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Enhancement of the masterclass robot

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Individual Design Assignment

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Summary

The masterclass robot is an educational robotplatform for showing students of secondary education the possibilities of robotics. At this moment the robot has proximity sensors and sensors for line following. To make it more challenging for the students it would be nice if the possibilities of the robot where enhanced in such a way that a group of robots can communicate together and know the location of each robot with respect to the others. This report describes the research to the possible enhancements of the robot. The conclusion is that there are good and easy to use modules for RF communication. For the position detection there are possibilities to use infrared, but there are no easy to use modules available.

Samenvatting

De masterclass robot is een robot die gebruikt wordt om leerlingen van het voortgezet onderwijs te laten zien hoe leuk robots zijn, en wat je er allemaal mee kunt doen. Om het voor de leerlingen nog uitdagender te maken zou het handig zijn als de robot uitbreidingen krijgt zoals positiedetectie, en de mogelijkheid tot communicatie tussen meerdere robots. Dit verslag behandelt het onderzoek naar de uitbreidingen van de robot met positiedetectie, en radiocommunicatie. De conclusie is dat er goede modules zijn voor radio communicatie, en dat het ook mogelijk is om positie detectie te doen met behulp van infrarood licht.

list of abbreviations

AGC Automatic gain control

IR Infrared

IrDA Infrared data association, protocol for infrared communication

LDR Light dependent resistor

RF Radio frequency

RSSI Received signal strength indication

US Ultrasound

Contents

1 Introduction

1.1 Context

According to the 'shorter oxford english dictionary' a robot is *'a machine which carries out a variety of tasks automatically or with a minimum of external impulse'*. Robots are used in very different areas. For example robots are often used in industries, for welding cars, but robots are also used for applications such as vacuum cleaning a house. The masterclass robot is a small robot which is designed and used to show the possibilities of robotics to students of secondary education. The students can write their own program for the robot to let the robot move, follow a hand of somebody, or to battle with each other in a robosumo game, in which it is the goal to push another robot out of a circular playing field.

1.2 Assignment

The masterclass robot is a robot which is used to show the possibilities of robotics to students of secondary education, and to let them write their own software for the robot. The goal of this project is to enhance the robot with RF communication and sensors. The RF communication can be used to let robots communicate with each other and with a host system. A sensor system (possibly optical) is necessary for the robots to find their locations with respect to each other.

1.3 Report survey

The report start in chapter 2 with an analysis of the problem. What should be done, and what are the possibilities. After that some of the measurements that are carried out are described in chapter 3. The fourth chapter describes the final design. Chapter 5 describes the conclusions and recommendation. The report ends with some appendixes.

2 Analysis

2.1 Introduction

Adding sensors for position detection or communication to the masterclass robot can make the robot more challenging for the students who work with it. It would for example be nice if the robots could talk to each other, in order to cooperatively complete a certain task. But for many tasks, such as for example move a box which is to heavy to be replaced by 1 robot[4], the robots also need information about their position. So adding sensors for position detection is also an enhancement for the robot to give it more functionality. section 2.3 describes different methods for position detection, and which way is chosen to measure the position. Section 2.4 describes the communication method between the different robots.

2.2 Requirements

2.2.1 Introduction

Because the masterclass robot is an already existing robot, there are some requirements for the enhancements. The robot is relatively small, and has already a PCB of 5 by 5 centimeter. The enhancements should not exceed that size, so the maximum size for the PCB is 5 by 5 centimeter. Because the masterclass robot is battery powered, the power consumption of the enhancements should be taken into account. The robot has already a power regulator onboard which can produce a stable 5V. This supply can deliver a maximum of 500 mA, so the robot should not exceed that. In order to prevent exceeding the 500 mA, the enhancements should consume no more than 200 mA.

2.2.2 Position measurement

The goal is to let the robot know it's position with respect to the other robots. To do this the angle and distance to the other robots should be known. The angle should be measured with an accuracy of at least +/- 22.5 degree. The distance between two robots should be measured with an accuracy of at least +/- 10 cm, but preferably better. The position detection should work for distances up to 1 meter.

2.2.3 Communication

To let the robots communicate together, a communication module is needed. Two robots with a communication module should have the possibility to communicate in a range of at least 5 meter. The speed of communication should be at least 38400 bits per second.

2.3 Position measurement

To let the robot know what its position is, position detection is necessary. There are a lot of different techniques for finding the location of the robot, and when the choice for a technique is made, it is still possible to buy a module, or to design an own module.

2.3.1 Measurement techniques

For position detection a lot of different techniques are possible. A list with some of the possible position detection techniques can be found in appendix A. Some of these methods could be useful for measuring the distance in this situation, where others seems not very handy to use. The methods that look useful are marked with an 'x' in appendix A. These methods are described here.

Infrared

To measure distance, and angle between the robots(and thus the position with respect to the other robots) by infrared light, one possibility is to measure the intensity of the received light when a light pulse is emitted from another robot. The signal strength is dependent on the distance and the angle of receiver and transmitter. With a couple of measurements it is possible to measure both the angle and the distance. This method is used by EPFL [3] for the moorebot, one of their robots. Also at the control engineering group infrared is already used to measure distance, for example at the humke robot [1].

Ultrasound

Ultrasound can be used to measure the distance between two objects. This is for example used in the humke robot [2] for the game capture the flag. If a pulse is emitted by the sender, the sound travels with approximately 340 m/s. This means that if you can measure the time the sound travels between the emitting robot and the receiving robot, the distance between them can be calculated. To measure this time the clock on the robots need to be synchronized, because else it is not known how long the sound is on its way to the other robot. This synchronizing could give some troubles, but should be possible. A way to synchronize the 2 robots could be to send a pulse by the first robot, and let the second robot wait 1 ms before it sends the pulse back, in that time the robot has time to find out when the pulse exactly started, so when to start an reply. The first robot can now calculate the time the pulse has traveled to and from the second robot.

Linear CCD

Linear CCDs could be used to measure the angle between two robots. These CCDs have a row of light sensors. With a lens it is possible to direct the light from a different angle to a different location on the CCD. So the angle can be measured. For the distance the intensity should be used. One of the problems is that it is difficult to find lenses for these CCD sensors.

Ultrasound and infrared

A combination of ultrasound, and infrared light could be used for position detection. The ultrasound part could measure the distance, while the infrared part could measure the angle. It is also possible to let the infrared light give an pulse at the very same moment the ultrasound pulse is released. At this way it is possible to synchronize the robots at once. The speed of light is approximately 300000 km/s, so the time the light is on its way to the receiver is negligible at the distances of about 1 meter.

Ultrasound and CCD

A combination of ultrasound and a linear CCD is also possible. The CCD can be used to measure the angle, and the ultrasound for the distance.

The measurement methods compared

To get a closer look of these methods the most important aspects of them are put in table 2.1. In this table the different methods for position detection are compared. Because anything should fit onto an PCB that is square with sides of 5 centimeter and the costs should not be too high the systems using two different techniques *'US and CCD'* and *'US and IR'* are abandoned. The possibility of using a CCD module has the problem that it is difficult to find lenses and the CCD chips are usually larger than the IR or US transducers. IR has the problem that measuring the signal strength can be sometimes less accurate because of environmental light, like the sun, or electric lights. But the pro is that there are a lot of IR receivers with internal demodulator. This decreases the area needed on the PCB, and the number of external components needed. US has the problem that the received sound needs to be demodulated, in order to get the signal strength, and the time of flight. Another problem is that the ultrasound transducers usually are larger than the infrared transducers. So the decision is made to further investigate the possibility to measure the position by using infrared light.

	precision distance	precision angle	small components	costs	modules available	hard to get parts	few components necessary	low processor power needed	disturbance insensitivity	range of sensors	fast detection possible
IR	0	0	0	0	+	0	-	0	0	0	0
US[a]	+	-	0	0	-	0	-	0	0	0	0
CCD	0	+	-	-	0	-	+	-	-	0	0
US and CCD	+	+	-	-	-	-	-	-	+	0	0
US and IR	+	0	-	-	-	0	-	0	+	0	0

[a] ultrasound

Table 2.1: The different position detection methods compared

2.3.2 Available infrared modules

There are some modules available for robots to find a location using infrared light. These modules are shown and there possibilities are described in the next pages.

The lynxmotion proximity detector(fig 2.1, uses 2 LEDs, and 1 sensor. The LEDs emits a signal modulated at 38 kHz, and the receiver can see the reflection if an object is close, or none reflection if the object is not close. This module can only detect if the object is in 1 of three quadrants, as can be seen in figure 2.2. So the module can not see the difference between another robot very close and a wall, therefore this module will not be used.

Figure 2.1: The lynxmotion proximity detector

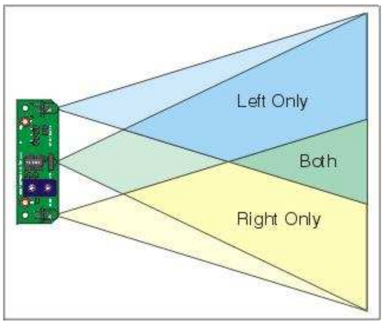


Figure 2.2: The three quadrants the lynxmotion proximity detector can see

The robomaker Control freak (fig 2.3) is a little more advanced. This module has the possibility to let robots communicate with each other using the infrared, this module also has the possibility to measure the amount of environmental light, so it could move let the robot drive to the brightest light source. But this module uses just like the lynxmotion module reflection of the infrared signal for measuring the distance between modules, meaning that a different reflector (black paper vs white paper)could also make differ the measured distance. Another problem is that this module has only 180° visibility, so it can not answer to a robot directly behind it. Therefore this module will also not be used.

