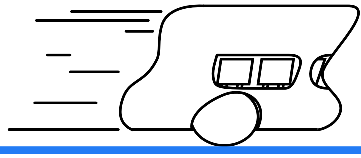
Khepera^2



IR Sensors Report

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Table Of Contents

1 Introduction **3**

2 Test Conditions **4**
- 2.1 Environment 4
  - 2.1.1 Test Setup 4
  - 2.1.2 Ambient Light 4
- 2.2 Measurements 5
  - 2.2.1 Distance and Angle 5
  - 2.2.2 Mean Value and Deviation 5
  - 2.2.3 Sensors Residual Value 6
- 2.3 Detected Object 6
  - 2.3.1 White Object Detection 6
  - 2.3.2 Other Robot Detection 6
  - 2.3.3 Reflective Paper Detection 6

3 Test Explanation **7**

4 Object Detection Test Results **9**
- 4.1 Khepera I Reference Test 9
- 4.2 Khepera^2 Basic Setting $A_0 = 12$ 10
- 4.3 Increased Sensitivity $A_0 = 22$ 11
- 4.4 Very High Sensitivity $A_0 = 39$ 12

5 Robot Detection Test Results **13**
- 5.1 Khepera^2 Basic Setting $A_0 = 12$ 13
- 5.2 Increased Sensitivity $A_0 = 22$ 14

6 Reflective surface test Results **15**

7 Changing Sensor Amplification **16**
- 7.1 Operating Instructions 16
- 7.2 Warranty Agreement 17

1 Introduction

Basically, the Khepera is only able to detect its environment using 8 IR sensors, detecting IR reflecting objects in all directions. A proper sensor management system can be critical for applications to run correctly.

As any sensors, IR devices are subject to noise and environmental disturbance. These phenomenon could cause false detections or undetected obstacles problems. The first method to avoid such detection problems is to use a robust software system, such as debouncing methods or software filtering. But to match some specific applications needs or when software is not sufficient, IR sensors response can be adapted using minor hardware modification.

Detailed description of IR sensors testing, with various hardware configuration is given in this document. It should help evaluating the IR sensors behavior for application specific requirements.

2.1 Environment

2.1.1 Test Setup

As IR sensors are very sensitive to environmental conditions, setup for testing is particularly important. The chosen setup is not meant to be the most representative nor the one giving best results, it is just designed to provide a coherent constant environment and uniform lighting conditions for all tests. An overview of the test setup is given on figure 2.1.

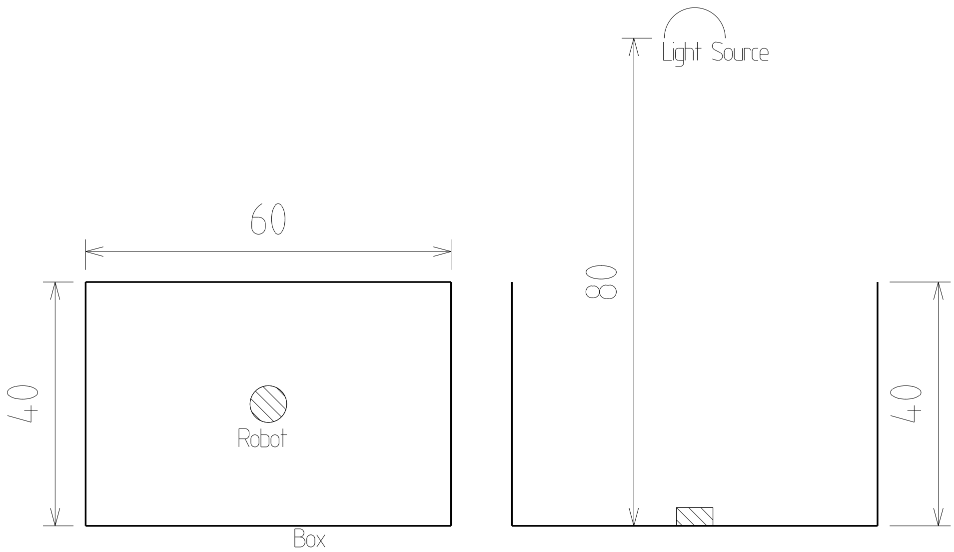


Figure 2.1: IR sensor test setup (all measurements in cm)

2.1.2 Ambient Light

Ambient light has a major influence on sensors performances. Object detection capability is completely different under full daylight or total dark conditions. For testing, a constant 35W white light source is used. A general advice when using Khepera robots is to avoid infrared emitting light sources as they can disturb the IR sensors.

