Tests of Selected Sensors Applicable in Autonomous Mini Sumo Robots

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***Abstract*—The purpose of this article is to compare 3 selected sensors commonly used in sumo robots for their ability to detect objects with 3 different surfaces: white, black and reflective. They have been tested on a special measuring stand with the possibility of changing the inclination of the tested surface in the vertical axis (range from 0 ° to 50 °) and in the horizontal axis (range from -45 ° to 45 °). The range of the tested distance is 80 cm, with subsequent measurements being made every 5 cm. Research results are presented in the form of charts and descriptions. The measurement results allowed to determine which sensor has the highest detectability. Finally, each sensor was summarized by listing their pros and cons, taking into account the aforementioned detectability, price and size of the housing compared to the size of the robot itself.**

***Index Terms*—autonomous robot, sumo robot, sensor, navigation, control**

I. Introduction

The main thing about mobile robots is their system of navigation. It has to be adapted to needs put before them. Mini and Nano Sumo robots use basic type of navigation, which deals with obstacles in short distance to detect another robot and undertake appropriate operations. There is a second type of navigation, which provides more specific and extended data about localization, such as global or pre-specified topological maps. However, in view of small space, which is a circle with a radius of 40 centimeters, where sumo robots fight, there is no need for more advanced types of navigation. [1]-[4]

Common types of sensors used in autonomous sumo robots are infrared, laser and optoelectronic. These sensors are used to provide data about the nearest obstacles, like distance from the target or simple detection of another robot. Optoelectronic sensors can detect a border of operational space for sumo robots, which commonly is determined by white lines. There is another type of sensors, such as encoders, which calculates the position of rotating motor to provide better controlling, or another type of laser sensor with microcontrollers to detecting distance between sensor and obstacle. Ultrasonic sensors are also used, but they are relatively slower in providing data than the photoelectric ones. [5]-[7]

A proper choice of sensor is really important because builders of robots use different ways to trick them. It can be lowering a white flag in low but sufficient distance from the robot. The flag is detected by photoelectric sensors due to high reflection of light, which causes avoiding an opponent's robot and exit of the fighting area. It also can be black surfaces, which absorb light sent by sensor or reflecting surfaces, which in fact reflects the light but in different paths avoiding the receiver. On the Fig. 1 down below is presented as an example Mini Sumo robot. [5]

Another reason of the proper choice of sensors is the high dynamic nature of sumo robots, which require sensors with sufficient frequency of taking readings. When frequency is to low, it can lead to failure in detecting an opponent robot and cause a lost fight. [8]

Figure 1. An example Mini Sumo robot.

The robot sumo competition is based on original, Japanese sumo sport. The robot has to push its opponent from the fighting area, which field size depends on the sizes of competing robots. For this purpose, they use a wide range of devices like gyroscopes, encoders and accelerometers, which is responsible for controlling robots and sensors providing data for the navigation system. [7], [9], [10]

II. Research Station and Measurement Methodology

For the purpose of making measurements, a proper research station has been made presented in Fig. 2 and Fig. 3.

The operation of this device is based on the appropriate positioning of the vertical and horizontal axis of the tested surface using two servos. They are controlled by Arduino Uno and powered by a four-channel power supply. The sensor is moved towards the test Surface

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every 5 cm on a trolley in a special runner. The maximum distance of the sensor from the tested surface can be 80 cm. Servos allow setting the tested Surface in the vertical axis (X-axis) in the range from $0^{\circ}$to 50°(50°in total), as well in the horizontal axis (Z-axis) in the range from -45° to 45° (90° in total). These ranges are based on the construction of sumo robots. The surface itself with each test changes its inclination by 5°on the horizontal axis. After reaching the end of the range for the horizontal axis, the surface tilts by 5°on the vertical axis and returns to the starting position on the horizontal axis (i.e. to the -45° position). There is a 500 ms delay between each measurement in order to stabilize the vibrations of the tested surface made of laminate and lave time for transmission and saving the result to the text file. Signal processing from the sensors is carried out by Arduino Uno, together with a contact plate. The voltage divider was created to adjust the signal voltage from sensors that are powered by 12V. This voltage is able to damage the microprocessor. The signal voltage is reduced to approximately 4V. The results from the sensors are processed in a module with a microcontroller and sent to a PC computer via a USB cable, and then saved in a text file. In total, 180 measurements are made for each distance tested.

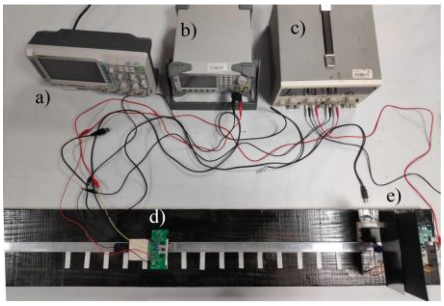


Figure 2. Research station: a) oscilloscope, b) function generator, c) four-channel power supply, d) tested sensor, e) surface and servos.

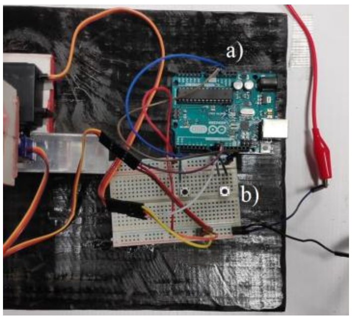


Figure 3. Research station: a) module with Arduino Uno microcontroller, b) contact plate with a button.

The research was carried out in conditions that best reflect those found at sumo robot competitions. This means that the lighting can be unevenly distributed, objects placed near the research station can reflect light uncontrollably, which can affect the test results and the surfaces were made of materials commonly used in the construction of the sumo robot. Those surfaces may have imperfections in the shape of mechanical damage or smutting to reflect the conditions prevailing during sumo robot battles.

