Effect of Infrared Light on Line Tracking

Konstantin Lindorfer, Seref Efe Haylaz,
Bernhard Klauninger, Jeremy Sztavinovszki,
Timon Koch, Daniel Novak

Höhere Technische Bundes Lehr- und Versuchsanstalt Wiener Neustadt
(Federal Technical Secondary College)
Department of Computer Science
2700 Wiener Neustadt, Austria

Author's email: lindorfer.konstantin@student.htlwrn.ac.at

***Abstract*—Following a line is a common task in Botball. The most apparent way of doing so is by using an infrared light sensor to detect sharp differences between bright and dark areas below the robot. However, as this type of sensor measures infrared light, it may deliver different values if the amount of infrared light emitted by the lamps used during a game changes. In this paper we are going to examine the differences in sensor output values as well as line tracking performance with different types of lamps.**

I. Introduction

Robots are very often exposed to various light scenarios during a robotics event. For Botball in particular, different event locations may use different types of lamps to illuminate the game table. Apart from the changed light colour and intensity, a person can also notice a varying amount of heat being emitted by the light source.

A traditional light bulb (incandescent lamp) is known to be a very energy-inefficient light source. The majority of energy supplied is converted into heat, while only a small amount ends up as light energy. Starting in September 2009, the European Union released regulations to slowly remove such and similar energy-inefficient lamps from the market [1]. However, trading these lamps is still allowed, and sometimes they are still in use.

The increased temperature does not affect robots at all – but the infrared light causing this phenomenon might have some impact on a robot's sensors, namely infrared light sensors. As this type of sensor is very commonly used to follow a black line drawn on a white ground, we have decided to examine the intensity of differences in line tracking functionality and performance with different table lightings.

II. Line Tracking in Theory

A. Line Sensors

The component used to detect the presence of a dark line on a bright surface is called a "line sensor" [2]. It consists of two main components:

1) the IR emitter – an infrared light emitting diode
2) the IR receiver – an infrared light dependent resistor

The IR emitter emits infrared light, which is reflected once it hits a surface. The greater the distance to said surface, and the darker its colour, the less infrared light is reflected back at the line sensor. The IR receiver measures this amount of infrared light, causing a respective voltage, which can then be measured by a microcontroller.

Multiple line sensors can be used simultaneously, or even combined in one component to form a "line sensor array", enabling more precise location of the line's position. They also allow detection of other lines crossing the line your robot is currently following.

loop
  if left sensor on black **then**
    drive left
  else if middle sensor on black **then**
    drive forward
  else if right sensor on black **then**
    drive right
  else
    drive backwards
  end if
end loop

(a) A basic line tracking algorithm for an array of three line sensors

loop
  $error \leftarrow sensorValue - targetValue$
  $integral \leftarrow integral + error$
  $derivate \leftarrow error - lastError$

  $correction \leftarrow (K_p \times error) + (K_i \times integral) + (K_d \times derivate)$

  set motor A to $targetPower + correction$
  set motor B to $targetPower - correction$

  $lastError \leftarrow error$
end loop

(b) An advanced algorithm for line tracking with one line sensor [5]

Fig. 1: Examples of algorithms used for line tracking

B. Line Tracking Algorithms

To follow a line using a line sensor, an algorithm to control the robot based on the sensor's output values must be implemented. When developing or choosing an algorithm, one has to consider the number of line sensors available.

When using three line sensors simultaneously, an algorithm such as shown in Fig. 1a can be used to detect if the robot

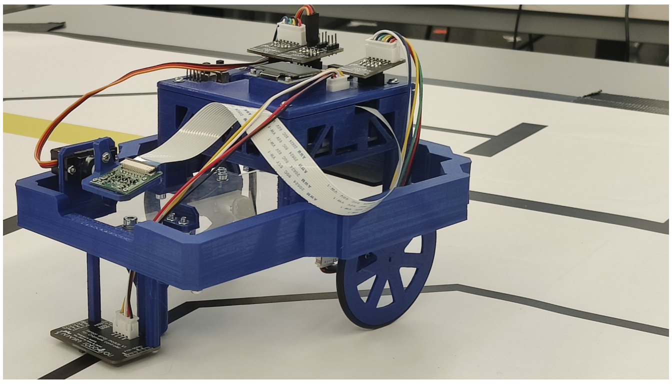


Fig. 2: A Chipmunk robot on the compAIR game field

is turning away from the line, and adjust its course to stay centred on the line.