All test results include ambient light measurements. Ambient measurement value is usually stable over time when using the test setup described above.

2.2 Measurements

2.2.1 Distance and Angle

Objects position around the robot is given using distance and angle, the absolute reference point for these measurements is the robot's center. Angular position is according to figure 2.2, the given distance is from the sensors to the object surface. Absolute, and exact distance is from the robot's center to the object surface so that:

$$AbsoluteDistance = DistanceToObject + 3cm$$

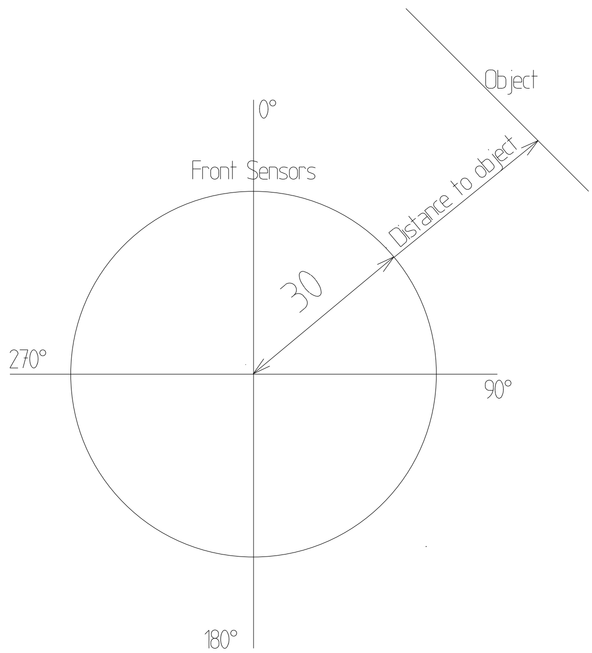


Figure 2.2: Distance and Angle (all measurements in mm)

2.2.2 Mean Value and Deviation

As IR sensors value can vary quickly over time, the instantaneous value may be irrelevant. That is why an average value for sensors is calculated during the measurement period. This average value is defined as:

$$Average = \frac{\sum_{n=0}^{N} value_n}{nsamples}$$

Variations of the sensors value over time is approximated using an average deviation over a measurement period. The bigger is the deviation, the bigger are the variations from sample to sample. This deviation is defined as:

$$Deviation = \frac{\sum_{n=0}^{N} |Average - value_n|}{nsamples}$$

For all the following tests, the measurement period has been defined as 1 second and the sampling time 20ms. Thus, average value and deviation is given for 50 samples.

2.2.3 Sensors Residual Value

The sensors residual value is defined as the value returned when there is no object to detect. This residual value is due to the sensors high sensitivity and cannot be suppressed without reducing detection range. This value is given in the 'Empty Space' column and use the average method.

2.3 Detected Object

2.3.1 White Object Detection

The first kind of test is evaluating the robots capability to detect obstacles. As it is a commonly used material, the detected object is a plain 5cm x 5cm square bit of standard white paper. The surface is placed perpendicularly to the ground and parallel to the robot's body.

2.3.2 Other Robot Detection

The second test is evaluating the robots capability to detect each other. A second robot is used, placed facing the tested Khepera in front of the tested sensors. The given distance is from body surface to body surface.

2.3.3 Reflective Paper Detection

To evaluate maximum detection capability for IR sensors, a reflective surface has been used. The detected object is a 5cm x 5cm square surface, covered with IR reflective paper. The surface is placed perpendicularly to the ground and parallel to the robot's body.

3 Test Explanation

As described in Khepera User Manual, sensors value is a difference between ambient light and reflected light. The circuit responsible for this operation can be seen as a simple Differential Amplifier such as displayed on figure 3.1. The real circuit is much more complex but this is enough to understand the sensor signal amplification system.

