Mechatronic Design and Construction of an Intelligent Mobile Robot for Educational Purposes

A thesis presented in partial fulfilment of the requirements for the degree of

Master of Technology
in
Engineering and Automation

at Massey University, Palmerston North,
New Zealand

Julian George Phillips

2000

ABSTRACT

The main aim of this project was to produce a working intelligent mechatronically designed mobile robot, which could be used for educational purposes. A secondary aim was to make the robot as a test-bed to investigate new systems (sensors, control etc.) if possible.

The mechatronic design of the robot was split in to three sections: the chassis, the sensors and the control. The design and construction of the chassis unit was relatively simple and very few problems were encountered. The drive system chosen for the robot was a four-wheeled Mecanum drive. The major advantage of this system is that it allows multiple degrees of freedom while keeping the control and the number of drive motors to a minimum.

The design and construction of the sensors was the main research section. The sensor design evolved around the use of ultrasonic sensors. While a phased array type arrangement was tried with the intention of improving the angular accuracy of the sensors, the use of frequency modulation was used in the end and it proved to be excellent except that the problem of angular accuracy was still not solved.

The entire mechatronic system was completed except for the micro controller programming. It operated well when it was given the correct inputs and performed all of the functions it was designed for.

It is strongly recommended that further work be done on the use of a computer motherboard instead of the current micro controller as this would allow for easier programming, more complex programs and easy implementation of map building.

ACKNOWLEDGEMENTS

The research was carried out under supervision of Dr Peter Xu, Senior Lecturer, Institute of Technology and Engineering, Massey University.

The work in this thesis was made possible by the help of Ken Mercer and Collin Plaw who helped me with the design and construction of the circuits and also helped me learn how to use Orcad.

The wheel and chassis unit was also constructed with the help of Leith Baker who machined the rollers for the wheels and gave suggestions, which made the design easier to construct.

The technicians in the engineering workshop and particularly Don McLean were also very helpful in producing parts of the chassis unit.

The work presented in this thesis was partially supported by MURF (Massey University Research Funds).

CONTENTS

Figures and Tables

1 AIM, OBJECTIVES AND CONCEPTUAL IDEAS

1.1 Aim

The main aim of this project was to produce a working intelligent mechatronically designed mobile robot, which could be used for educational purposes. A secondary aim was to make the robot as a test-bed to investigate new systems (sensors, control etc.) if possible.

1.2 Objectives

The objectives of this project were as follows:

1) Create a working mobile robot.
2) Make the sensor system by means of which the robot can avoid objects in a cluttered room.
3) Give the robot some intelligence so that it can adequately avoid obstacles.
4) Make the robot in such a way that it can be built on in future projects.
5) Make the robot self-navigating (if there is time).
6) Carry out some new research on one or more aspects of the design.

The following sections are about the requirements for each part of the robot and the intended solutions.

1.3 Mechanical/drive system

1.3.1 Requirements

The requirements for the robots mechanical configuration were that the robot had to be able to manoeuvre in tight spaces. It had to be stable. It had to be able to operate by battery power and it had to be robust.

1.3.2 Mechanical complexity

The complexity of the drive configuration decides the mobility and agility of a mobile robot. It was not seen as a major problem because the physical aspects of a mobile robot are relatively easy to build (apart from the space requirements). Also the mechanical design and construction is straight forward although time consuming and as long as everything is built strong and light enough with consideration being taken for the circuitry, navigation etc. there should not be any major problems.

1.3.3 Proposed drive configuration

The proposed drive system uses a four-wheeled Mecanum drive. This was chosen because the Mecanum drive has multiple degrees of freedom, which give good mobility and agility. The Mecanum drive also uses very few motors, which keeps the complexity of the programming to a minimum. The Mecanum system is where the wheels have free rotating rollers around their circumference. These rollers are set at 45º to the normal direction of travel. The rollers are also made in such a way as there is at least one roller in contact with the ground at all times.

