GROUND PLANE OBSTACLE DETECTION FOR MOBILE ROBOT NAVIGATION BASED ON OPTICAL FLOW FIELD

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

FEBRUARY 2006

Dedicated to my beloved family

ACKNOWLEDGEMENT

First and foremost, I would like to express my sincere gratitude and appreciation to my supervisor, Prof. Dr. Shamsudin H. M. Amin for his invaluable and critical comment throughout this project. Their guidance and assistance have given me a strong basis in handling this project.

Appreciation also extended to my friends in UTM Robotics lab for their patience and cheerfully sacrificing their precious time to share their knowledge, experience and most of their wisdom during the length of time this project was carried out.

Lastly, warmest regards are sent to my family members and many friends for their seamless caring and moral support.

ABSTRACT

The main objective of this work is to develop a vision-based obstacle avoidance capability for autonomous mobile robot. The basic assumption is that the robot is moving on a planar pavement and any objects not lying on this plane are considered to be obstacle. The robot will not be able to detect overhanging object as obstacle. An important feature is that the knowledge of the camera parameters and vehicle motion is not required. The method used for obstacles detection is Ground Plane Obstacle Detection where the robot is moving with the camera is facing the ground plane, hence observing a planar surface in motion. With this assumption, there is a globally valid parameterisation for the corresponding optical flow field. The detection mechanism simply relies on the fact that the optical flow should be globally constant no matter what the motion direction and speed of the robot might be. Thus, detecting the incoherent area in the optical flow field is equivalent to detecting the obstacle. Information from colour images is introduced to solve the problem of under constraint in optical flow computation using gradient-based method. By treating a colour image as three individual monochrome images, produced from extracting red, green and blue colour component of a colour image, the system will become over constraint. Thus, neighbouring sampling approach is introduced to solve the problem. Since the interest area for obstacle avoidance can be minimize to a small area in front of the robot, therefore optical flow is only calculated on the interest area. This method of calculating optical flow from sub-sampled images has greatly speed up the process of optical flow computation. Besides, this system has proved that gradient-based optical flow computation can also be sufficient with only using two subsequent images. The experiments conducted have given evidences about the good performed of the proposed method for mobile robot navigation utilizing only information from optical flow field.

ABSTRAK

Tujuan utama penyelidikan ini dijalankan adalah untuk menghasilkan satu fungsi yang membolehkan robot otomatik mengelak daripada pelanggaran semasa bergerak dengan menggunakan sistem penglihatan komputer. Anggapan dalam sistem ini adalah robot bergerak pada permukaan rata dan sebarang objek yang berketinggian berbanding dengan permukaan akan dianggap sebagai halangan. Objek yang tergantung tidak dapat dikesan sebagai halangan. Keistimewaan sistem ini ialah parameter kamera dan pergerakan robot tidak diperlukan. Cara yang digunakan dalam sistem ini adalah “Ground Plane Obstacle Detection”. Robot bergerak dengan cameranya manghala ke permukaan lantai dan memerhati pergerakan di permukaan ini. Dengan anggapan tersebut, permukaan lantai akan wujud satu parameter berkaitan dengan optical flow field yang pada keseluruhannya benar. Sistem pengesanan hanya berpegang pada fakta bahawa tidak kira pegerakan dan halaju robot, parameter ini adalah pemala. Maka, pengesanan kawasan yang tidak sekata adalah sama dengan mengesan kewujudan penghalang. Informasi daripada gambar berwarna diperkenalkan untuk menyelesaikan masalah kekurangan maklumat dalam pengiraan optical flow yang bergantung pada gradient. Sistem ini menjadi terlebih maklumat kerana komponan merah, hijua dan biru suatu gambar berwarna digunakan untuk membentuk tiga gambar hitam putih. Cara neighbouring sampling telah diperkenalkan untuk menyelesaikan masalah ini. Sebab kawasan untuk pengesanan halagan boleh diperkecilkan kepada kawasan di hadapan robot sahaja, maka penggiraan optical flow hanya dilakukan pada kawasan ini sahaja. Cara sub-sample ini telah mempercepatkan proses penggiraan optical flow. Selain itu, sistem ini telah membuktikan bahawa cara yang bergantung pada gradient boleh dijalankan dengan berkesan dengan hanya menggunakan dua gambar yang berterusan. Experimen yang dijalankan telah membuktikan keberkesanan teknik yang dicadangkan untuk pergerakan robot yang hanya menggunakan maklumat daripada optical flow.