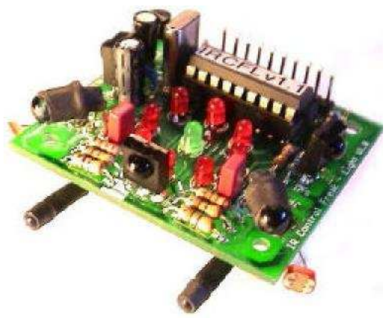


Figure 2.3: The robotmaker control freak

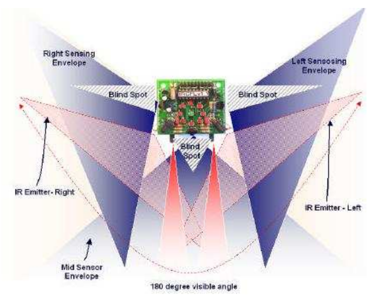


Figure 2.4: The areas the control freak can detect.

Another IR module is the pololu IR beacon (fig 2.5. This module has the possibility to look for 360° around for other robots, but it can only find out in what direction the other robot is, not the exact distance. Also the direction is not very accurate. There are only 4 directions it can detect, in front, left, behind, and right. This module has the advantage that it sees the other module, not the reflection of it. This makes it possible to distinguish a robot and a wall, which is necessary. Two modules can communicate together .While 1 module is receiving, the other is sending. If the receiving module sees something, it knows that there is another module at that side sending. As can be seen in figure 2.6 the left module is sending IR light into all directions, and the right module receives IR light at only 1 sensor, that way it knows in what direction the other module is.

Figure 2.5: The pololu infrared beacon

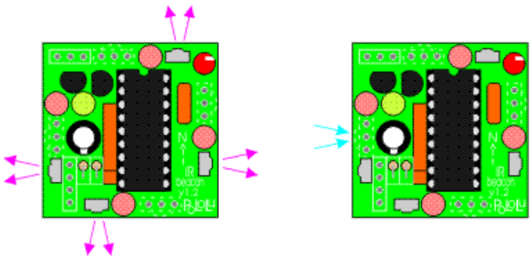


Figure 2.6: Two pololu IR beacons can detect if they are in the area of each other

The problem is that none of these modules have the possibility to measure both angle and distance accurately for 360°. Another problem of some of these modules is that they can not detect the difference between a robot, and a solid object such as a wall. So these modules are not a real good option to choose and another way to measure the position has to be found.

2.3.3 How to measure distance and angle

Because the available modules did not fulfill the requirements, an own module for position detection should be designed. There are already some other people who have built their own infrared position detection modules. For example EPFL[1] has a couple of robots which can communicate together, and find their relative position by using infrared light[3].

What needs to be measured is the angle of the two robots, and their distance. In figure 2.7 these angles are θ, and ϕ. The distance is d. For measuring these data, the signal strength can be used. The signal strength depends on the angle of the LED, the angle of the receiver, and the distance.

Measuring the distance

The signal strength depends on the distance with an $\frac{1}{d^2}$ relation. This is because when the light source has a certain angle, and the distance to the other object doubles, the area over which the

[1] Ecole Polytechnique Fédérale de Lausanne

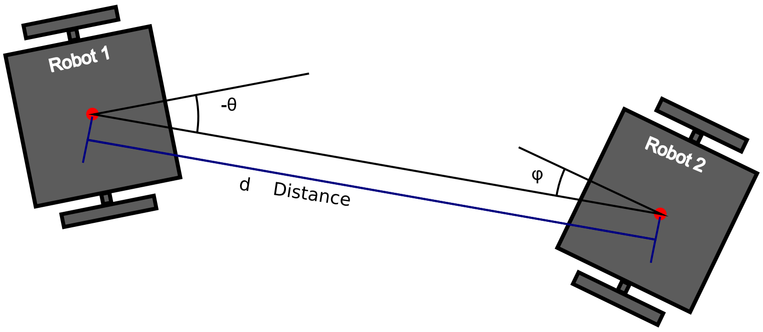


Figure 2.7: The angles, and distance between the two robots

light is spread increases quadratical. This can be seen in figure 2.8, here the sphere is the source, and the plane above has a certain area, the lower plane has a distance doubled, but the is area squared. Because the area the light is spread about increases quadratic, the signal strength on a certain location decreases by $\frac{1}{d^2}$. The problem is that the signal strength is not only depending

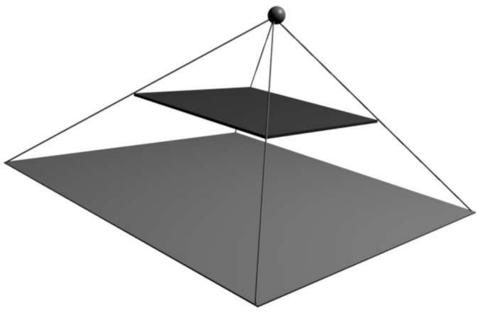


Figure 2.8: As the distance doubles, the area goes up quadratic

on the distance, but also on the angle of the different LEDs. Right in front of a LED the signal strength is very strong, where at an angle the signal strength is lower. In order to measure the distance, it is necessary to know the angle.

Measuring the angle of the transmitter

For the angle measurement the fact that the intensity of a LED changes as the angle changes is used. All LEDs have an intensity that is strongly related to the angle. In figure 2.9 the radiant intensity versus the angle is shown, and it is possible to see that as the angle from the center increases, the radiant intensity decreases. For the rest of the explanation of the idea for the angle measurement a LED is used for which the radiant intensity vs the angle looks like a sine, as shown in figure 2.10. If now a second LED is added with a different angle, the situation of figure 2.11 in created. If now the receiving robot is at a distance great enough to think these 2 LEDs are at approximately the same location, there is a ratio between the signal strength of LED 1, and LED2 which depends only on the angle of the transmitters, and not on the angle of the receiver or the distance. This is because the intensity is caused by the angle of the receiver, the angle of the transmitter and the distance.

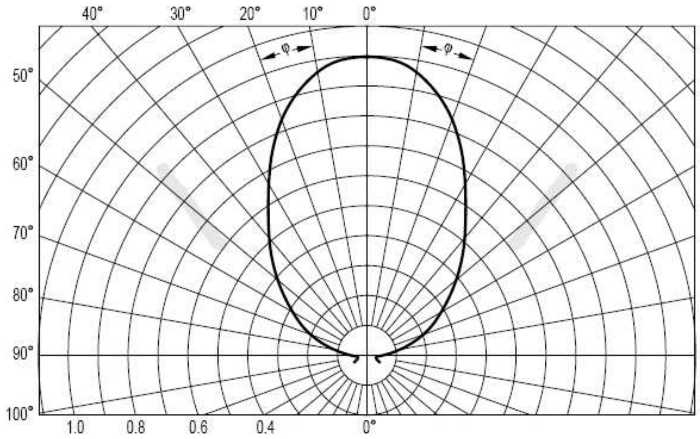


Figure 2.9: angle vs radiant intensity

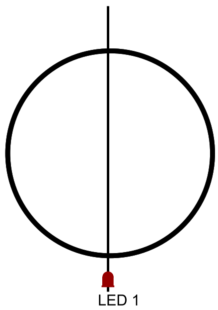


Figure 2.10: The intensity of a LED versus the angle

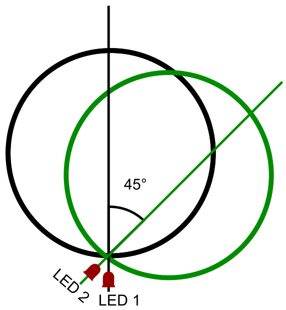


Figure 2.11: The intensity of a LED versus the angle for two LEDs

If the received intensity I is expressed as function of the distance d between receiver and transmitter, the emitted signal strength E, the damping of the receiver $R_{receiver}$ and the damping of the transmitter R_{LED} the formula 2.1 appears.

$$I = E * \frac{1}{d^2} * R_{led} * R_{receiver} \tag{2.1}$$

If now there are 2 LEDs a ratio can be calculated as in formula 2.2

$$ratio = \frac{I_{LED1}}{I_{LED2}} = \frac{E_{LED1} * \frac{1}{d^2} * R_{LED1} * R_{receiver}}{E_{LED2} * \frac{1}{d^2} * R_{LED2} * R_{receiver}} \tag{2.2}$$

If now LED1 and LED2 are supposed to be at the same location, with only a 45° difference in angle, as in figure 2.11. The distance, and damping from the receiver are equal. If now also the emitted signal strength is set constant, the ratio can be calculated using formula 2.3

$$ratio = \frac{R_{LED1}}{R_{LED2}} \tag{2.3}$$

Because the damping of the LEDs is changes by the angle the ratio can say something about the angle. If the ratio is plotted versus the angle of the transmitting LEDs with the receiver(in figure 2.7 when robot 1 emits, and robot 2 receives the angle ϕ) the graph from figure2.12 appears. Is can be seen in the graph that when the robot has an angle of 22.5 degree, both LED1, and LED2 have the same damping caused by the LED angle, and the ratio is 1. It is also visible from the graph that there is a clear relation between the angle and the ratio. So this can be used to distinguish the angle of the transmitter.