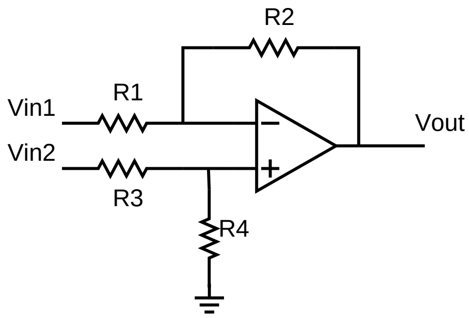


Figure 3.1: Difference Amplifier

A classical result for a difference amplifier transfer function is:

$$V_{out} = \frac{R2}{R1}(V_{in2} - V_{in1})$$

$$\begin{array}{ll} for & R1 = R3 \\ and & R2 = R4 \end{array}$$

This transfer function is obtained considering a perfect operational amplifier and exactly equal resistors. The difference amplification depends only on the ratio between these resistors. Changing this ratio can change the IR sensors detection capability as demonstrated with the following test results. The resistors ratio could eventually be set to any value, according to the application needs, as long as relations $R1 = R3$ and $R2 = R4$ are respected.

When resistors are not perfectly equal, this is introducing an amplification bias and an undesirable common mode amplification. The usual transfer function for a differential amplifier is actually:

$$V_{out} = A_{V_d}.V_d + A_{V_{mc}}.V_{mc}$$

$$\begin{array}{llcl} with & A_{V_d} & = & \text{Differential mode amplification} \\ & A_{V_{mc}} & = & \text{Common mode amplification} \\ & V_d & = & V_{in1} - V_{in2} \\ & V_{mc} & = & \frac{V_{in1}+V_{in2}}{2} \end{array}$$

A tolerance applies on any commercial resistor, most common errors are around 5% or 1%. When considering error e on the resisors value with a worst case configuration such as:

$$\begin{cases} R1 &= R1_n\,(1+e) \\ R2 &= R2_n\,(1-e) \\ R3 &= R3_n\,(1+e) \\ R4 &= R4_n\,(1-e) \end{cases}$$

Quite long calculations that are beyond the scope of this document lead to the following relations for A_{V_d} and $A_{V_{mc}}$.

$$\begin{aligned} with \qquad & A_0 = \tfrac{R2}{R1} \\ A_{V_d} \approx \qquad & A_0 \left(1 - \frac{2.A_0.e}{(1+A_0)}\right) \\ A_{V_{mc}} \approx \quad & \frac{4.e.A_0}{1+A_0} \end{aligned}$$

So that the real differential amplification A_{V_d} equals A_0 when $e = 0$ but when $e \neq 0$ the bias on the differential amplification can can be as high $2e$.

Common mode amplification $A_{V_{mc}}$ is null when error is null. When $e \neq 0$, gain can vary up to $4e$ depending on A_0. This common mode amplification can introduce large errors in the measured value depending on the environment and light conditions.

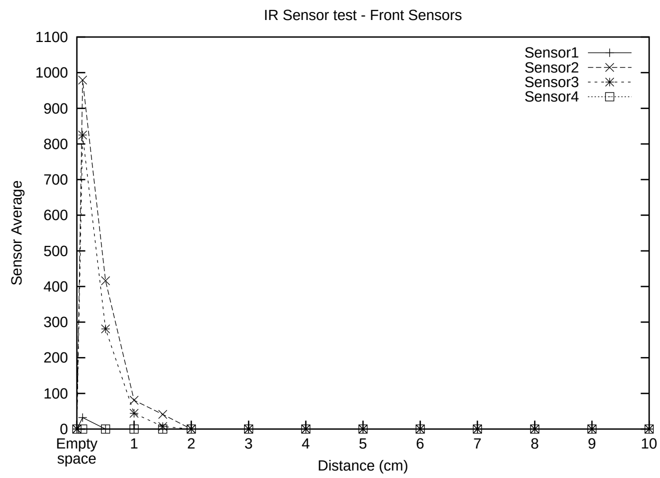
Resistors ratio choice can help adapting sensor behavior to custom application needs, but careful design is necessary to avoid measurement bias. Best results are obtained with exact $R1 = R3$ and $R2 = R4$ relations, so a tighter tolerance on resistors value should imply better results.