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LIST OF ABBREVIATIONS

1D	-	One dimension
2D	-	Two dimension
3D	-	Three dimension
API	-	Application program interface
b	-	Blue component in rgb color space
B	-	Blue component in RGB color space
DC	-	Direct current
g	-	Green component in rgb color space
G	-	Green component in RGB color space
MHz	-	Mega hertz
I	-	Intensity component in Modified HSV color space
I/O	-	Input-output
LCD	-	Liquid crystal display
LS	-	Least squares
MB	-	Mega byte
OS	-	Operating system
r	-	Red component in rgb color space
R	-	Red component in RGB color space
R/C	-	Radio Control
RAM	-	Random Access Memory
RGB	-	Red, green, blue color space
rgb	-	Normalized Red, green, blue color space
SLA	-	Sealed Lead Acid
SDK	-	Software development kit
UPS	-	Uninterrupted power supply
USB	-	Universal serial bus

UTM	-	Universiti Teknologi Malaysia
v	-	Volt
VFF	-	Virtual Force Fields

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CHAPTER I

INTRODUCTION

1.1. Introduction

As a person walks around at the office, or at home, he or she can find information about the surrounding in a number of ways. The foremost sensory ways used are sight, sound, touch, and smell. His eyes let him to see that his boss is coming toward him and to see that his cup is empty. His ears allow him to hear what is said on the radio, and also to hear what his boss tell him. The feeling of gravity helps out to orient a person. When present in a dark room, kinesthetic (relating to the ability to feel movements of the limbs and body) sensors are more active than otherwise. A person will use hands to follow a wall and to find the switch of a light. He or she will probably switch on the light, because, often humans use their visual system to a greater extent than other sensors for navigation. As a matter of fact, vision is the most highly developed of our senses. Humans are good at extracting the 3D structure of the surroundings, even though having only 2D projections of the surroundings onto the retinas. Thus, the complex human vision system has inspired and encouraged much of the research in computer vision and image processing.

At indoor environments, such as offices, homes and factories, planar surfaces dominate most of the floor. However, human brains can easily detect when a surface is planar or slightly curved and seem to incorporate various visual cues. Even with a single eye, humans can often instantly determine whether a certain part of an object is planar or not. The visual cues that are used are shading, texture, edges and corners. When these cues have a certain structure on the retina, a conclusion can be made that the surface is planar. Human more or less continuously move their eyes and head, giving a movement of the projected features in the retinas. This motion provides further information about the structure of the surroundings to the brains. When a part of the viewed scene has a particular shape, the motion in the retinas is constrained, allowing the brains to develop knowledge about that shape. Planar surfaces are no exception, and human vision system employed this cue too.

1.2. Mobile Robot Navigation

Mobile robots and autonomous vehicles are crucial for many tasks that could not be performed by manned vehicles in hazardous environments. The mobile robots' action need to be based on information extracted from its surrounding. Before any task can be accomplished, navigation capability need to be inherited inside the mobile robots, which will enable the robots to find sufficient free spaces to move around in the environment. However, obstacle avoidance is one of the basic requirements in mobile robot navigation. For autonomous mobile robot operation in unstructured environments, obstacles must be detected before any obstacle avoidance activity can be taken. Obstacles are defined as any region in space where a vehicle should not or cannot traverse, such as steep terrain, objects lying on top of the terrain, or potholes in the terrain.

Most existing approaches ([1], [2], [3], [4], [5], [6], [7], [8],) perform obstacle detection based on range information obtained either from active sensors or passive sensors such as infrared, laser scanners, radars, sonars, stereo vision, optical flow, etc. A priori knowledge is also employed by most existing methods. Such knowledge may include road model (or map), coordinate transformations, sensor motion, model optical flow fields, etc. Errors in a priori knowledge will cause errors in the output, even with perfect knowledge of road models or model optical flow fields. However, the successes of an obstacle avoidance method also heavily rely on the resolution that can be provided by the sensor used. With a higher resolution, the mobile robots can make a more precise decision on the obstacles. For example, due to the limited sensing area of a sonar sensor, a mobile robot will not be able to detect the existence of obstacles beyond the sensing area. Whereas, every pixel in an image used for vision-based robot system can be considered as one particular sensor.

1.3. Vision-Based Mobile Robots Navigation

Motivated and inspired by the highly efficient human vision system, robot scientists and engineers have persistently used video cameras mounted on the robots to gain information about the world, which known as computer vision. A major area in computer vision is to imitate the human vision system as well as possible. At first, this task was not expected to be very complicated. However, the problem has indeed proven to be complex, and this research field has grown into a large one, and is still growing.

