This section covers the problems encountered while working on the hardware side of the project, and provides an insight into the techniques employed to overcome these difficulties as well as the reasons behind them.

## Robot design

The design of the robot had gone through several phases of alterations, in response to the physical limitations posed in the experiments. Figure 1 and Figure 2 show the final design, the description of which will be covered in the following subsections.

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| C:\Users\zy13643\Desktop\RS\illustrations\DSC_0964.jpg  14 cm  18.5 cm  Figure 1 Top view of the robot | C:\Users\zy13643\Desktop\RS\illustrations\DSC_0965.jpg  4.1 cm  14 cm  Figure 2 Side view of the robot |

### Caster wheel

A caster wheel was added for the purpose of keeping balance. The original version was bidirectional, i.e. it could only move forwards and backwards. The problem with this approach was that the caster wheel gets caught on the surface of the arena while turning. The workaround for this problem was to build an omnidirectional wheel so that it can move freely in all directions, which was proved to have rooted out the problem in test runs.

### Motors

A total of 3 motors were used, 2 of which are attached with wheels for movement. A problem encountered while moving near a wall was that one of the tyres would rub against the wall, and the robot would turn towards the wall as a result. The solution to this problem was to mount a wheel shell on each side to prevent the wheels from making direct contact with obstacles.

When the robot navigates around the arena, it relies on the use of the ultrasonic sensor to perceive its surroundings. To enable the robot to perform such task, one can either command it to turn its body and take measurements as appropriate, or place the sensor on a motor to allow it to do a 360° scan while staying put. The former has a disadvantage of accumulating turning error; therefore, the latter was adopted to keep the turning error at minimum. The sensor is located slightly off the centre of the robot (see Figure 1), so that the readings are approximately the distances between the centre of the robot and the walls.

### The Brick

The brick is placed upside down to keep the robot as high above the ground as possible, which would reduce the likelihood of being interfered by the bumps.

### Other

The wire keeps coming in the way of the sensor whilst it is turning was another problem that had to be dealt with, and the solution was to build a structure using beams to hold the wire down.

## **Motion functions**

A set of motion functions were created to enable the robot to roam around, each of which will be explained in detail in this section.

### Move

In order to enable the robot to move back and forth, a move function was created. This function makes both wheels turn in the same direction at a given speed for a given number of degrees. However, since the readings from the ultrasonic sensor are in centimetres, it would be more sensible to command the robot to travel a specified distance measured in the same unit. To do this, the relationship between the degrees at which the wheels turn and the desired travel distance has to be established. Since the distance travelled by each wheel per rotation is equivalent to the circumference of the wheel, the circumference equation was used to form part of Equation 1, where *D* denotes the desired travel distance.

Equation 1 Correlation between the degrees to turn and the travel distance

However, since the values used to calculate the distance were rounded off, the result is only an estimate; hence, calibration was done with regard to the conditions of the arena by trial and error. To prevent the robot from dashing into the walls, the ultrasonic sensor is used to actively detect the distance to the wall in front while moving, and a threshold distance was set at which the robot ceases going any further.

### Turn

As well as moving forwards and backwards in a straight line, the capability of turning is also essential for the robot to traverse through the arena. In general, a mobile robot can perform three types of turns.

The first method is to make the robot turn on the spot by turning the wheels in reverse directions for the same number of degrees, the centre of rotation is at the centre of the distance between the wheels as illustrated in Figure 3. However, since the wheels are not aligned with the centre of the robot, when the robot performs such a turn, the centre of the robot will orbit around the centre of rotation, as shown in Figure 4 and Figure 5.

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|  | Figure 3 Turn on the spot | Figure 4 Before rotation | Figure 5 After rotation |

Ideally, the centre of the robot should not be shifted. Thus, Equation 2 is used to work out the offset that the robot should move before and after turning, where *D* represents the distance between the wheels, and *rad* is the desired degrees to turn in radians.

Equation 2 Turn on the spot offset

The second method is to turn one wheel in either direction while keeping the other wheel still, the resulting position is shown in Figure 6. An obvious disadvantage of this type of turn is that the centre of rotation is at one of the wheels depending on in which direction the robot takes the turn, the circle drawn is subsequently two times bigger than that of turning on the spot; taking the size of the robot and the physical attributes of the arena into consideration, this approach is likely to cause collisions with the walls, and it was therefore not implemented.

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| --- | --- |
| Figure 6 180° turn with one wheel being still | Figure 7 Manoeuvre around a corner |

The last turning tactic is manoeuvre, by which means that each wheel of the robot rotates for a different number of degrees, with the wheel on the opposite side of the turning direction moving further. This type of turn plays a major role in a situation that resembles Figure 7, where performing a turn on the spot is not only insufficient to bypass the walls, but may also result in a crash. The robot does a local scan to check the distances to its surrounding walls in 8 directions, and each direction is split into a number of readings on the basis of the number of scans. For instance, in the case of 18 scans, the north direction consists of readings 1, 2 and 18 (i.e. front readings, assuming that the robot is facing north with respect to the orientation of the arena). These readings determine whether if a direction is blocked, based on which the direction of manoeuvre is decided. For example, if the mean of the front readings is below a threshold value, and each reading is below another threshold value, then the front is asserted to be unnavigable.

### Correct angle

It was noted that the motor is not guaranteed to turn a specified number of degrees each time, which implies that there is a turning noise. To improve the precision, the actual degrees turned is subtracted from the expected degrees after each turn, the robot then takes another turn for the number of degrees equal to the offset.



Figure Offset after turning

### Ultra scan

This function allows the robot to perform a 360° scan of the distances to its surrounding walls on the spot. The function had gone through several changes, in pursuit of efficiency. Originally, the idea was to rotate the sensor 360° in one direction and pause to take a measurement at every 45°. Although the accuracy is retained using this strategy, it is extremely time-consuming. To boost the efficiency, the strategy was switched to taking measurements while rotating, and the sensor rotates 360° clockwise and anticlockwise in turn to prevent the wire from getting tangled.

## Sensor calibration

It was noted that the ultrasonic sensor has its limits, in terms of its effective measure distance and the angles at which the measurements are accurate. Others have pointed out that the effective working angle for ultrasonic sensors is approximately 30° (Generation Robots, n.d.), as seen from Figure 9.

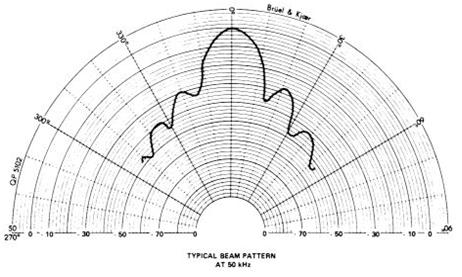


Figure Typical shape for an ultrasonic beam (Generation Robots, n.d.)

To have an idea of how the accuracy of the sensor varies as the angle and distance change, the sensor was positioned at different angles and distances to a wall inside the arena, and measurements were taken. As a result, the following Gaussian distribution was generated.



Figure 10 Gaussian distribution of the sensor readings from different angles and at different distances

Conclusion

The progress was slow at the beginning of the assignment, as there was no clear division of labour. If a second chance was given to reattempt at this project, agile development would be used.

## References

1. Generation Robots. (n.d.). *Ultrasound sensor ? high quality ultrasound sensors available now.* Available: http://www.generationrobots.com/en/content/65-ultrasonic-sonar-sensors-for-robots. Last accessed 19th Mar 2014.