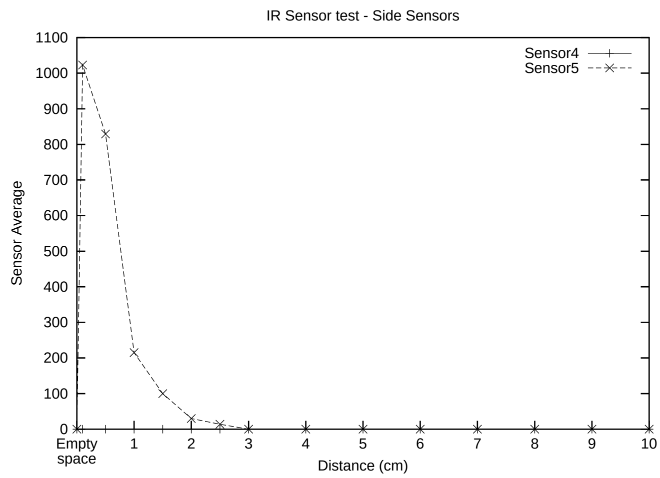
4 Object Detection Test Results

Object detection tests are using a white paper surface as described in section 2.3. Each test includes a front sensors test and a side sensor test. When referring to figure 7: "Position of the 8 IR sensors", *in the Khepera User Manual*, front sensors are number 1,2,3 and 4. On the same figure, side sensors used for these tests are number 4 and 5.

Ambient light level for all sensors is given as well as the measurement deviation. The ambient light value is an approximated indication for light conditions. Measurement deviation, as defined in section 2.2.2, is an indication for measurement stability.

4.1 Khepera I Reference Test



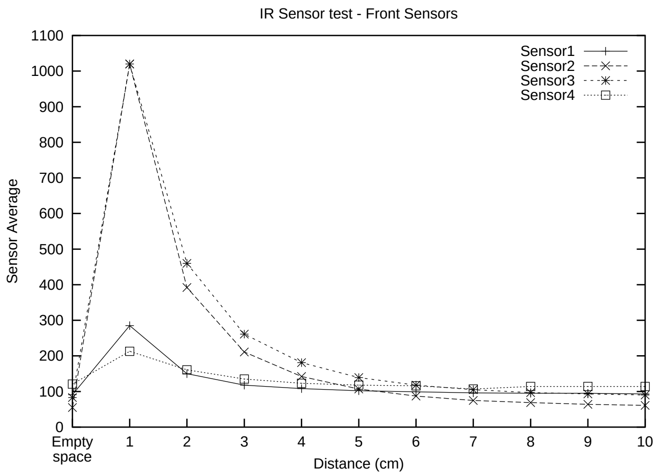


4.2 Khepera^2 Basic Setting $A_0 = 12$

Khepera^2 is basically built with $R2 = 12k$ and $R1 = 1k$ thus with a sensor amplification $A_0 = 12$. This sensor sensitivity is quite high and saturation at 1024 is reached at 1cm distance. The sensors residual value (Empty space value) is under 100 in most cases.

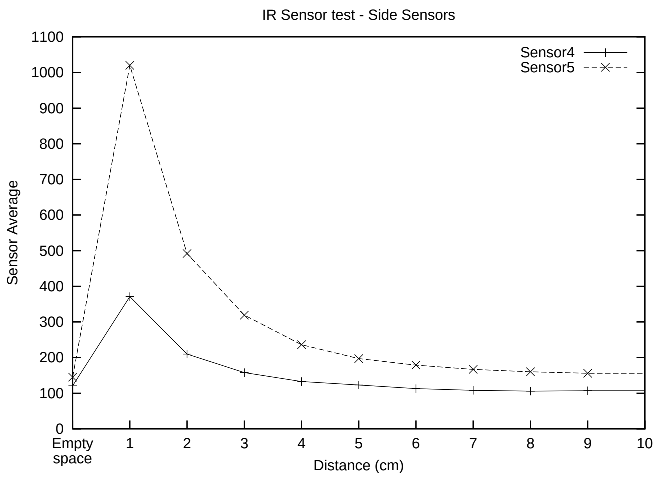
Ambient Light							
88	78	79	75	73	84	82	84

Ambient light for this test, first column is sensor 0 value, last column is sensor 7 value.