Figure 1.1 (page 3) shows the types of movements that can be achieved with a four-wheeled Mecanum drive system:

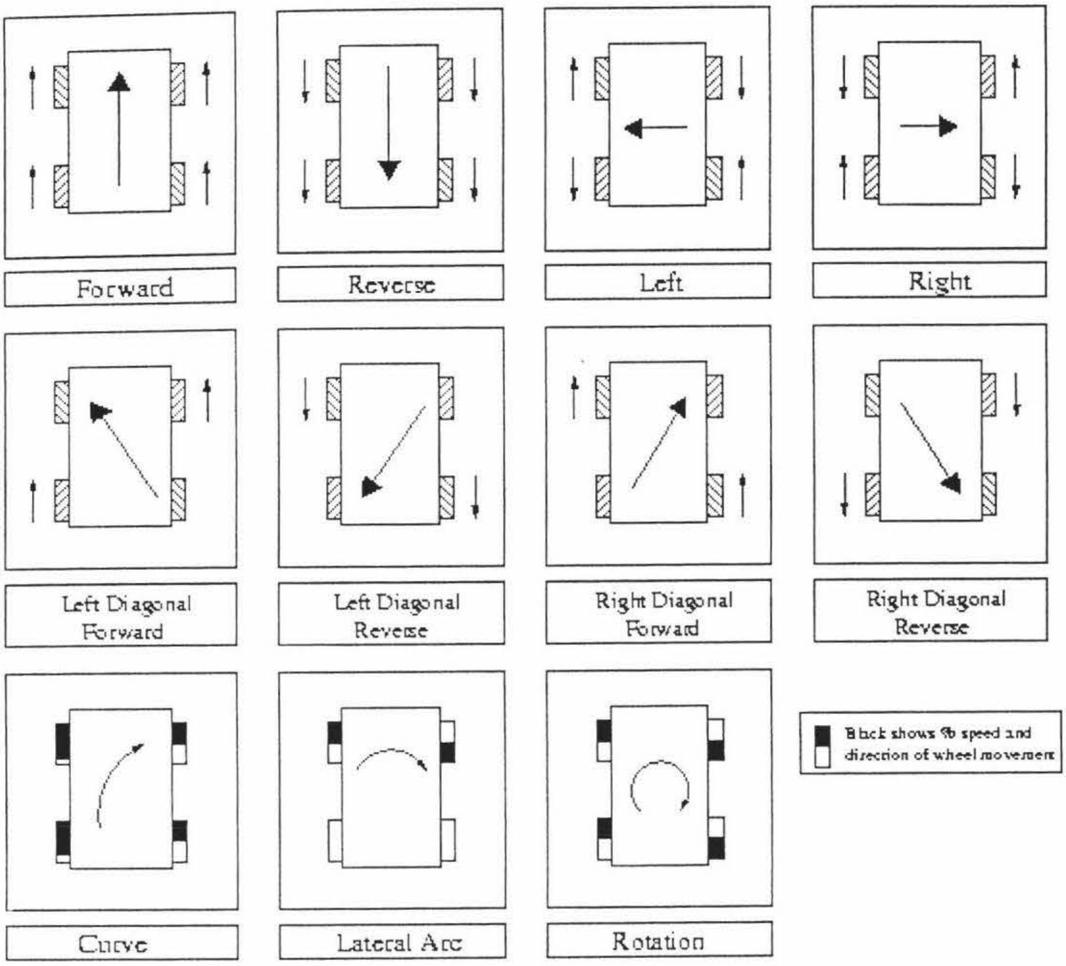

Figure 1.1 Some of the different drive directions possible with a Mecanum drive system. Adapted from [20].

A four wheeled Mecanum drive system requires one motor for each wheel but due to there being no steering of the wheels the only complexity is in the construction of the wheels themselves. It is however believed that the wheels can be constructed relatively easily using the facilities at Massey University. For rigidity and ease of construction it is recommended that the construction of the chassis and wheel units be made from aluminium. Aluminium also has the advantage of being lightweight. For the circuit box it is also recommended that aluminium be used for the same reasons but it will need the use of some insulation material. The rollers on the wheels will need to be made from plastic in order to increase the grip as they only have point contact with the ground.

It was proposed that the use of all of the drive directions shown in Figure 1.1 be implemented except for the curve and lateral arc as these required more difficult control of heading and motor speeds. The remaining drive directions are easy to implement, as they only require three states; forward, reverse and stopped. These can be achieved through the use of motor controller chips.

1.4 Control

1.4.1 Requirements

The control needs to enable the robot to make a choice about what direction to go in when an obstacle is encountered. It also needs to make sure the robot does not get stuck. This then necessitates a control strategy, which either avoids repetition, or avoids local minima.

1.4.2 Electronic Complexity

The complexity of the electronics is not considered to be a serious problem although it will have to be kept to a level, which will be able to be implemented on a small mobile robot and within the time constraints. This of course depends on the complexity of the sensors, the control and the navigation. If the robot creates its own maps or has to store maps the circuitry will of course be more complex because a large memory is required.