When using a single line sensor, the robot cannot distinguish whether it is leaving the line to the left or to the right. To follow the line nonetheless, the robot can be programmed to stay on the edge of the line by detecting if the robot is above a darker or lighter area, and adjust its heading to keep it right in between the dark and light area. This can be done in a simple manner by using an if-else statement or, more effectively, by using a proportional–integral–derivative controller, in short "PID controller" [3].

The algorithm shown in Fig. 1b utilises such a PID controller. It uses the current and past deviation from the edge sensor value to dynamically adjust the robot's course. The proportional constant K_p represents the weight of the current deviation from the target value, the integral constant K_i determines the weight of accumulated past errors, and the derivation constant K_d modifies the intensity of the correction based on the effectiveness of the previous correction. Once properly configured, this algorithm makes the robot follow a line with very efficient movements, resulting in the correction process being almost to completely invisible to the human eye. The Ziegler-Nichols method has proven successful in finding optimal constants for such a PID controller [4].

III. Experiments

To examine the performance differences more closely, we let two types of robots follow a one centimetre wide black line on a white background. To simulate significantly different lighting scenarios, the experiments were conducted using three distinct light sources:

- an LED ceiling lamp
- an incandescent lightbulb
- an infrared heat lamp

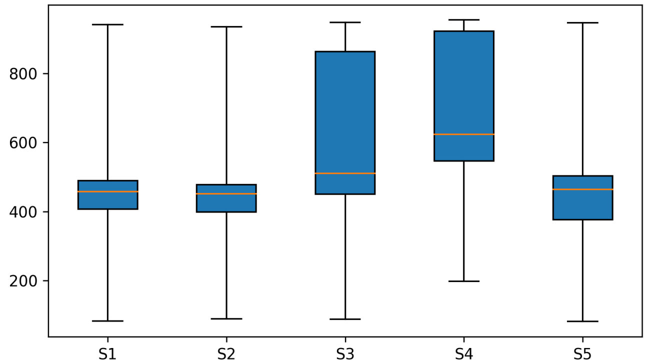
The sensor output values as well as course deviations in each of those environments will show the impact of infrared light on line tracking.

A. Line Tracking using the Chipmunk Robot

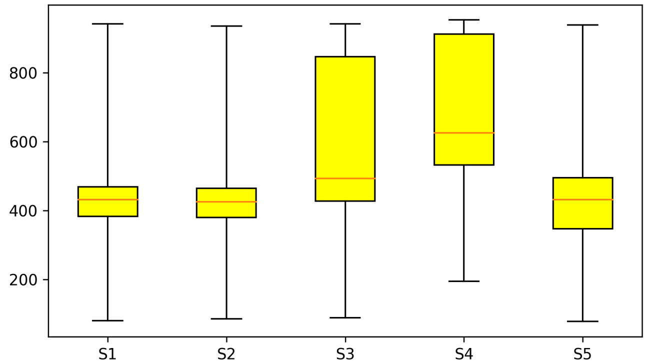
The first robot used is the Chipmunk of the compAIR competition [6], visible in Fig. 2. It is equipped with an IR-sensor array consisting of five infrared light sensors, which is mounted at the very front, facing the ground at a distance of approximately 3 millimetres. To make the Chipmunk follow the line, a basic algorithm using all five sensors was implemented to detect if the robot is about to leave the line and, if necessary, readjust its heading.

The boxplots shown in Fig. 3 represent the Chipmunk's line sensor array output values, measured while tracking the main line of the compAIR game field under the three different lighting conditions.

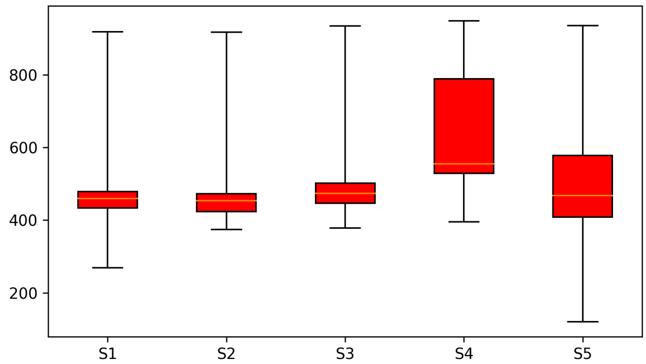
Using an LED ceiling lamp as light source, the Chipmunk



(a) Measurements with an LED ceiling lamp



(b) Measurements with an incandescent lightbulb



(c) Measurements with an infrared heat lamp

Fig. 3: Boxplots depicting the Chipmunk's line sensor array output values over three course completions with each lamp