Deviation			
45	40	45	55

Calculated deviation for front sensor test. First column is sensor 1 value.



Deviation	
50	50

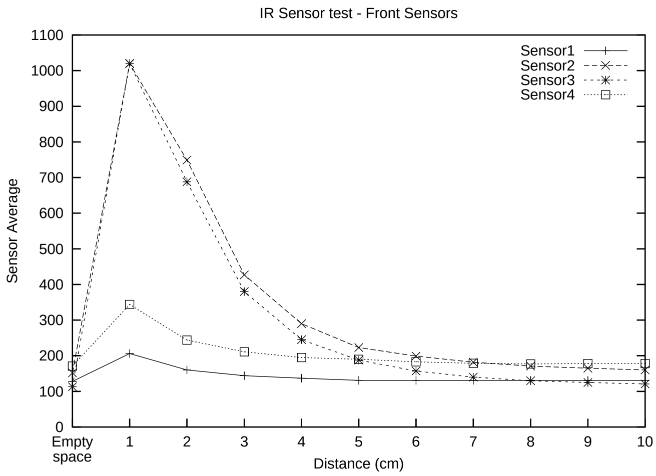
Calculated deviation for side sensor test. First column is sensor 4 value.

4.3 Increased Sensitivity $A_0 = 22$

With $R2 = 22k$ and $R1 = 1k$ sensitivity is higher. Sensor response is faster when distance is decreasing so that object detection might be easier. However the residual value and deviation are higher as well.

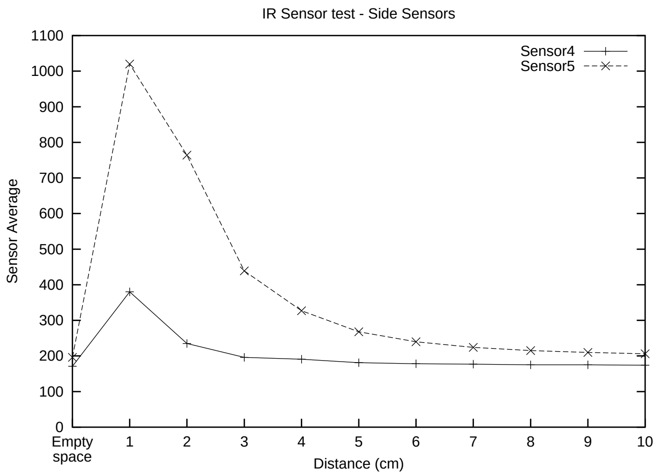
Ambient Light							
256	228	235	232	187	208	202	212

Ambient light for this test, first column is sensor 0 value, last column is sensor 7 value.



Deviation			
75	77	80	85

Calculated deviation for front sensor test. First column is sensor 1 value.



Deviation	
85	85

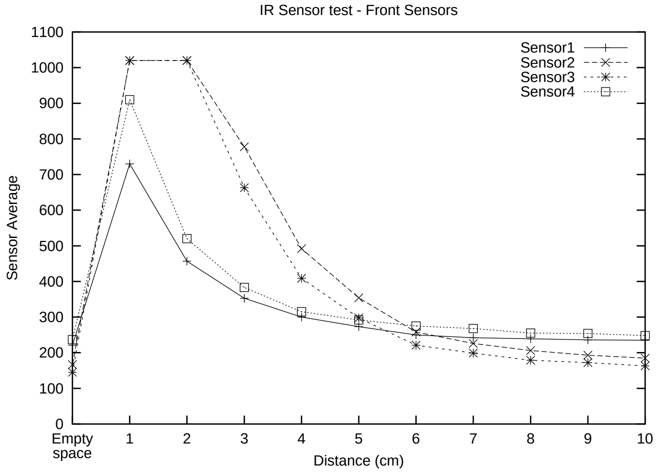
Calculated deviation for side sensor test. First column is sensor 4 value.

4.4 Very High Sensitivity $A_0 = 39$

Configured with $R2 = 39k$ and $R1 = 1k$, the sensor response is even faster, and detecting object from long distance should not be a problem. In the other hand, residual value and deviation is very high as well, increasing the risk of false detection without a proper sensor management. Sensor saturation is reached with obstacle 2cm away so that precise positioning very close to objects is difficult.

