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Design of A Three-Wheel Omni-Directional Mobile Robot Base Module

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Abstract

In this research, the aim is to develop a modular autonomous mobile robot base that has a certain degree of flexibility and cost effectiveness for some indoor mobile robot applications that may have limited maneuverable space. The structure of the mobile robot and the wheel design are the major investigation areas. A modular mobile robot construction that is able to quickly integrate with different wheels and add on sub-systems has been developed for this project. The experiments made on the test model are positive.

In this project, the mobile robot is built with omni-directional wheels. The omni-directional wheels make the mobile robot maneuverable in its motions. The shape of the mobile robot base and number of wheels that are mounted on the mobile robot were decided based on the structure of the omni-directional wheels.

Modular design makes the omni-directional mobile robot a very practical application. Most of the parts in the omni-directional mobile robot can be easily replaced and reused. The mobile robot itself is constrained to be one that is inexpensive and simple. This would allow others to replicate its concept and improve on it. The control system can be improved by simply replacing the control circuit board on the mobile robot. The new control system can be easily integrated with the peripheral devices, such as motors and sensors. Moreover, the size of the mobile robot base is adjustable, which makes this base design valuable for those who are interested in the development of omni-directional robot applications but are concerned about the size of the robot.

The omni-directional mobile robot consists of three parts: the mechanical system design, the electric and electronic system design, the control system design and programming. When designing mechanical systems, the software “Solidworks” was used. It is a powerful computer aided tool for mechanical drawings and machinery. The software “Altium designer” was selected to design the electric and electronic circuits. It is excellent in drawing schematics of the circuits and producing printed circuit board (PCB). The microcontroller “ATmega32” was selected as the center controller for the mobile robot. It connects every part of the mobile robot together to form the control system. The software “AVR studio” is the communication tool chosen between the microcontroller and the computer, and “C language” is the computer language that was used for programming.

The maneuverability and moving accuracy of the omni-directional mobile robot was examined and the results were analyzed with the computer software “Matlab”. The three-wheel omni-directional mobile robot performs differently between its rotational motions and linear motions. The results show that the mobile robot has better moving accuracy when it is in the rotational motions. The maneuverability of the omni-directional mobile robot has been proven to be effective. The mobile robot is able to perform motions like sliding, self-rotating, curving, circling which other mobile robots are either not able to do so or do so with difficulty.

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List of notation

List of Symbols

DIR	Direction
EN	Enable
GND	Ground

List of Abbreviations

ADC	Analogue to Digital Convertors
ADCSRA	ADC Control and Status Register A
ADMUX	ADC Multiplexer Selection Register
AGV	Autonomous Guided Vehicle
ALU	Arithmetic Logic Unit
COM1A	Compare Output Mode for compare Unit A
COM1B	Compare Output Mode for compare Unit B
CS	Clock Select it
CTC	Clear on Timer Compare
DAC	Digital to Analogue Convertor
HDPE	High Density Polyethylene
ICR1	Input Capture Resister in timer 1
IO	Input and Output
OCR1A	Output Compare Resister1 A
OCR1B	Output Compare Resister1 B
P&F	Phase and Frequency correct PWM mode
PCB	Printed circuit board
PID	Proportional–Integral–Derivative
PWM	Pulse Width Modulation
RAM	Random Access Memory
RPM	Revolution per Minute
TCCR1A	Time /Counter1 Control Resister A
TCCR1B	Time /Counter1 Control Resister B
TCNT1	Timer/Counter1 in Timer1 mode
WGM	Waveform Generation Mode