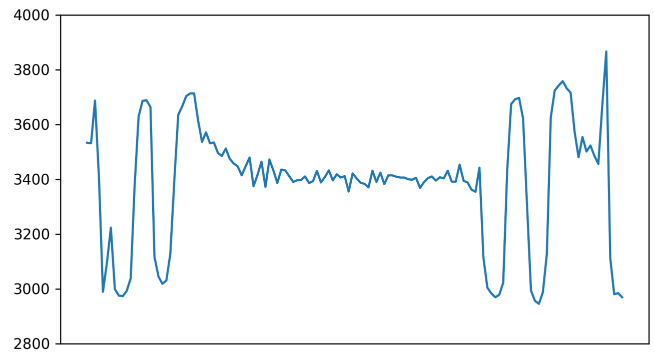


Fig. 4: Graph depicting the Wombat-controlled robot's line sensor output values over a course completion

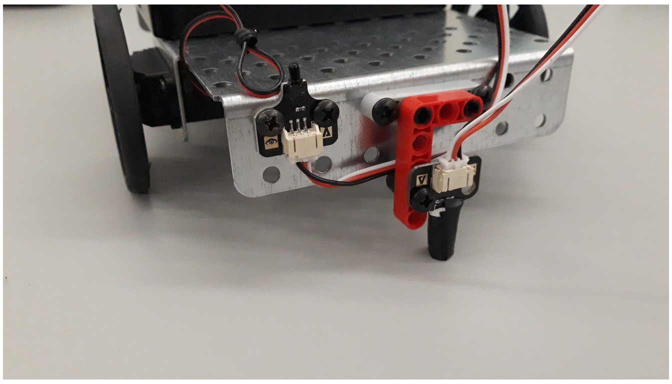


Fig. 5: A simple robot made of Botball parts with a shielded IR-sensor

was able to complete the entire course with ease, including the sections with crossing lines. As shown in Fig. 3a, the outer sensors S1 and S5 returned low values, as they mostly measured white areas. S2 also mostly measured white area, contrary to S4, which returned a lot of higher values, but also a fair share of lower values.

The graphic indicates that the black line was mostly detected beneath S4 and S3, which measured similar values. The higher values of S4 and the asymmetry in the graphic are caused by the curvature of the black line, which contains significantly more right turns than left turns.

Illuminating the course in front of the robot using an incandescent lightbulb did not pose any problem. As visible in Fig. 3b, the line sensors' output values barely changed compared to the values in Fig. 3a. Hence, adjusting the static threshold value for detecting the black line was not necessary to achieve equal performance. All in all, the robot was able to complete the course under these less optimal lighting conditions just as fine.

However, using an infrared heat lamp to illuminate the course did pose a problem. Since this lamp does not illuminate the course evenly, completing a course under these lighting conditions was unfeasible. The interquartile ranges shown in Fig. 3c are smaller, making it harder to distinguish between bright and dark areas. The infrared light reaching the IR receivers also greatly varied with each measurement. The line sensors' output values changed to an extent where determining black and white was no longer possible. Given these lighting conditions, the robot lost track of the line in the first curve, and completing the course was not possible.

B. Line Tracking using a Botball Robot

The second robot used is a Wombat-controlled robot based on the Demobot provided by KIPR [7]. It is equipped with a single line sensor which is also mounted at its very front and faces the ground at a distance of approximately 5 millimetres. Since only a single sensor is used, detecting crosslines is not possible, and only part of the course can be completed with this robot. It attempts to stay on the edge of the black line in this section using an algorithm that utilises a PID controller, such as shown in Fig. 1b.

With the LED ceiling lamp as light source, the robot was able to complete the section without troubles. The sensor always stayed very close to the line, even in curves. Fig. 4 displays the robot's sensor output values measured while driving along this line. The sections with higher amplitudes signify a part of the course where the robot had to correct its heading more aggressively, such as a curve. In these sections the robot overcorrected itself, whereupon it had to partially undo the correction. Since this process happens within a very short time frame, the result is a very tidy movement.