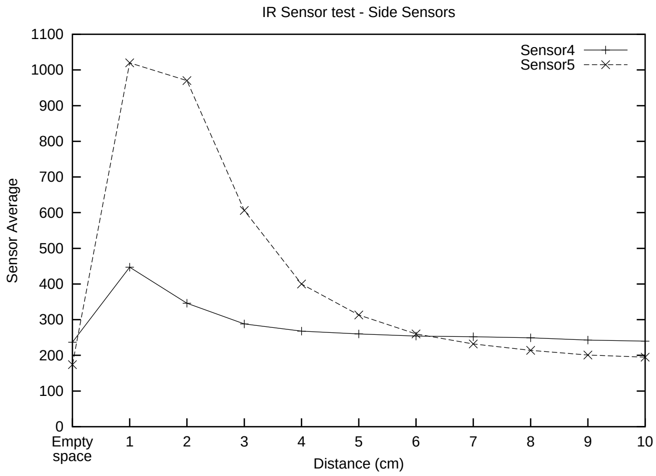
Ambient Light							
352	232	268	259	196	219	220	288

Ambient light for this test, first column is sensor 0 value, last column is sensor 7 value.



Deviation			
130	125	130	160

Calculated deviation for front sensor test. First column is sensor 1 value.



Deviation	
155	145

Calculated deviation for side sensor test. First column is sensor 4 value.

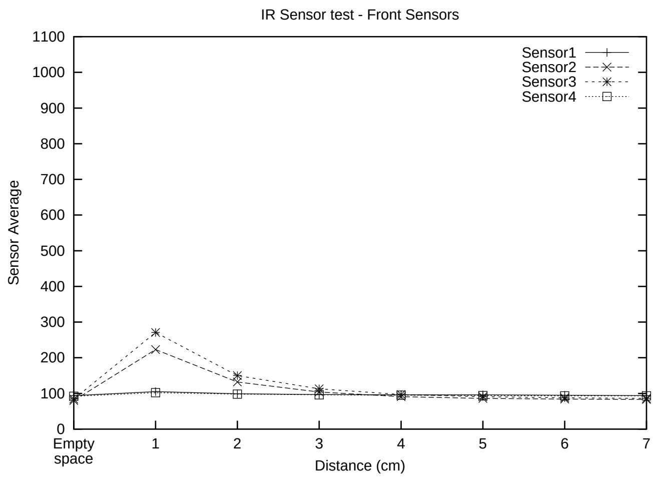
5 Robot Detection Test Results

5.1 Khepera^2 Basic Setting $A_0 = 12$

This is the basic Khepera^2 setting, using $R2 = 12k$ and $R1 = 1k$.

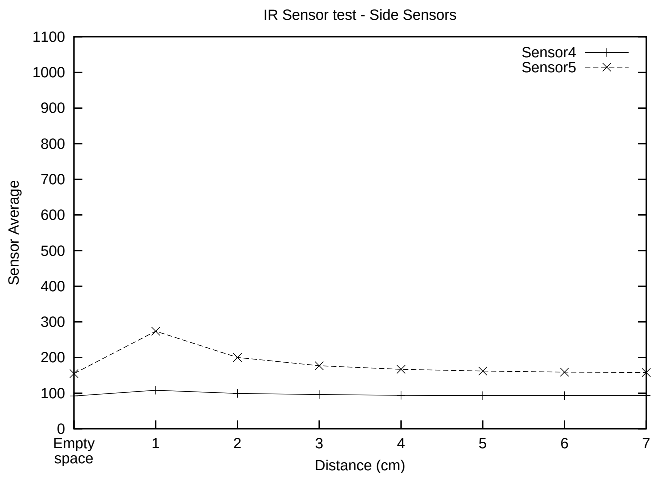
Ambient Light							
252	208	244	226	134	199	224	188

Ambient light for this test, first column is sensor 0 value, last column is sensor 7 value.



Deviation			
40	35	35	50

Calculated deviation for front sensor test. First column is sensor 1 value.