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CHAPTER 1- INTRODUCTION

Electronic autonomous mobile robot designs have been widely developed in the last hundred years. From the first electronic autonomous mobile robots back in 1945 (Grey, 1945) to the variety of fanciful robots in recent years, mobile robot designs have become more practical and achievable. In the past, the mobile robots were controlled by heavy, large, and expensive computer systems that could not be carried and had to be linked via cables or wireless devices. Today, however, small mobile robots with numerous actuators and sensors that are controlled by inexpensive, small, and light embedded computer systems which are carried on board the robot have become very popular. There has been a tremendous increase in the interest of studying in mobile robotics. Not just as interesting toys or inspired by science fiction stories and movies, but as a perfect tool for learning engineering, and real life applications which benefit our human society (Vukosavljev, Kukolj, Papp, & Kovacevic, 2011). The prime foci of modern robotic systems are to achieve the designs with high flexibility, moving accuracy, robustness, and efficiency. This research mainly focuses on autonomous mobile robot investigation and study, especially the mobile robot with a special type of wheel design, to achieve better maneuverability. Throughout this research, the aim is to develop a modular autonomous mobile robot base that has a certain degree of flexibility and cost effectiveness for some indoor mobile robot applications that may have limited maneuverable space. The structure of the mobile robot and the wheel design are the major investigation areas. A proposed modular mobile robot construction that is able to quickly integrate with different wheels and add on sub-systems was developed. The experiments made on the test model were positive. With further improvement and the add-on of more intelligent functionalities, the mobile robot should be useful for some of the indoor applications such as service robots in healthcare, hospitality and warehouse management.

1.1 Introduction of autonomous mobile robotics

Autonomous mobile robotics is a fascinating research topic that a large number of researchers have put a lot of effort into, and still, there is great potential for people to study and develop more functional and stable robotic designs. In autonomous mobile robot designs, there are three popular research domains, which are “Mobile robot design principle and control methodologies”, “Humanoids mobile robot”, and “Service robot” (Ulrich Nehmzow, 2003).

1.1.1 Mobile robot design principle and control methodologies.

Ulrich Nehmzow (2003) stated that “To change a mobile robot from a computer on wheels that is merely able to sense some physical environmental properties through its sensors into an intelligent agent, able to identify features, to detect patterns or regularities, to learn from experiences, to localize, build maps, and to navigate requires the simultaneous applications of many research disciplines. In this sense, mobile robots reverse the trend towards more and more specialization, and demands lateral thinking and the combination of many disciplines. Engineering and computer science form the core of mobile robotics; obviously, when questions of intelligent behavior arise, artificial intelligence, cognitive science, psychology and philosophy offer hypotheses and answers. Analysis of system components, for example, through error calculations, statistical evaluations etc. are in the domain of mathematics, and regarding the analysis of the whole system, physics proposes explanations, for example through chaos theory.” (p, 1).

1.1.2 Humanoids mobile robots.

For centuries, the interest that people have shown in building machines which mimic human beings has kept increasing. Developing human like machines that can help us achieve different tasks has drawn great attention from robot researchers. As the robotic technology develops, topics like “walking robots”, “robotic arms”, “robotic sensing systems” become more popular. People even try to make the robots to be able to anticipate their actions and correct their wrong moves. In other words, the robots are designed to be more and more human like with higher intelligence. As a result, autonomous mobile robots offer a uniquely suited research platform for investigations of intelligent behaviors.

One of the most common humanoid mobile robot applications is the walking robot. Walking robots are considered the most adaptable robot. They can generally move on various environments as their special leg structures enable them to do so.

Robots with six or more legs have the advantage of stability. When a six legged robot is moving, it keeps three legs on the ground at all times, while the other three legs are in the air. As a result, the robot’s center of mass will always be within a triangle formed by its three legs on the ground, this gives the robot great stability. (Yanto, XiaoLei, & Bowling, 2004). Figure 1.1 shows an image of the six-legged mobile robot.

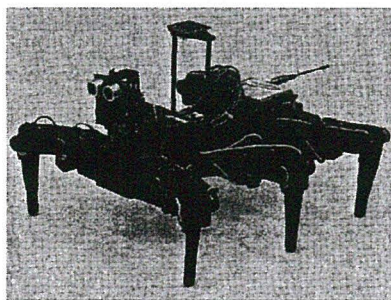


Figure 1.1: six-legged mobile robot.