1.4.3 Difficulty of Programming

The programming can be made easier by splitting the required programming into navigation, sensor control, motor control and robot strategy. The programming could also be done on a higher level programming language but this would involve putting a computer on the robot, which may be a possibility if there is time or it could be the subject of a future project.

1.4.4 Proposed control strategy

Firstly it was proposed that a modular system be used for the electronics where extra or different control systems, memory etc. can be put in or swapped at a later date. Also the circuits should be properly designed and etched so as to produce optimal performance, cut down on space and reduce wiring/connection problems.

For the actual control system two micro-controllers should be used. One is for the motor and direction control and the other one is for the navigational control. These micro-controllers will have to work together but by making it a master/slave relationship there should not be any problems. It is also proposed that the two micro-controllers should be able to work separately so that the drive and/or navigation systems can be changed at a later date. Also this should help in the testing stage as it makes each part simpler.

The programming of the motor control should be simple as the instructions given to the motors are simple and there are only a few outputs and inputs. The programming of the navigation system will likely be a lot more difficult as it requires the timing and comparing of several inputs. This is likely to be the most difficult part of the project and initially it is intended to keep it as simple as possible.

1.5 Sensors

1.5.1 Requirements

The main requirement of the sensors is that they can detect obstacles at a range sufficient enough to avoid obstacles. Secondary requirements are that the sensors should be accurate and be able to detect the majority of common obstacles. If map creation is used then the sensors also need to be accurate in both distance and angle.

1.5.2 Complexity

The complexity of the individual sensors is not seen as a significant problem as most sensors come as a package. The operation of the sensors is however more important due to the limited computing power available. The use of the sensors is however considered to be a significant and vital part of the project.

1.5.3 Proposed sensor system

The sensor system proposed was to use ultrasonic sensors for detecting the range and angle of obstacles. The sensors would be placed in an arrangement similar to radar where there is one detector on either end of a rotating beam. This beam is horizontal and is rotated at the centre. The transmitter is also fixed at the centre. The system is intended to work in the following way:

1) The transmitter sends out an ultrasonic pulse at intervals. These intervals are sufficiently far apart to allow the previous pulse to return and be recorded before the next one is sent out.
2) The receivers both pick up the returning signal (if there is an object present).
3) The two signals from the sensors are then added together.

4) The resulting signal is then given to a peak detector and when the object is equally distant from both sensors the peak will be at its highest magnitude. This means that the angle can be measured from the angle the beam is at when the peak is at its maximum.

5) The return delay of the signals is also recorded when the maximum peak is reached. This gives the distance measurement of the object.

There was no intention to use any alternative types of sensor because the aim was to try and get the ultrasonic sensing good enough to avoid all obstacles before the robot gets close enough to hit them.

1.6 Navigation

1.6.1 Requirements

The robot is required to navigate in a room/corridor type environment without bumping into obstacles. A secondary requirement may also be to avoid other moving objects in the environment. It is also considered that the room or corridor may be cluttered and there may be many narrow objects such as chair legs.

1.6.2 Complexity

The navigational complexity must be such that the necessary computations can be made by the robot while allowing the robot to move at a reasonable speed. The number of sensors required for the navigation also needs to be kept to a small number to reduce the amount of information processing. The navigation must also be able to handle the majority of situations the robot is faced with and therefore a reasonable complexity will be required to achieve this.

1.6.3 Range

The range of the sensors needs to be sufficient to allow the robot to avoid obstacles in the environment. This means that the robot must have enough space to stop in before it hits the obstacle. A secondary requirement is a sufficient range for the robot to be able to see which path is best.

1.6.4 Accuracy

The navigation also needs to be relatively accurate so that the robot is able to see the majority of obstacles and doesn't see fake obstacles (phantom obstacles which are caused by reflections etc.). Also if map building is to be used then the navigation needs to be accurate enough to build a meaningful map of the environment.

1.6.5 Proposed navigation technique

The proposed navigation technique was to use local mapping where the robot creates its own maps from sensor scans. The map would consist of an array of cells. The cells will each contain a probability that an obstacle exists within the area of the cell. The reason for this was to hopefully overcome one of the major problems with ultrasonic sensing which is that of reflections causing fake obstacles. The reasoning behind this is that as the robot moves the fake obstacles will only be in a particular position at a particular angle. This means that the cells where a fake obstacle is detected will not register that an obstacle is there because the majority of the sensor sweeps will register no obstacle producing a low probability of an obstacle existing in the cell.

As the robot moves the map will also move with it. This means that the robot will always be able to choose the best path through the obstacles around it by consulting the map.