of related works that has been conducted prior to this thesis. Three main issues are reviewed in this chapter mainly vision based AGVs, landmark recognition and its detection methods, and path planning with the landmark for mobile robot navigation.

Chapter 3 explains the methodology used in this research in order to identify and recognize the landmark and gathering data from the AGV actual path. This includes the description of image processing steps for landmark recognition and path planning.

Chapter 4 discusses the AGV trajectory using mathematical model of the four-wheel steering and four-wheel drive AGV and mathematical model of the generated path on which the AGV should follow towards the landmarks.

Chapter 5 discusses the data from the experiments and compares with the calculated simulation of the generated path. The deviation of experimental data from the simulation is then justified.

Chapter 6 presents the concluding remarks, knowledge gained and future works recommendation.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

This chapter is a review of past work from other researchers. There are three main issues being reviewed in this chapter mainly vision based AGVs (AGV), landmark recognition and its detection methods, and path planning with landmark for the mobile robot trajectory. These issues are relevant to the research objectives as presented in Chapter 1.

Early AGV utilises physical guide path such as line, wire or radio signals buried in the ground. The intelligent system was built on the ground instead of onto the AGV itself. This kind of system is known as a fixed path AGV. In recent years AGVs have begun to employ microcomputer on-board. This change allows the navigation system of the AGV to have more control in terms of route selection, obstacle avoidance, and velocity control in order to navigate around its operational area. The later generation of AGV is more susceptible to modification of operations such as changes of flow, new station or equipment change (Martínez-Barberá and Herrero-Pérez, 2010).

With the application of contactless technology such as ultrasonic (Ratner and McKerrow, 2003, Tong et al., 2005, Yan et al., 2006), laser (Golnabi, 2003, Guo et al., 2013, Yu et al., 2013) or vision (Aixue et al., 2012, Her et al., 2013) as range sensor, the AGV has become more similar to autonomous mobile robot especially in terms of its navigation system.

2.1 VISION-BASED AUTOMATED GUIDED VEHICLES

Vision based AGV utilises vision sensor and computer image processing for navigation. AGVs may share a common generic architecture where the vehicle is governed by it sensors to gather information from the surrounding and response to its surrounding by several actuators. Information processed from the vehicle's sensors is called perception. The perception can be in the form of image processing to get usable information for path planning and control when the vehicle is using a camera as its sensor.

Figure 2.1 shows the generic system architecture of an AGV. The level of complexity for each block depends on the environment where the vehicle operates. The higher environment complexity the more sensors may be needed to complement each other for robust and reliable motion control of the vehicle (Ilas, 2013).

A review by DeSouza and Kak revealed that researches on vision based AGV for indoor navigation can be classified into three main groups namely map-based-navigation, map-building based navigation, and mapless-navigation. The first group is map-based-navigation where the AGV depends on a system based on a topological map of the environment or a user-created map by modelling the environment where the AGV will operate. The second group is map-building based navigation where the AGV is equipped with a system that constructs its own geometric or topological representation for its navigation and the third group employs mapless-navigation where the AGV uses no explicit representation about the operational environment. It makes use of the visual images cue to recognize objects in the surrounding to determine a collision-free navigation path. (DeSouza and Kak, 2002)

Although the review by DeSouza and Kak is focused mainly on AGV researches before the year 2000, their main classification seems to guide more recent researches. A more recent review by Guzel (Güzel, 2013) and Bonin-Font (Bonin-Font et al., 2008) also featured researches in the same classification.