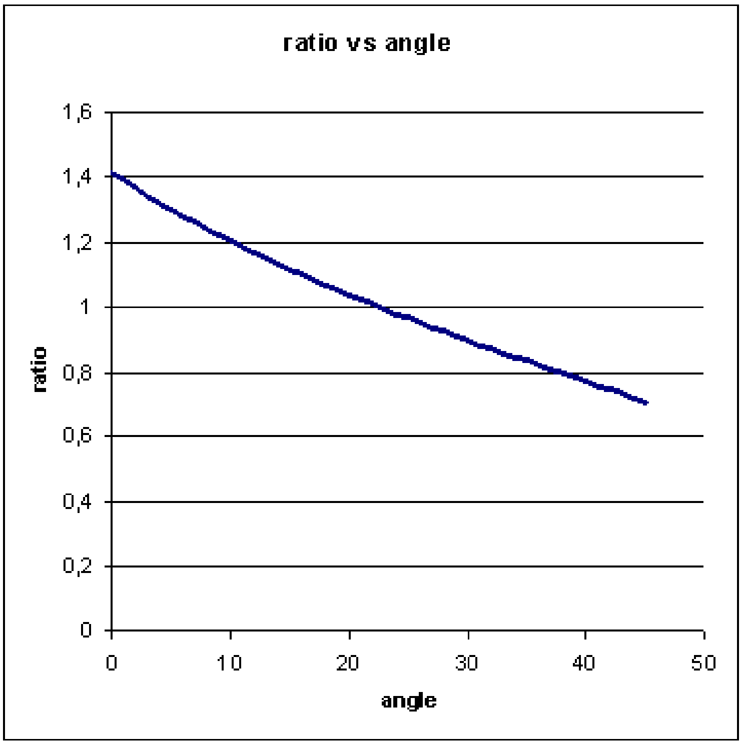


Figure 2.12: the ratio versus the angle

The angle of the receiver

The receiver has also a damping which depends on the angle. To find the angle of the receiver the same method as used for finding the angle of the transmitter can be used, because both robots have the transmitters and receivers, and so the task of the robots can be changed. So it is possible to first determine the angle of robot1, and then the angle of robot2. When the angle of the robot is known, it is also clear what the angle of the receiver is, because the receivers are fixed on the robot.

2.3.4 Measuring the intensity

Modulating the light

Because the environmental light has a great influence on the amount of light that is received by the receiver, a modulated signal is used. The modulation of the signal makes it possible to filter the light from the sun, and electric lights in the area.

Measure the signal strength

For the calculation of the distance and angle it is necessary to know what the emitted and received intensity is. There are a few options to measure how much the intensity is influenced by the path it has to go (distance and angles).

- Emit light with a constance intensity, and measure the received signal strength.
- Change the intensity of the transmitted light, and check if the light is still visible.

Demodulating of the received light could be complex if an own receiver should be designed. But there are receivers available that demodulate the signal, and give a digital output (signal or no signal). These receivers make it possible to avoid building a demodulation circuit and that is why these receivers are used.
Unfortunately these receivers don't have an RSSI[2] output, they can only be used to check if the transmitting LED is visible. So the second possibility for measuring intensity is used. This method changes the intensity of the transmitted light and check if it can be received with the receiver or not.

2.3.5 IR receivers

There are a lot of infrared receivers with an internal demodulator. Four of them are actually tested for the speed of measurement, and accuracy. These IR receivers are in figure 2.13. The receivers are designed for different speeds, and protocols. The receivers will be described in the next paragraphs.

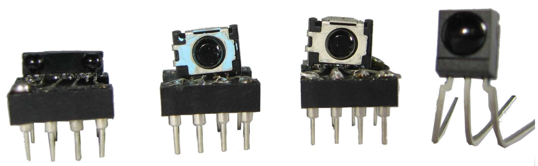


Figure 2.13: The IR receivers, from left to right TFDU4300, TSOP 5700, TSOP 36236, TSOP 4836

Remote control

The tested modules with TSOP in their name are meant for remote control purposes, such as controlling a TV or radio. They can receive a signal that is modulated along an carrier wave. If there is an signal with an carrier wave of the right frequency, the receiver will make the output 0V, if there is none signal with that carrier wave, the output is 5V. The different receivers could

[2] RSSI = Received signal strength indication

require different carrier waves. The TSOP4836 needs an carrier wave of 36 kHz, where the TSOP 5700 requires an 445 kHz carrier wave. The receivers that were tested all had an automatic gain controller (AGC). The AGC is used for immunity against ambient light. The AGC can change the amplification, so the signal strength caused by the ambient light will not be able to trigger the receiver to give an output. The problem is that if the LEDs emit pulses too fast, the receiver also sees these signals as ambient light. Therefore it is an problem to send pulses close after each other with rising signal strength, because the AGC will adapt. This causes the receiver to see a very faint signal, the AGC thinks it is environmental noise, and makes the threshold for a signal a little higher. If now another pulse with a little more intensity is sent, again it does not reach the threshold value, and again it is seen as noise, and again the threshold goes a little higher. Therefore there should be a long pause between two pulses, because else the AGC will adapt, and give no consistent data. In the most extreme case the receiver has adapted the AGC so far that pulses that definitely should be seen by the receiver are not any more.

IrDA

The IrDA protocol is used for low power devices that need to communicate with each other. For example mobile phones, and computers. This protocol uses no carrier wave, but send a pulse that is 3/16 of the time on for a logical 1, and always off for a logical 0. If for example the baud rate of 115200 bps is used, 1 bit takes $8,6\mu s$, so a logical 1 is $3/16 * 8,6\mu s \approx 1.6\mu s$ on, and $7,1\mu s$ off. As can be seen in figure 2.14.

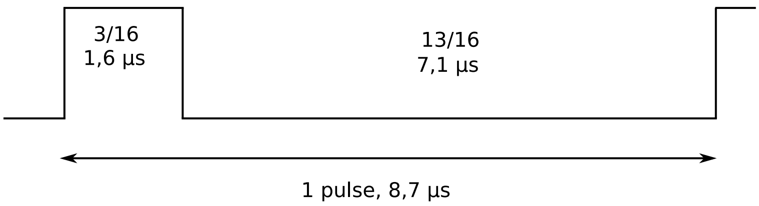


Figure 2.14: The pulse for IrDA communication, with timing

TSOP 36236

This receiver is made for remote controlling purposes. It has an carrier wave of 36 kHz. This IR receiver need to have some time between the pulses, because of the AGC described in section2.3.5.

TSOP 4836

This receiver is almost equal to the TSOP 36236 receiver, with the only difference that this is an through hole model, where the TSOP 36236 is a SMD device.

TSOP5700

This receiver uses an 445 kHz carrier wave, and can therefore measure much faster than the TSOP receivers with an carrier wave of 36 kHz.

TFDU 4300

This receiver is an IrDA receiver, it can operate at an baud rate of 115200 baud. Therefore it should also have the possibility to receiver 115200 pulses per second. But also this module has an AGC which makes it impossible to measure accurately and fast.

2.4 Communication

To let the robots communicate together there a few different techniques that can be used.

- Use RF communication.
- Use the infrared receivers and transmitters.

The infrared receivers and transmitters that are used for the position detection have a range of approximately 0 to 100 cm, where the communication should take place over a larger range. So the choice is made for RF communication. There are a lot of modules for RF communication. Some of them are in appendix C.
Because the xBee module has a RSSI output, is small and not very expensive this module has been chosen. The xBee module is a module that uses the IEEE 802.15.4 standard for sending messages. This is a standard which is meant for the lowest layers of communication for low power wireless networks.

3 Measurements

A lot of measurements are done for this project. This chapter describes the different measurements and their results shortly. Paragraph 3.1 describes different algorithms for finding out the intensity of the received infrared light. Paragraph 3.2 describes the method used for finding out if a infrared pulse is visible. The measurements for distance and angle are treated in paragraph 3.3. Paragraph 3.4 describes the influence of the environmental light on the position detection.