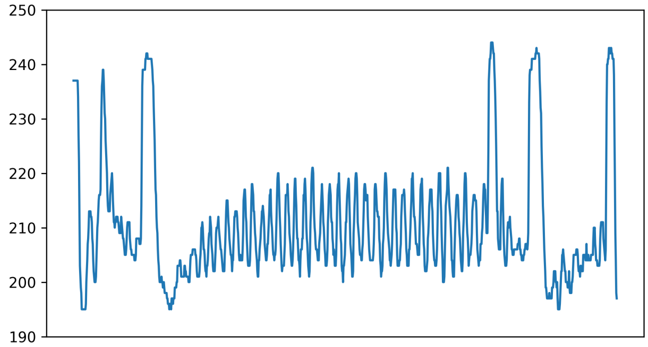
Similarly to the Chipmunk robot, using an incandescent lightbulb to illuminate the course did not show any differences in performance compared to the LED ceiling lamp. It was not necessary to adjust the target sensor value or the constants of the PID controller to achieve equal performance under these lighting conditions.

Using an infrared heat lamp to illuminate the course in front of the robot also caused similarly bad performance as with the Chipmunk robot. The sensor's output values were very inconsistent, and reliable differentiation between black and white was no longer possible. The robot failed to detect the line entirely, and was therefore unable to complete the course under these lighting conditions.

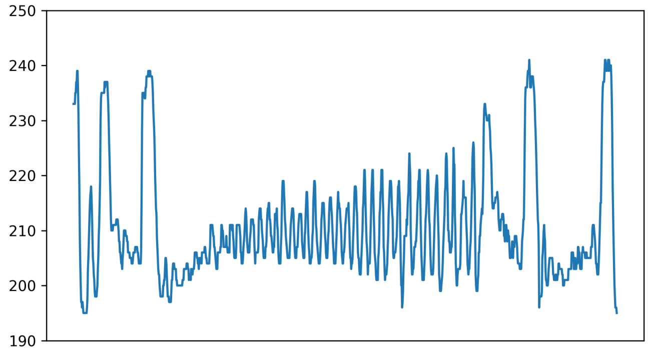
C. Infrared Light Influence Countermeasures

Since the Chipmunk robot may not be modified in the compAIR competition, countermeasures on hardware level are not an option. In Botball, however, modifying your robot's hardware is a core part of the competition, and protecting its sensors against external influence using soda straws or electrical tape is explicitly allowed according to the Game Review [8]. The shieldings should block out any external infrared light, which would result in the line sensor only receiving the reflected infrared light it sent out itself.

To determine the effectiveness of such sensor shieldings, we installed different types of shieldings on the Wombat-controlled robot's sensor, and let it track the black line on the compAIR game field again. This time we compared the



(a) Measurements using an LED ceiling lamp



(b) Measurements using an infrared heat lamp

Fig. 6: Graphs depicting the Wombat-controlled line sensor's output values while shielded with electrical tape

improved robot's performance under an LED ceiling lamp to its performance while influenced by an infrared heat lamp.

In our first attempt to block out infrared light we used mundane printing paper to surround the sensor with a narrow tunnel to the ground. Unfortunately, this simple shielding showed no effect, as too much external infrared light penetrated the shielding. The minimum and maximum sensor output values differed from those measured without shielding, but tracking the line was still not possible due to the sensor output values fluctuating too much.

In our second attempt, we used black electrical tape to create a light guide in a similar manner, shown in Fig. 5. After adjusting the target value, the constants of the PID controller, and the speed at which the measurements were taken, the robot was able to follow the line just as fine as without infrared light influence. It turned out that the black electrical tape shields against infrared light well enough that the sensor's average output values remained almost exactly the same even when the infrared heat lamp was aimed directly at the shielding. Fig. 6 shows the shielded sensor's output values under both lighting conditions, with both graphs showing behaviour similar to the graph in Fig. 4. The gradually increasing amplitudes in Fig. 6b were caused by the robot driving towards the external infrared light source, showing that a small amount of infrared light still penetrates this shield. Nevertheless, the robot was able to complete the course section under both lighting conditions without failure.

IV. Conclusion

Our experiments showed that infrared light is a source of disturbance in robotics that should not be underestimated. Large fluctuations in the amount of infrared light a sensor is exposed to can render brightness measurements useless. A significant amount of external infrared light can make a task that depends on such measurements impracticable, even if the change in infrared light is taken into consideration when programming the robot.

However, our experiments also showed that smaller changes in the amount of infrared light, such as those caused by older types of lighting like incandescent lightbulbs, do not affect the robot's performance at all. Considering this change of lighting in the robot's program is not necessary for the robot to perform equally well.

Furthermore, for tracking a line in a Botball-like scenario, the line sensor can be shielded using a material impermeable to infrared light. This prevents interference to the extent that accurate measurements can be taken even when influenced by larger amounts of external infrared light. It is therefore highly recommendable to shield a robot's sensor in order to be prepared for any lighting scenario.

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