Deviation	
50	40

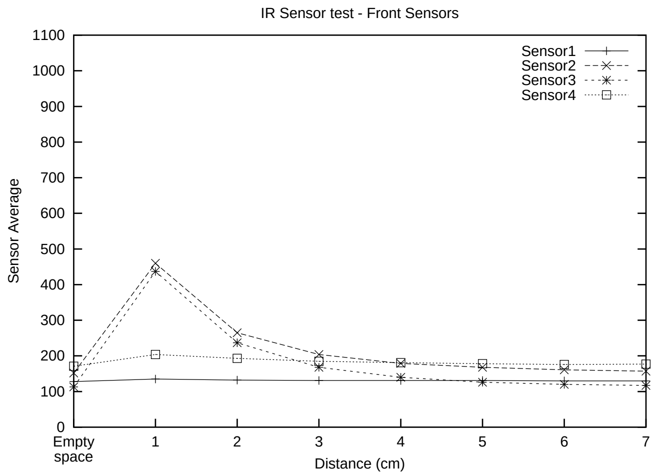
Calculated deviation for side sensor test. First column is sensor 4 value.

5.2 Increased Sensitivity $A_0 = 22$

Using $R2 = 22k$ and $R1 = 1k$ for higher amplification is enhancing robot detection as well. When the ability to detect other robot is critical, the basic amplification might not be sufficient, especially for long distance detection, and such a configuration may be preferred.

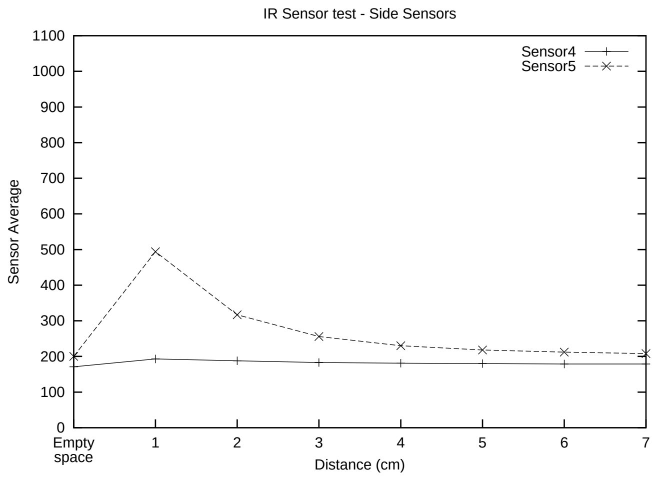
Ambient Light							
330	340	319	324	313	320	342	339

Ambient light for this test, first column is sensor 0 value, last column is sensor 7 value.



Deviation			
53	58	57	60

Calculated deviation for front sensor test. First column is sensor 1 value.



Deviation	
67	66

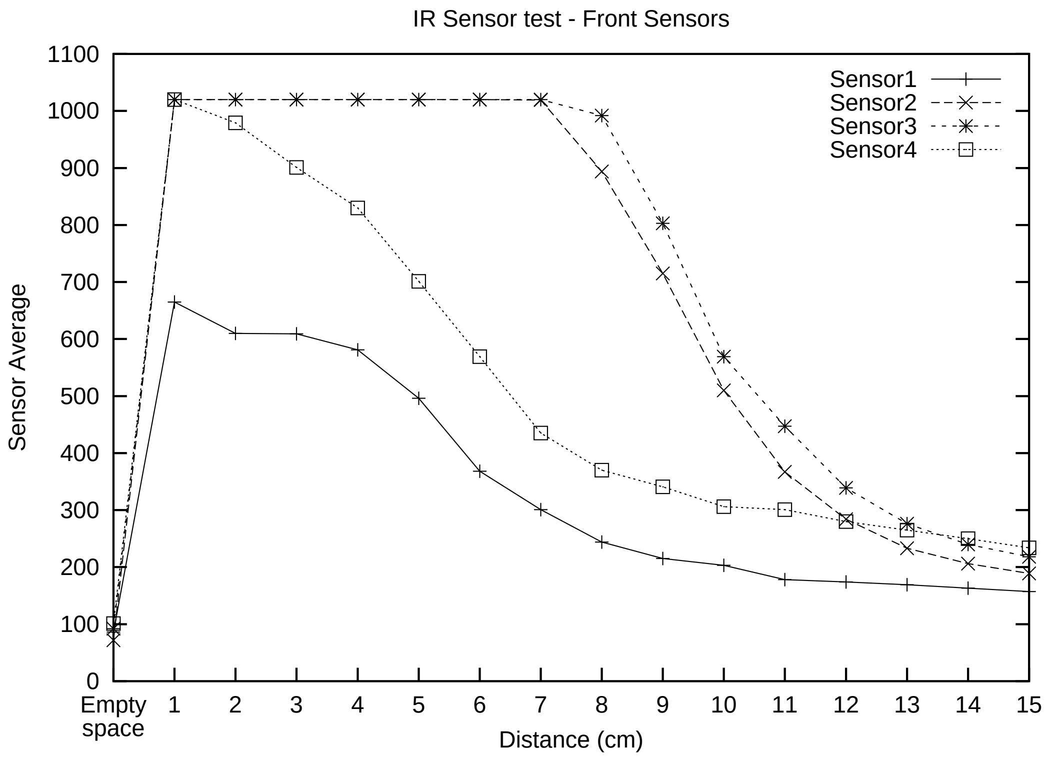
Calculated deviation for side sensor test. First column is sensor 4 value.