3.1 Measurement algorithms

For measuring the signal strength there are different methods. Some of these methods and their differences will be described in this section. For the measurement in this section a TSOP IR receiver is used. The transmitting LED is connected to the microcontroller according to the schematic in figure 3.1. With this setup, the current through the LED, and thus the intensity emitted can be changed. This is done by changing the value of the digital potentiometer. Changing the value of the digital potentiometer leads to a change in voltage at the + of the opamp(U1). This creates a change in the voltage over the resistor R2, which implies that the current through the LED also changes. This experiment was used to find out how to measure

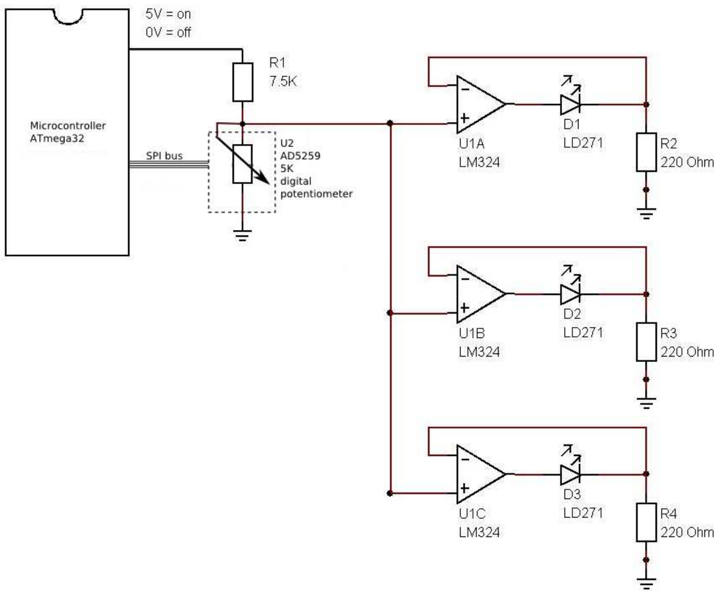


Figure 3.1: The schematic of the circuit used for this measurement

the signal strength. Because it is more to find the method than to find the exact signal strength, the values from the digital potentiometer were not converted into intensities.

3.1.1 Simple signal strength measurement

This algorithm sends 256 pulses, starting with an pulse with maximum strength, going down to the minimum signal strength. The value of the potentiometer at which the last receivable pulse was emitted is used as the signal strength. This method is simple to implement, but very time consuming to measure. Because there are 256 pulses to be send to check the complete region the potentiometer can cover. Because every pulse takes 3.7 ms, 256 pulses take approximate 945 ms. If there are more measurements needed to get an accurate result this can cause problems. This is because than robots can drive a large distance during a measurement. So the measurement will always be wrong if the robots are driving fast. In figure 3.2 there is an oscilloscope view of this way of measuring. It can be seen that the emitted pulses(above) become weaker, and that the received signal (below) stops before the emitted signal is completely off.

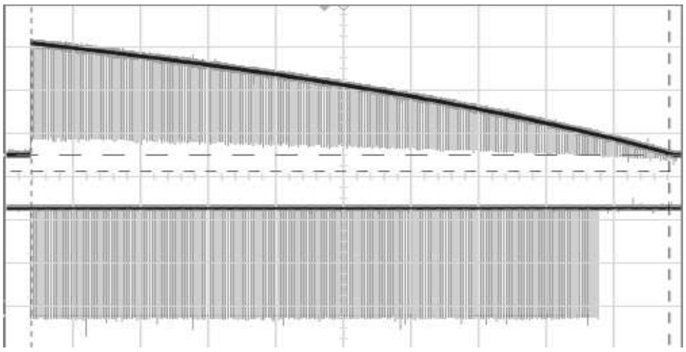


Figure 3.2: The signal that is emitted(above), and received(under) with the measurement algorithm simple

3.1.2 Successive approximation

This method sends a pulse of half the strength of the maximum. If it is received, then the signal strength is lowered, else increased. In this way it is only necessary to send 8 pulses to get the signal strength. This makes the signal strength detection a lot faster than the method in the previous section, and brings the time for a measurement back to 30 milliseconds. An image of this measurement is shown in figure 3.3.

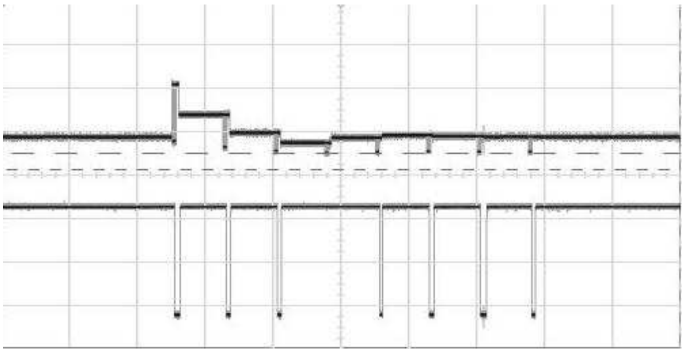


Figure 3.3: The signalstrength emitted (above) and received (under) with the successive approximation algorithm

3.1.3 Successive approximation, recheck

This algorithm works at the same way as the algorithm described in section3.1.2, except that it sends three pulses of the same strength, and checks if all three of the pulses are received or not. If the three responses are not the same, a retry follows, and again the responses are compared. This method makes the signal strength more reliable. But the problem is that the measurement also becomes slower. One measurement takes now at least 87 milliseconds, this can be longer if there are signals that are not correctly received the first time. A measurement with this method is shown in figure 3.4. In this figure it is possible to see that the fourth signal level that is send was the first time not correctly received (1 received, 2 not) and had an retry.

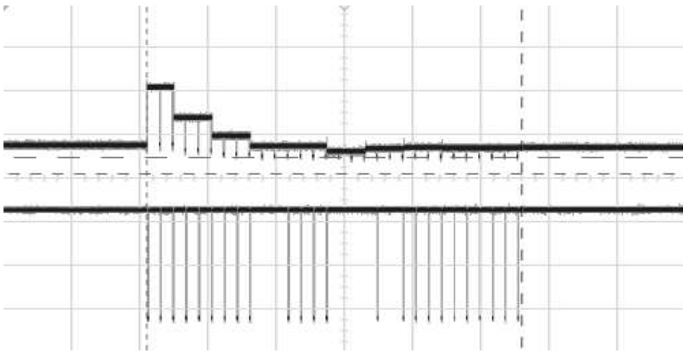


Figure 3.4: The signalstrength emitted (above) and received (under) with the successive approximation recheck algorithm

3.1.4 Summary

The most important aspects with respect to the timing and reliability of the different algorithms are put in table 3.1.

algorithm	**pulses needed**	**time needed**	**standard deviation**
simple	256	819 ms	2.5
successive approx	8	29 ms	9.5
successive approx recheck	24 or more	88+ ms	2.0

Table 3.1: The different algorithms, and their timing

3.1.5 Conclusion

Based on the data in this table it is clear that the 'successive approximation' method is definitely the fastest, but has a large standard deviation[1]. The standard deviation of the method 'successive approximation recheck' is the smallest, and this method also does not take very much time. So this method is now the used method.

[1]the standard deviation is calculated by the stdev function in excel, and is based on 50 measurements

3.2 Visibility of a signal

3.2.1 Introduction

In section 3.1 the conclusion was that the successive approximation recheck method was the best for determining the signal strength. But when the choice was made to use an IrDA receiver instead of an TSOP receiver, the measurement results became less stable. This was because the old check for finding out if a LED is visible was by checking if from the 3 pulses send 3 were received. If three pulses on a row where received, the LED was marked as visible. The problem is that the IrDA receiver often misses the second pulse, and so always has to retry. This is probably caused by the AGC and is described in the next paragraph.

3.2.2 AGC problems when using the IrDA receiver

The problem with the automatic gain control(AGC) of the IrDA receiver was that it adapted to the weak signals. If the first pulse received by the AGC was just enough to be visible, also the AGC would adapt a little bit to it, which lead to the situation where the second pulse could not be received. Because this happens a lot of times when the signal strength is close to detectable intensity, but also sometimes when it was not really close it gave very inconsistent results. To test this, 500 measurements for the signal strength are carried out. The result is the value of the potentiometer at which the LED was visible. A higher value for the potentiometer means a higher intensity was needed for the LED to be visible. The result is plotted in figure 3.5. This figure shows that a lot of measurements have the correct value, but there are also a lot of measurements that need a intensity to be visible that is much higher than the most. These results are also plotted in figure 3.6. Here the horizontal axis is the potentiometer value, and the vertical axis is the number of occurrences. It can be seen that there is clearly a peak around the value 24, which means that the potentiometer was set to 24 in order to be just visible, but there are also a lot of measurements that needed a higher intensity to be visible.

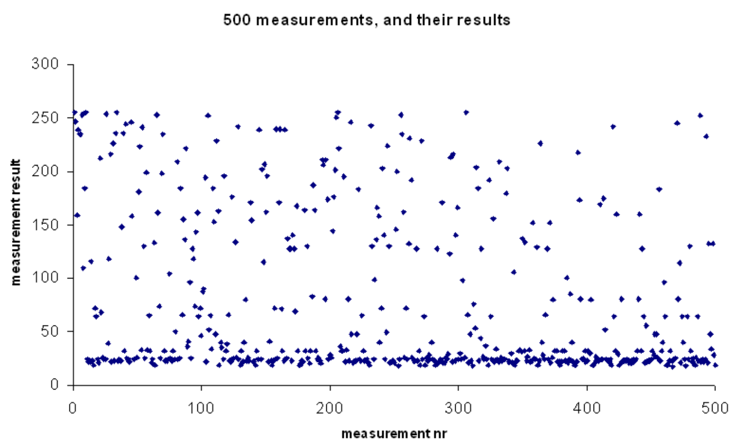


Figure 3.5: Inconsistent results in 500 measurements.