Four-legged robots are considerably harder to balance, but are still fairly simple when compared to the dynamics of bipedal robots. Figure 1.2 shows an image of a four-legged robot (Kiriki, Kimuro, & Hasegawa, T, 1999).



Figure 1.2: four-legged mobile robot.

The bipedal robots are the most difficult to balance, with only one leg on the ground and one leg in the air during walking. Static balance for bipedal robots can be achieved if the robot's feet are relatively large and the ground contact areas of both feet are overlapping (Ali, Amran, & Kawamura, 2010). Figure 1.3 and figure 1.4 show images of two bipedal robots.



Figure 1.3: bipedal mobile robot

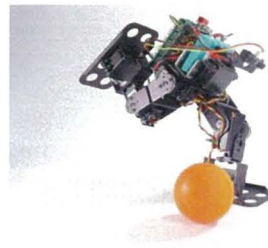


Figure 1.4: bipedal robot with larger feet

Aesthetic and artistic elements are also big considerations for mobile robotics. For example micro-robots, or miniature legged robots, match our sense of beauty. Figure 1.7 shows an image of an aesthetic mobile robot.



Figure 1.5: a good looking robot design.

There are some advantages and drawbacks of the walking robots:

➤ **The advantages of legged locomotion:**

The walking robots have great adaptability and maneuverability on rough terrain. They can move over rough surfaces or even across holes and chasms, as long as their legs' reach exceeds the width of the irregular ground terrain. In addition, they can move over an object if there is enough clearance between their legs and the ground.

➤ **The disadvantages of legged locomotion:**

The legged robots are generally hard to balance in their movements, especially for four legged and bipedal robots. The power required for the legged robots is quite high since the legs are able to move in several degrees of freedom and have to be capable of lifting and lowering the robot. Compared to the wheeled robots, the mechanical complexity of the legged robots is another disadvantage. The cost for building a walking robot is generally higher.

1.1.3 Service robots.

Ulrich Nehmzow (2003) pointed out that “There are also commercial applications for mobile robots. Transportation, surveillance, inspection, cleaning or household robots are just some examples. However, autonomous mobile robots have not yet made much impact upon

industrial and domestic applications, mainly due to a lack of robust, reliable and flexible navigation and mechanism behavior for autonomous mobile robots operating in unmodified, semi-constructed environments. Installing markers such as beacons, visual patterns or instruction loops (guiding wires buried in the ground) is one solution to this problem, but it is expensive, inflexible and sometimes outright impossible. The alternative navigation in unmodified environments requires sophisticated sensor signal processing techniques which are still in their experimental evaluation phases. So, to let mobile robots work in areas which are inaccessible to humans, or to perform repetitive, difficult or dangerous tasks, is yet another strong motivation for developing intelligent, autonomous robots.” (p,2).

Wheeled mobile robots, being one of the most popular service mobile robot applications, has a unique advantage over the other kinds. First of all, with the great locomotion mechanism of the wheeled mobile robot, effective movement can be achieved with relatively simple mechanical structural design. Secondly, wheeled mobile robots have great performances when running on flat surfaces. They can accomplish the tasks with high efficiency and relatively low power consumption compared to the other types of mobile robots, i.e. legged mobile robots. Lastly, wheeled robots are more robust and easy to maintain. As a result, nearly all industrial applications of mobile robotics apply some form of wheeled locomotion (Bräunl, 2006). Figure 1.5 and figure 1.6 shows two images of a 3 wheeled and a 4 wheeled mobile robot.



Figure 1.6: three wheeled mobile robot



Figure 1.7: four wheeled mobile robot

In this research, the focus will be studying wheeled mobile robots rather than legged robots, due to their simplicity in mechanism, relatively low cost and less power consumption.