6 Reflective surface test Results

This test is using an IR reflective surface to demonstrate maximum detection range using the Khepera[2] basic setting. Up to 7cm distance, front sensors are saturated. Up to 15cm distance a pretty high signal is available, and detection is possible up to 20cm. Such results may be useful for object detection from a very long distance.

Ambient Light							
323	316	330	308	292	307	317	316

Ambient light for this test, first column is sensor 0 value, last column is sensor 7 value.



7 Changing Sensor Amplification

Sensor amplification is determined with four resistors, as detailed in chapter 3. Changing the sensor amplification value, to match application specific needs, is a matter of changing these four resistors placed on the bottom of the Khepera robot. Hardware configurations tested in this document are not supposed to be the best ones, any resistor ratio could be used as long as relations $R1 = R3$ and $R2 = R4$ are respected. Further testing might be necessary to determine which ratio suits a given application.

7.1 Operating Instructions

Surface mounted resistors can be easily removed and replaced. Positions for resistors to be changed are displayed on figure 7.1, and the new amplification ratio can be calculated using the method described in chapter 3. Tolerance for these resistors should be chosen carefully, the tighter the better. The Khepera[2] is originally built using 1% resistors, tolerance for replacement resistors should be equal or tighter.

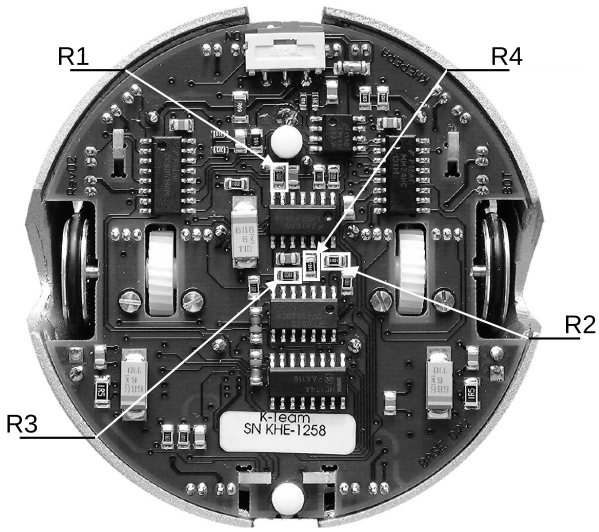


Figure 7.1: Position of the resistors

Please read the warranty agreement in section 7.2 before operating. Improper operations or wrong soldering tool manipulation can cause damage to the robot, if you don't know exactly the operating method to replace SMD resistors without damage, contact your Khepera dealer for support.

7.2 Warranty Agreement

By applying any hardware modifications to a K-Team product, you are consenting to be bound by this warranty agreement.

In no event will K-Team S.A. or any of its distributor be liable to you for special, incidental, or consequential damage, caused to you or to the product itself, arising out of or in connection with the applied hardware modification to any K-Team product.

K-Team products warranty does not cover any damage, failure, or performance degradation, caused by or related to any user modification on the concerned product.

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