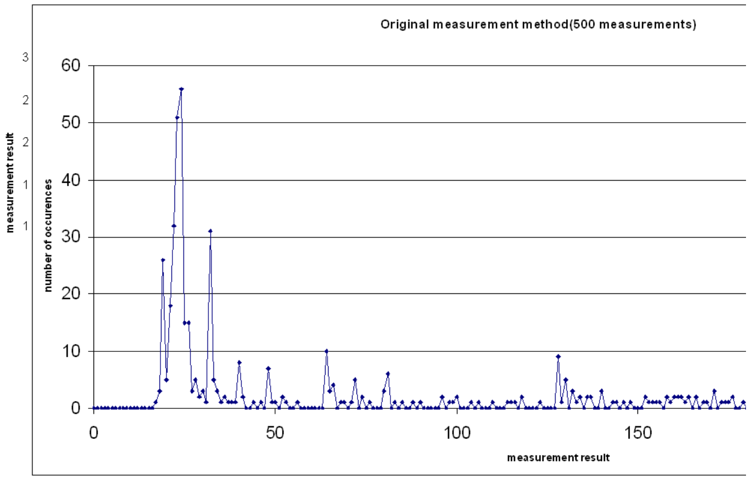


Figure 3.6: The measurement result vs the number of occurrences.

3.2.3 The new method described

Because these measurements are not good enough to find out what intensity is needed to be just visible, another method for finding out if a pulse is visible is carried out. For this new method of checking visibility, a P pulses are sent. If more than N pulses are received, the LED is considered as visible. To find out what values to use for N and P an experiment is carried out.

Maximum time for a measurement

Because a measurement of position can not take to much time, a maximum time for a complete position detection between two robots is set to 100 ms. In order to find the distance, and angle between the two robots, at first every robot needs to find out which LEDs are pointing to the other robot (because each robot has 8 LEDs, this makes 8 visibility checks per robot). Then each robot has to find the distance between the two robots. In the worst case scenario, both robots need from three LEDs to know the intensity needed to be seen by the other robot. Because of this, there are at maximum 64(2*8+6*8) visibility checks in each position detection. So each visibility check can take 1.56 ms as maximum.
In order not to exceed this time limit, the time between two measurements was changed if another number of pulses P was send. In figure 3.7 it is shown that when 2 pulses are emitted, the time between the pulses will be shorter, in order to let the total time be the same. This experiment is carried out with 1 to 20 pulses for a measurement (P). The minimum number of received pulses to get a visible(N) indication is changed between 1 and 3. For each combination from the number of pulses emitted, and the minimum number of received pulses, 500 distance measurements are carried out. In figure 3.8 the relation between the number of pulses send, and the average signal strength is shown. It can be seen that when only 1 LED that is seen gives the lowest intensity needed to be visible. This is a good property for a measurement, because then the current through the LED can be lower, and that saves battery energy.

But the average signal strength is not the most important property. More important is the stability of the signal. In order to measure that, the standard deviation for the measurements is taken using the excel function stdev(). The result for the standard deviation is shown in figure 3.9. In this figure the standard deviation is divided by the average value of the measured signal.

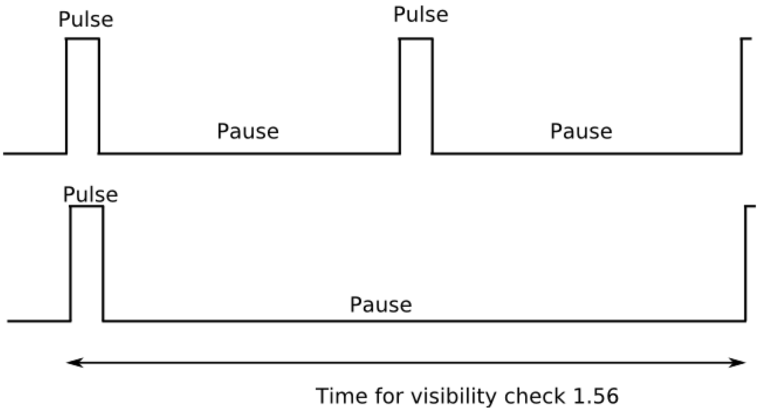


Figure 3.7: The time for a pulse when 1 pulse is used, and when 2 pulses are used for a visibility check.

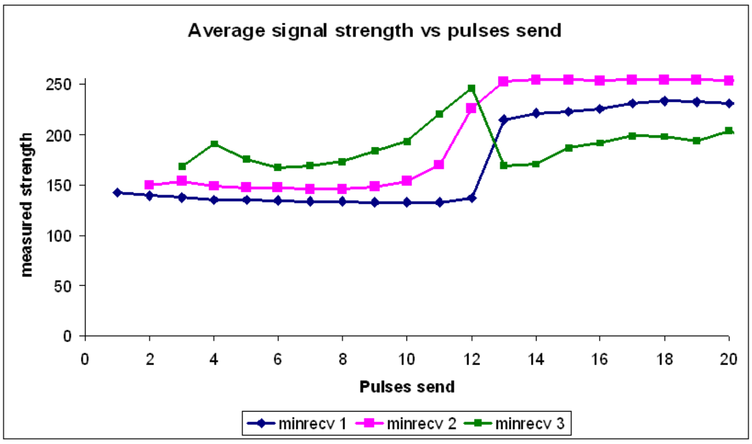


Figure 3.8: The new method to check if a signal is visible for a different number of pulses.

This is done because when the robots are 1 meter away, an error of 10 cm in the measurement is less worse than when the robots are 10 centimeters away from each other.

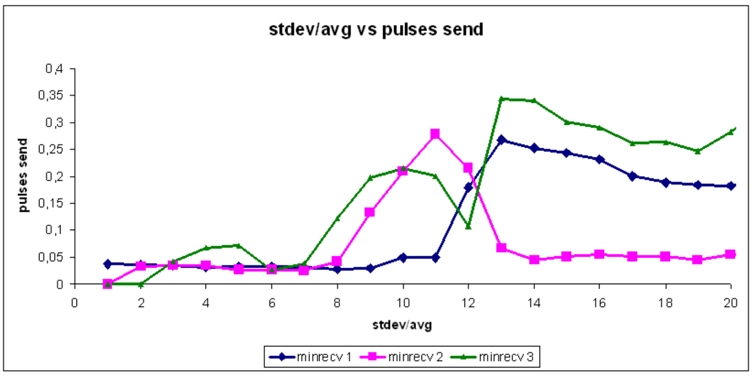


Figure 3.9: $\frac{standarddeviation}{averagevalue}$ for different number of pulses send.

3.2.4 Result

In figure 3.8 it can be seen that the average potentiometer value is the lowest when only 1 pulse needs to be received. Because in the standard deviation plot, figure 3.9 the difference between the minimum received pulses is very low, the choice is made to use the minimum number of received pulses to be 1.
The number of pulses to be send is set to 8, because for the average value it does not matter as long as the value is below 12, and for the standard deviation it should be lower than 11. The choice of 8 is made, because it is some distance from the very steep ramp in the figure of the standard deviation. And also because 8 bits fit exactly in 1 byte, and visible /not visible can be saved in a bit. This is not used at this moment, but maybe in the future there will be some application where it is useful to store this information, and than it is nice to have exactly 1 byte per visibility check.

3.3 Distance and angle

3.3.1 Introduction

In order to relate the measured values of the digital potentiometer to a distance and angle, some calibrations are needed. This section describes measurements that are carried out in order to find the relation between the angle, the distance, and the measured values.

3.3.2 Measurement setup

For this measurement, there is one module which sends an infrared pulse, and the other module tells the first if it has seen something, or not. The schematic for the receiver and transmitter are shown in figure 3.10. For determining if a pulse is received, the way in the conclusion of paragraph 3.2.4 is used. This means a signal is considered visible if at least 1 out of 8 pulses is received.

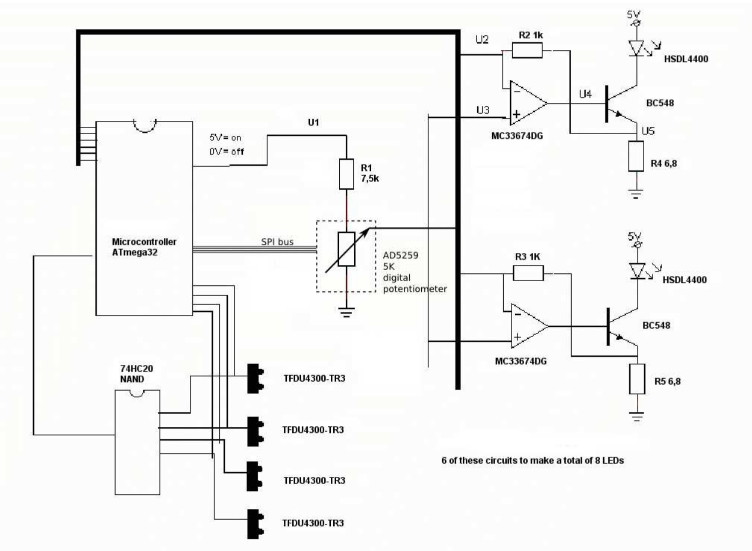


Figure 3.10: The schematic used for the distance, and angle measurements

3.3.3 Processing the measurement results

The measured signal is the value of the potentiometer where the signal is just visible. This value does not say that much about the distance. For that reason the measured value of the potentiometer is translated to the signal strength of the transmitter. To do this, first the current through the LED is calculated as a function of the value in the digital potentiometer.