From the literature above, there is still high potential for the study of mobile robotics. One of the many directions of the study is to increase the maneuverability for mobile robots. Wheeled robots have limitations when they are running on rough terrain, on the other hand, when they are running in human environments (i.e. engineered, smooth surfaces, both indoors and outdoors), their running smoothness, robustness and maneuverability make them valuable to be studied. In addition, their comparatively low cost is another reason for their popularity. In summary, this research chooses to investigate and study wheeled mobile robots over legged mobile robots. A mobile robot base module with a special type of wheel mount will be developed to achieve better maneuverability. The robot base module should have a certain degree of flexibility and cost effectiveness for some indoor mobile robot applications that may have limited maneuverable space. The structure of the mobile robot and the wheel design are major investigation areas. A proposed mobile robot construction module could be developed to be able to quickly integrate with different wheels and add on sub-systems. The experiments made on the test model are positive. With further improvements and the add-on of more intelligent functionalities, the mobile robot should be useful for some of the indoor applications such as for service robots in healthcare, hospitality and warehouse management.

1.2 The research topic

The aim of this research is to develop a wheeled mobile robot base module for studying mobile robotics with different wheel configurations, and control methodologies. The structure of the base module will allow the components that are mounted on the mobile robot to be interchangeable, and the size of the robot base to be adjustable, which gives the robot base potential to be developed using different add on sub-systems to achieve different tasks.

Moreover, with the wheel structure design, the robot will have a certain degree of flexibility for some indoor mobile robot applications that may have limited maneuverable space. The objectives are:

- 1 Design a wheeled mobile robot base module. The base module should be adjustable in size and able to easily integrate with different add on sub-systems. The base module also needs to be reliable and robust.
- 2 Study the wheel structure of the mobile robot. Choosing a specific wheel design for this project which would suit the base well. The wheel design will gain the robot a certain degree of flexibility so that it would benefit some indoor mobile robot applications which may have limited maneuverable space.
- 3 Design a control system for this mobile robot. The control system needs to be reliable.

1.3 The scope of the research

The scope of this research is to develop a reliable, robust, and economic mobile robot base module. The base can be easily adjusted in size and integrated with different add on sub-systems. In addition, a wheel structural design which gains the mobile robot a high maneuverability will also be developed. The mobile robot should be able to benefit some indoor mobile robot applications that may have limited maneuverable space.

- ✧ Mobile robot design with modular design methodology.
- ✧ Design of a wheeled mobile robot mechanical system.
- ✧ Design of a mobile robot electric and electronic system.
- ✧ Mobile robot control system design and programming.
- ✧ Testing prototype building

1.4 The organization of the thesis:

The thesis contains eight chapters. Each chapter has a short introduction to give an overview of its content. Following is a summary of the chapters. Chapter 1 explains the topics of this research by stating its requirements, objectives and scope. Chapter 2 provides a background to the history behind mobile robots, the available approaches and techniques used in moving a mobile robot around an indoor environment, and the growing need for mobile robots in general. Chapter 3 introduces the history of omni-directional wheels, characteristics of different omni-directional wheels, and omni-wheel applications with different wheel combinations. Chapter 4 discusses the mechanical design of the mobile robot base module. It firstly introduces the concept of modular design, and then presents the mobile robot hardware selection. Lastly, the process of designing the mobile robot mechanical system is described. Chapter 5 explains the electric and electronic system design of the mobile robot. It discusses the selection of the electric and electronic components of the robot. Most importantly it describes the process of the electric and electronic system design. Chapter 6 presents the mobile robot's control system. It introduces the controller that is chosen for this project and the programming for the robot's control system. Chapter 7 demonstrates the testing prototype build for the mobile robot. Five tests were set for the mobile robot, so that its linear and rotational motions could be examined. The collection and analysis of the results are presented. Chapter 8 concludes with the research's future improvements and conclusions.