An important part of the computer vision literature is regarding the navigation task. The low cost of cameras and vision equipments, coupled with the intuitive appeal of using vision information alone for robot navigation, is the driving force behind many efforts on developing a vision-based obstacle avoidance system. The important literatures of the more general robot navigation problem in this area include [9], [10], [11] and [12]. Since then, various approaches emerged, such as map-based, map-building-based and mapless navigation. Generally, in all these approaches, mobile robots are moving on the floor. Thus, the major problem to be solved is finding the free area from the images captured by the video cameras. In solving this issue, different ideas like navigation using optical flow, appearance-based matching and object recognition were developed by different researchers around the world.

1.4. Motivation and Problem Background

The current development of mobile robot research is always focusing on building mobile robot systems that can operate in human environment for various purposes. This is the main motivation of this work in developing a mobile robot system. However, the superiority of human vision system in objects detection that human always take for granted is another major motivation of this work in formulating a more suitable vision system for mobile robots in obstacles detection and avoidance. The advancement in microprocessor power and the low cost of the camera and vision system also drive this work in using computer vision for mobile robots navigation purpose.

In many existing mobile robot navigation system, complicated algorithms and methods such as sensor fusion and etc., are required to support and enhance the sensor technology used. This is because the limitation of the sensor technology has restricted the sensor data to be relatively less per number of sensors used comparing with vision sensor. Thus, a sensor technology that could provide higher data resolution per number of sensors used is required.

Similar with other obstacle avoidance methods using sonar, infrared and other sensor, another problem with most of the vision-based obstacle detection approaches in the literature is that much initial information is required. This priori information can be the positioning of the camera(s) in relation to the ground plane, camera calibration, the motion parameters, and/or the matching between feature points in different images. Realizing that such information is not necessarily given in a particular real-life case, hence there is a need for methods requiring a minimum of a priori information.

When discussing vision-based mobile robot navigation, many researchers have tried to reconstruct the exact 3D space or objects location in front of the robot using optical flow field. This 3D space representation or objects location was later used for determining the free space that the robot can maneuver through. However, these optical flow field methods consume a lot of computational power and seem not very practical. Since, mobile robot navigation in human environment is a task that required a robot to react fast to its environment. The computation of optical flow need to been done immediately, which will lead the researchers to use dedicated machines for these purpose. Special image processing units may be the right choice but they are relatively expensive. Therefore, a new optical flow field method that need less computational power and time but still providing good results is needed. With this new method, vision-based mobile robot navigation can be carried out on a general purpose computing system, which is cheaper in price such as a personal computer.

1.5. Objectives and Scope of Project

The objectives of this work can be summarized as below:

i). To study the latest finding in vision-based mobile robot navigation especially the problems faced. From the literature, three problems have been identified. First, the heavy computation required for image processing tasks slowed the response of the robot to its environment. Expensive dedicated processing unit is required in return of making the robot to have a real time response in navigation. Lastly, the necessity of using priori knowledge or calibration of the robot, which might cause errors to the robot's navigation results.

ii). To search through the literature about the problem faced on using optical flow field for mobile robot navigation. The major problem in current works is the attempt to determine the exact location of an obstacle, which will cause expensive computation.

iii). To study on the concept of optical flow and identify the strength and weakness on various methods used for computing optical flow. A common setback on these methods is the lag of utilizing information provided by color images.

iv). To come out with a new method solving the problems determined in vision-based mobile robot navigation and optical flow computation literature study.

v). To design and develop a new mobile robot suitable for the implementation of the proposed method. The mobile robot is equipped with a personal computer function as a control and processing unit.

vi). To implement the proposed design on vision-based mobile robot navigation. This new system will be tested and the result will be analyzed.

Based on the literature review, the scope of this work has been set to cover these areas:

i). The new robot system is designated to navigate in indoor environment using only a camera as sensor. It uses the camera to “see” its world. The robot can navigate through any structured and unstructured indoor environments.

ii). This robot system can only navigate on a flat ground plane or a planar surface. Any objects above or below the ground plane will be considered as obstacles to the robot system. The robot system will not detect overhanging objects as obstacles.

1.6. Outline of the thesis

The remaining part of this thesis is organized in six main chapters. Chapter II gives an overview of vision-based mobile robot navigation. Various kinds of vision-based design are discussed and investigated from the point of mobile robot navigation problem. The overview of optical flow is discussed in Chapter III, as are the assumptions and philosophies behind this approach. In the meantime, the design of the optical flow field for ground plane obstacle detection and avoidance proposed in this thesis is discussed in Chapter IV. Each step in the design will be explained in detail. Chapter V is about the robot system designed specifically for the implementation of the obstacle detection and avoidance designed. Chapter VI covers the experimental results and discussion. The comparison with other techniques is explored. Finally, the conclusion is in Chapter VII. These include the contribution of the work presented and future development.

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