$$I_{led} = \frac{P_{val}}{867}$$

In this formula P_{val} means the digital value sent to the potentiometer. This formula is calculated as follows. First voltage U3 is calculated.

$$U_3 = 5\frac{\frac{5000}{255}P_{val}}{7500+5000} = \frac{P_{val}}{127,5}$$

Because when the LED is enabled, the microcontroller is used as input, and the opamp also has a high input impedance, there will be almost no current through resistor R2, and so $U_2 \approx U_5$. Because the opamp tries to make U_3 and U_2 equal, the formula for U_5 is the same as the formula for U_3. The current through R4 is almost completely caused by the LED, so the current through the LED is:

$$I_{led} = \frac{U_5}{6.8} = \frac{P_{val}}{867}$$

Now the current through the LED is known, but the transmitted intensity of the signal is not yet known. To transfer the current to a intensity, the formula :
$Intensity = -2,667 * 10^{-08} * I_{led}{}^3 + 8,000 * 10^{-06} * I_{led}{}^2 + 9,467 * 10^{-03} * I_{led} + 2,931 * 10^{-13}$ is used. This formula is found by reading some values from the current intensity graph of the LED's datasheet. These values are placed in excel, and then excel has created a formula to fit the graph. The picture from the datasheet is shown in figure 3.11

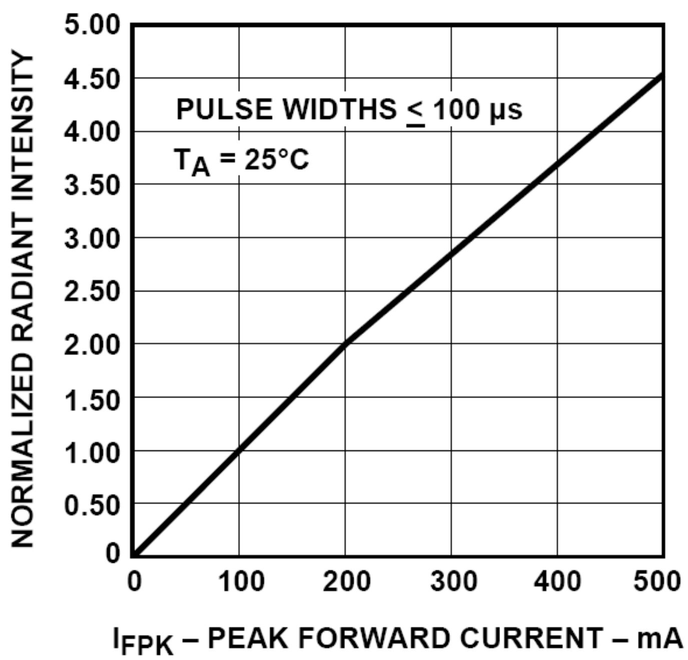


Figure 3.11: The relative intensity related to the current of a HSDL 4400 LED

3.3.4 The measurement, and it's results

For this measurement, the transmitting LED's are rotated, and the distance is changed. Measurements are carried out at a distance of 10, 20, 50, 75, and 100 cm. The angles are changed in steps of 5∘. In figure 3.14 the graphs of three different LED's are shown. It can be seen that when the angles become larger, the difference between the LED's becomes more clear. Because for the angle measurement, the ratio between two different LED's is needed, the ratio's are plotted in figure 3.15. It can be seen that the differences between the curves make it difficult to translate a ratio to an exact angle, but there is a relation between the angle and the ratio. The not exactly overlapping of the ratio lines is probably caused by the LED's that are not exactly equal, and can probably be compensated by calibrating each LED. In figure 3.12 the ratio is plotted with respect to the angle for different distances. It can be seen that the distance also influences the ratio, but there is a relation between the ratio and the angle. In figure 3.13 It can be seen that when using a single LED, it is clearly visible that the intensity depends on the distance.

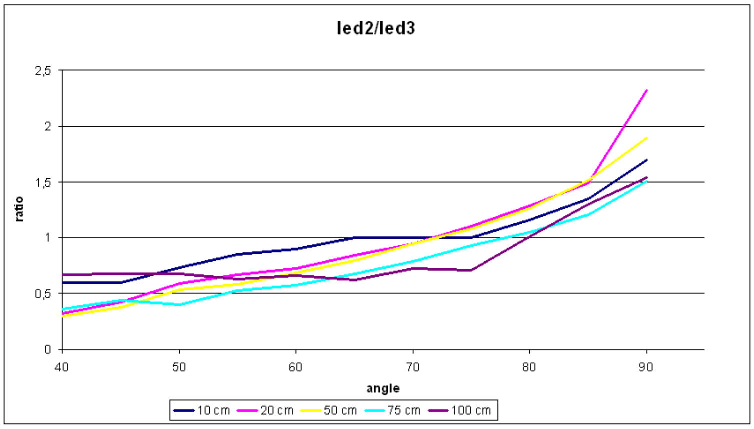


Figure 3.12: The angles versus the ratio(intensity led2/intensity led3) for different distances

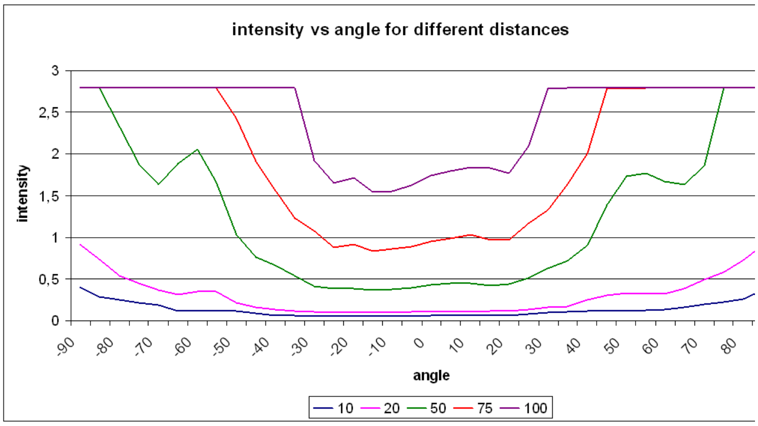


Figure 3.13: The intensity versus the angle for different distances

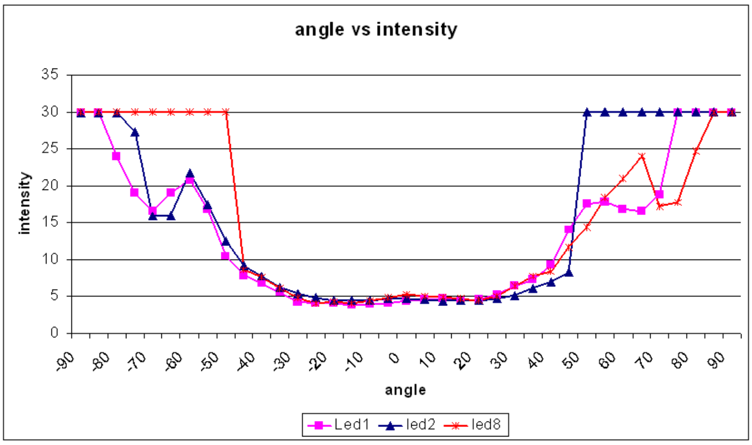


Figure 3.14: The angles versus the intensity for 3 different LED's

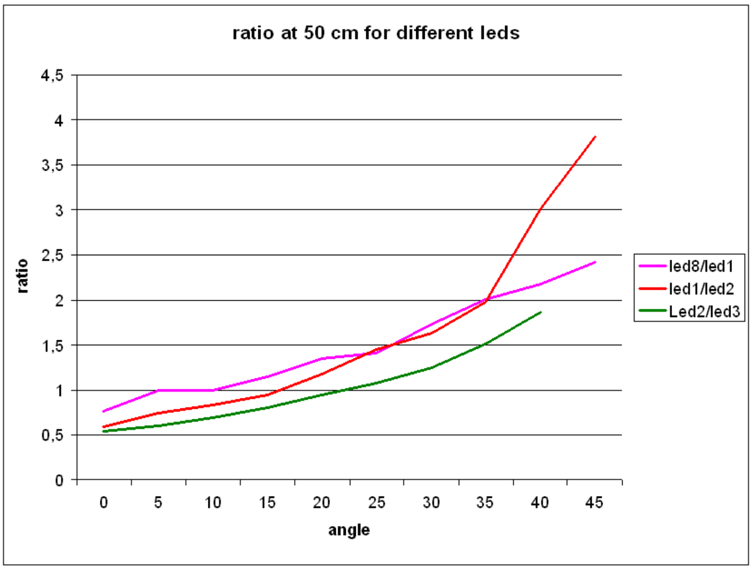


Figure 3.15: The angles versus the ratio for the different LED's

3.4 Environmental influence

3.4.1 Introduction

For the position measurement the IR-LED's emit infrared light which is received by the receivers. Unfortunatelly for the position measurement, the IR-LED's are not the only source of infrared light. Other sources for infrared light are for example the sun, and light bulbs. Because these sources can not be controlled by the position measurement module, there has to be taken account of the influence of these sources. This chapter describes a test that is carried out in order to find out if placing a cap on top of the receiver helps against these environmental influences.

3.4.2 Measurement setup

The measurement method used for this test is the successive approximation recheck method, described in paragraph 3.1.3. The used receiver is a TSOP 36236, and the transmitter is a LD271. In this experiment the environmental influence is tested by switching the fluoriscent light at the roof on and off. This test was mainly used to test if placing a cap on top of the receiver is a good way to prevent environmental influence. The receiver with and without cap can be seen in figure 3.16. For this experiment, the same schemetic as shown in figure 3.1 is used.

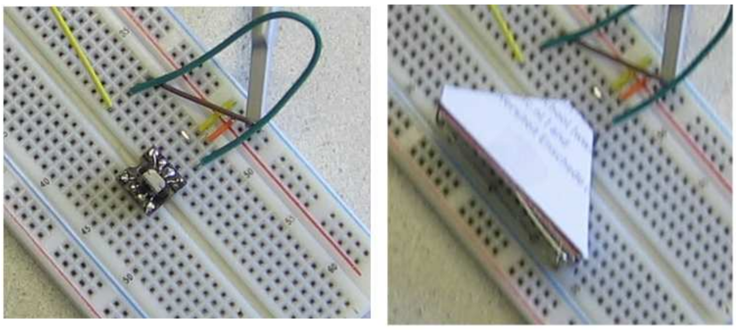


Figure 3.16: In the left part, the receiver without the cap placed. In the right image, a picture of the receiver with the cap.

3.4.3 Measurements

To test if the cap has a large influence, there are measurements done. The result in figure 3.17 shows the average value of the potentiometer when the signal was just visible. A higher value for the potentiometer means that less current through the LED is sent in order to be visible. It can be seen in the figure that putting the cap on top of the receiver does not make a huge difference. The switching of the TL light has a larger effect on the signal strength needed for the LED to be visible to the receiver than the cap. The TL light is not the only source effecting the signal strength. Figure 3.18 shows the effect of the sunscreen in the room where the experiment was done. For this experiment a different receiver is used. This time it was the TSOP5700. But it can be seen that the sun has a large influence at the measurement result. This is probably caused by the AGC, which will lower the gain when there is more light in the environment.

3.4.4 Conclusion

The conclusion of this experiment is that the sun, and fluorescent light have a influence at the measurement. In order to get a more accurate position, it will be advisable to find out if placing

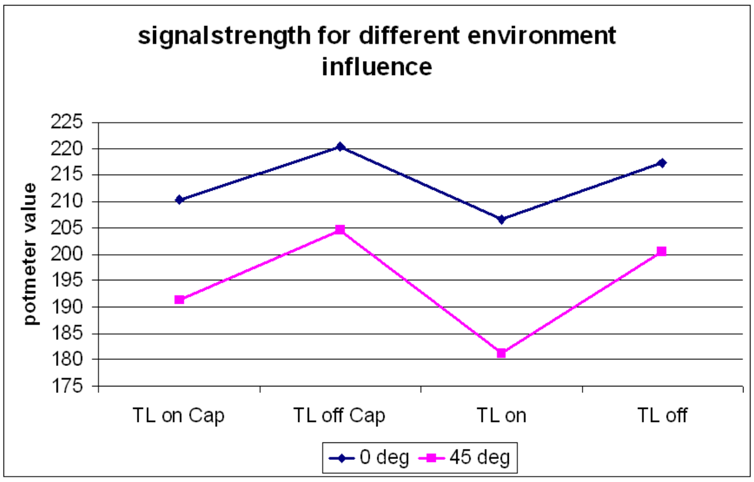


Figure 3.17: The effect of the cap on the environmental influence.

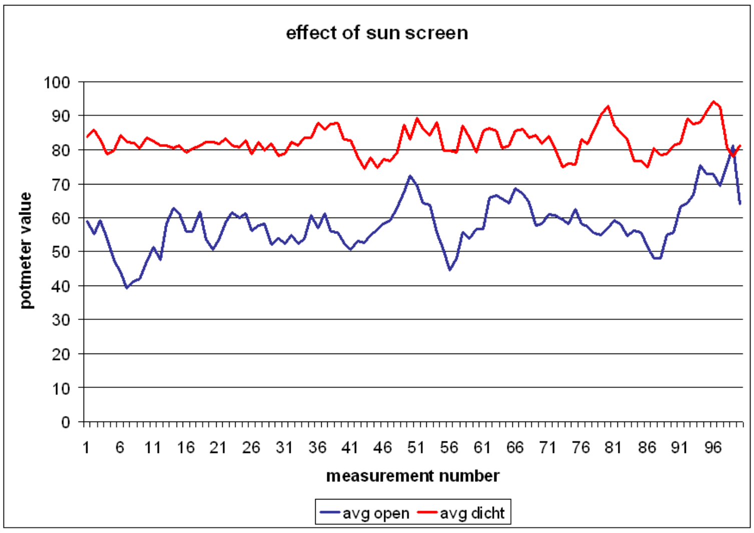


Figure 3.18: The effect of the sun screen down and up when measuring.

a LDR, or other light measure component to measure the environmental light intensity can be used to compensate for this effects. Without this, the measurement can be influenced a lot.

4 Final design

The measurements have lead to a final design, which is described in this chapter.

4.1 The electric schematic

The final design of the electric schematic is in figure 4.1. In the next few paragraphs some design choices will be explained.

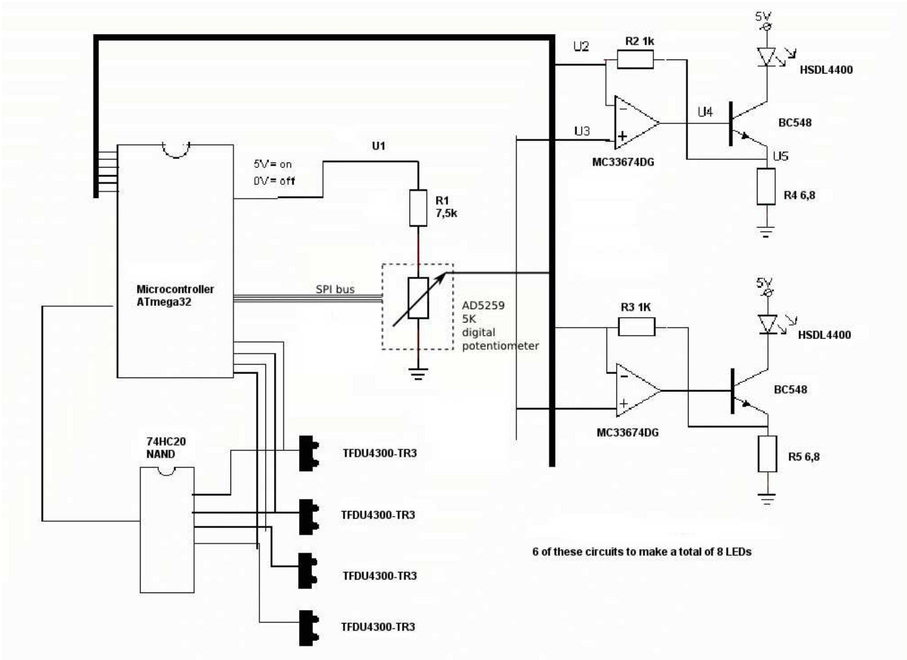


Figure 4.1: The electric schematic of the final design

4.1.1 The microcontroller

For the microcontroller a ATmega32 is chosen, because this microcontroller has a lot of memory compared to the other ATmega microcontrollers, and also enough I/O for this project. The idea for the pin usage is shown in table 4.1.

4.1.2 The receiver

The receivers are connected directly to the microcontroller, and also through a NAND port. This is done, because the receivers are only active when the light that a let emits is visible. This is a very short time ($1,6\mu s$). To make sure the microcontroller receives this, without continue scanning of the ports an interrupt is used. Because the ATmega32 has only 3 external interrupt inputs, there are not enough external interrupts for 4 receivers. Therefore the receivers are brought together using a NAND port. So only 1 interrupt is needed on the microcontroller. If an interrupt is received by the microcontroller, the microcontroller can check the port to find out which of the receivers is receiving something. This way the microcontroller has not to poll all the inputs continuously, and does not miss any pulses. It is possible to bring the receivers together through the NAND port because the receivers give a high voltage (5V) when they receive nothing and a low voltage (0V) when they receive data. The used receiver is an IrDA receiver, namely the TFDU 4300. This receiver is chosen because an IrDA receiver was necessary to have a high enough speed, and this one was available at Farnell.

4.1.3 The emitter

The emitter can send a pulse with different signal strength. If a LED should be on, U1 should be high. If no LED should be on, U1 should be low. The digital potentiometer can be used to change the current through the LED, and thus the intensity. Every LED can independently of the other leds be switched on or off. This can be done by the microcontroller. For the LED on top of figure 4.1 this can be done by changing U3. If U3 is high the opamp will make sure nu current flows through the LED. If U3 is switched to input state on the microcontroller, with the pull-up resistor off, the current through the LED becomes proportional to the value of the potentiometer. The relation between the current through the LED, and the potentiometer is:
$Iled = \frac{x}{867}$
In this formula x is the digital value of the potentiometer (0..255).

4.1.4 The LED and receiver setup

For the LED and receiver setup the choice is to use 8 LEDs with an angle of 45 degree between every two LEDs. The receivers are placed with an angle of 90 degree between them. This is shown in figure 4.2.

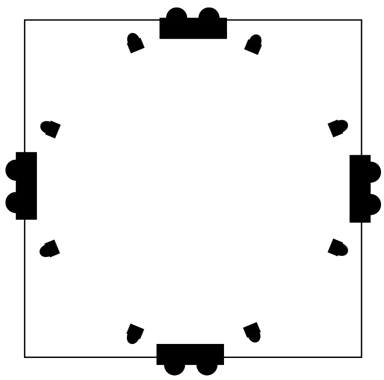


Figure 4.2: The setup of the leds and the receiver.

Pin	function	used for
PA0		Led1On
PA1		Led2On
PA2		Led3On
PA3		Led4On
PA4		
PA5		
PA6		
PA7	AD converter	Maybe in future a photodiode to measure environmental light.
PB0		Digital potentiometer SDA
PB1		Digital potentiometer SCL
PB2		
PB3	OC0	Pulse
PB4		
PB5	mosi	SPI
PB6	miso	SPI
PB7	sck	SPI
PC0	scl	I2C for communicating with the rest of the robot
PC1	sda	I2C
PC2		
PC3		
PC4		IR receiver 1
PC5		IR receiver 2
PC6		IR receiver 3
PC7		IR receiver 4
PD0	RX	XBEE
PD1	TX	XBEE
PD2	INT0	External interrupt for IR receivers
PD3		
PD4		Led5On
PD5		Led6On
PD6		Led7On
PD7		Led8On

Table 4.1: The pins of the microcontroller, and their function

5 Conclusions and recommendations

5.1 Conclusions

The goal of the project was to enhance the masterclass robot with position detection and communication possibilities. This paragraph describes the conclusions of the research.

Chapter 4 describes the final design. In this design, position detection is done by changing the intensity of the emitter, and finding out if the signal is receivable. This design has some similarities with the humke [1], but there are also many differences. This design has more resolution for the emitted intensity, and a 360 degree visibility.

- It is possible to measure the signal strength by changing the source and measure if the sent signal is received, but the automatic gain control of the receiver modules makes it difficult.
- The receiver that is the best suitable for this situation is a receiver which is made for the IrDA protocol, because they are much faster that the sensor used in remote controls.
- The IrDA receivers that I found are all equipped with an AGC(automatic gain control), which is usefull for communication, but creates problems when using the receiver for intensity measurements. The effect of the AGC can be reduced by a pause between the pulses.
- Based on the experiments the best measurement method is to send a maximum of 8 pulses, and if at least 1 of them is received, the signal strength is interpreted as visible. Using successive approximation for finding the signal strength is the fastest method of the tested measurement methods.
- For communication the xBee module is recommended.

5.2 Recommendations

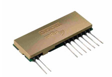
- It is recommended to search a method for easily calibrating all the LEDs and receivers, because during the measurements I found out that when a measurement is carried out by two different leds, the results can be different, using other receivers also leads to different signals. Therefore every LED and receiver has to be calibrated separately.
- I did not find time to fully implement the position detection. The angle for the receiver is not yet calculated or used in the code. It is highly recommended to implement it.
- The RF transceiver has a possibility to measure the RSSI. This can be used to measure the distance between two robots when they are out of visual range for the position detection. This can also be useful.
- The measurement accuracy can probably be improved by compensating for the environmental light. This can be done if the environmental light is measured with for example an LDR.

A Position detection methods

Method op position detection	Why (not) useful for this situation	Closer look
GPS	Not useful, because GPS is not always working inside buildings, and location is not exactly enough with cheap modules	
IR with respect to each other	Is possible to build, there are working robots with IR position detection	x
IR with respect to beacons	Is possible to build, but beacons are not preferred, because they should be at an fixed position, so difficult use at different locations.	
'radar' with current distance sensors	It is not possible distinguish an robot or an obstacle from each other. It is also not possible to distinguish different robots from each other.	
Linear CCD	It is possible to use an linear CCD to distinguish the angle between the robot and an sender.	x
Give each robot another color, and put an camera onboard	There are more cameras necessary for an 360° view, this is expensive, and not small enough for the robot.	
Induction loops under the floor	Position detection by electric field from the floor is possible, But for this method requires an special floor, so the floor should be portable, this can be difficult for an area of 10 x 10 meters.	
Starting on an predefined location, with optical mouse sensor under robot	The robots can not start all at the same location at the same time, so they must start after each other. The deviation will also grow larger when they drive a longer time. A computer mouse sensor is used for example in the cat and mouse robot [5].	
Barcode on the floor with the CCD sensor	The robot can read its location with CCD sensors that read barcodes on the floor. The problem is that the whole floor should be filled with barcodes	
Both ultrasound and IR	For an exact distance measurement ultrasound can be used, for the angle a combination of IR an ultrasound can be used.	x
Both ultrasound and linear CCD	For an exact distance measurement ultrasound can be used, the angle measurement can be done by the CCD.	x

Table A.1: Position detection techniques

B RF communication modules

	Product	Antenna onboard	Baudrate	RSSI[a]	Carrier frequency	size (mm)	Interface	VCC	costs
	ER400TRS	No	38,400 kbit	Yes	433 MHz	38 x 14 x 4	UART	5V	€29.33
	ICradio Module 2.4G	Yes	115,2 kbit	Yes	2.4 GHz	40 x 27 x 3	Microcontroller onboard, undefined	3.3V	€45.95
	MOD-NRF24LR	Yes	2Mbit	No	2.4 GHz	34 x 18 x 7	UEXT	3.3V	€24.95
	LI-433TR	Yes	20 kbit	No	433 MHz	52.5 x 37.6 x 11.3	UART	2.7 - 5.25	€28.56
	EZBEE	Yes	250kbit	No	2.4 GHz	44 x 20	SPI	3.3V	€37.29
	XBEE	possible[b]	115,2 kbit	Yes	2.4 GHz	22 x 27	UART	3.3V	€21.37

[a]Received signal strength indication
[b]There are modules with and without chip antenna

Table B.1: The different RF modules.

C Description of the software

For this project two different versions of the software are written. First a version for the TSOP receivers was written. When the switch was made to IrDA receivers, the program was rewritten for a part. This lead to the two different versions. The switch is made because the TSOP receivers are relatively slow, so timer interrupts are used. For the faster IrDA protocol, the timer interrupts were not fast enough, so waiting loops were introduced, but this changed a lot of the program.

C.1 Program for IrDA receiver

This is the program used for measuring signal strength, and doing experiments using IrDA receivers. The program for the IrDA receiver is controlled using command-line options from the serial port.

main.c

The main file. This contains a lot of command line functions, and that is all it does. Waiting until the command line tells the program to do something, and the follow the command.

irSignalStrength.h

irSignalStrength.c

This file is meant for determining the signal strength. It sends pulses, and finds out if something is received.

digipotDebug.h

Header file for digipotDebug.c

digipotDebug.c

This file contains the code used for controlling the digital potentiometer.

irDistance.h

Header file for irDistance.h

irDistance.c

This file is not used any more.

irMeasureDistance.h

Header file for irMeasureDistance.c

irMeasureDistance.c

This file contains code for measuring a distance. The file can call functions from irSignal-Strength.c, and calculates from the signal strengths a distance, and angle.

DebugFuncs.h

Header file for DebugFuncs.c

DebugFuncs.c

This file contains functions for setting global variables for debugging purposes, such as the number of pulses that should be received as minimum, or the time of a pulse.

irSignalStrengthConfig.h

Header file that contains all the mapping from pin numbers and ports to the names used in the program. With this file it is possible to tell the program at which port the receivers, leds, and potentiometer are connected.

text.h

A file that is not used in this program. This file was used in the TSOP program to store the texts to display on the screen.

lcdconf.h

A file that comes with the avrlib library. This file is used to tell the compiler at which ports the LCD is connected.

cmdlineconf.h

A file that comes with the avrlib library. File for configuring the command line.

i2cconf.h

A file that comes with the avrlib library. This file is means for configuring the i2c communication.

global.h

A file that comes with the avrlib library. Meant for some global definition.

global_CPU.h

A file that comes with the avrlib library. Used for setting the CPU speed.

C.2 The program for the TSOP receiver

This is the program used for testing the TSOP receiver. This program is made for use with the LCD, and buttons on the RT-avr board.

main.c

The main file. This file contains the functions for measuring using a TSOP receiver.

DebugFuncs.h

Header file for DebugFuncs.c

DebugFuncs.c

This file contains functions for setting global variables for debugging purposes, such as the number of pulses that should be received as minimum, or the time of a pulse.

irDistance.h

The header file for irDistance.c

irDistance.c

A file containing functions for measuring the signal strength. This file has no functions that are already calculating a distance, because before the real conversion of signal strength to distance was made, the switch was made from a TSOP receiver to a IrDA receiver.

cmdlineconf.h

A file that comes with the avrlib library. File for configuring the command line.

i2cconf.h

A file that comes with the avrlib library. This file is means for configuring the i2c communication.

global.h

A file that comes with the avrlib library. Meant for some global definition.

text.h

A file containing the texts that are displayed on the LCD display.

lcdconf.h

A file that comes with the avrlib library. This file is used to tell the compiler at which ports the LCD is connected.

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