III. Tested Sensors

During the tests 3 sensors were tested: Keyence PZ-G41N, Wenglor P1KY004, 5mm IR LED + IR Receiver Module TSOP 34438, whose parameters are shown in Table I. The appearance of the sensors is shown in Fig. 4.

TABLE I. Tested Sensors [11]-[13]

	Keyence PZ-G41N	Wenglor P1KY004	5mm IR LED + IR Receiver Module TSOP34438
Supply Voltage	10-30V DC	10-30V DC	14-17V DC + 2.5-5.5V DC
Working range	0-1000 mm	0-1000 mm	N/A
Light source	Red LED	Laser (red)	IR LED
Switching frequency	N/A	1000 Hz	N/A
Response time	0.5 ms	0.5 ms	N/A
Dimensions (L x W x H)	31.5x21.8x13.1 mm	32x22x12 mm	40x20x20 mm
Price	$90.00	$471.00	$3

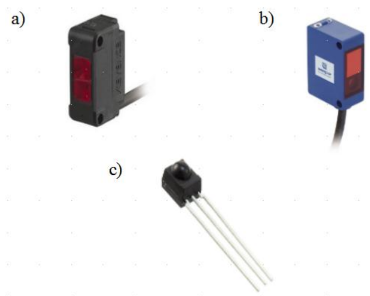


Figure 4. Sensors presented in a table: a) Keyence PZ-G41N, b) Wenglor P1KY004, c) IR Receiver Module TSOP34438. [11], [14], [15].

The Keyence PZ-G41N sensor is available for purchase on typical robotics websites including those specializing in components used to build Sumo robots.

The TSOP sensor is the cheapest of the presented above. It is used in many robotic constructions due to the low price.

The Wenglor sensor is the most expensive and one of the best sensors available in the market. It is used in robots that achieved high results in world-class competitions.

IV. Measurement Algorithm

The measurement algorithm is shown in Fig. 5 is as follows:

1. Manually position the sensor at a distance of 80 cm from the surface.
2. Pressing the button on the contact plate which starts the program loaded on the Arduino Uno plate.
3. Array the surface in the initial position (-45°on the horizontal axis and 0°on the vertical axis).

4. Take a measurement for a given position and save it in a text file.
5. Position change by 5 ° on the horizontal axis. If the end of the range is reached in this axis, the surface returns to the -45 ° position and tilts by 5 ° on the vertical axis. Return to step 4.
6. After making measurements for a given distance, the sensor is moved towards the tested surface by 5 cm. Return to point 3.

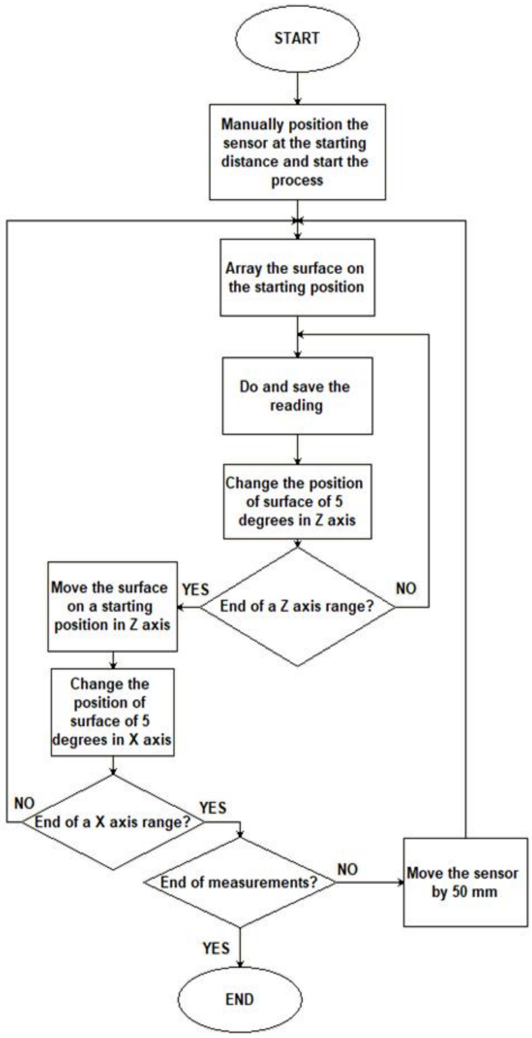


Figure 5. Measurement algorithm.

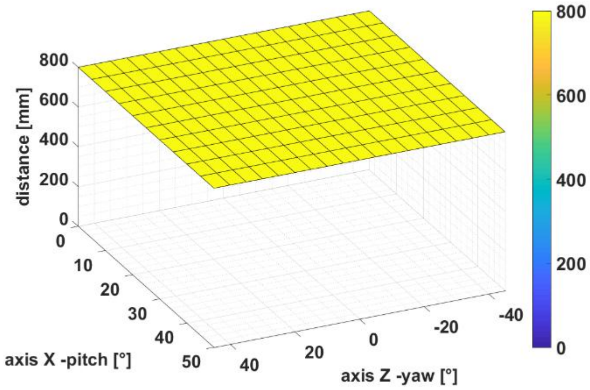
V. Presentation of the Results

The surfaces tested by the selected sensors were:

- A white sheet of paper as a white surface (dimensions: 170mm x 170mm),
- Black foil as a black surface (dimensions: 170mm x 170mm),
- A piece of spring steel sheet as a mirror surface (dimensions: 180mm x 90mm).

A. *White Surface*

White surfaces are the easiest to detect by sensors because they reflect most of the light sent to them in many directions, including the light beam sent by the sensor.



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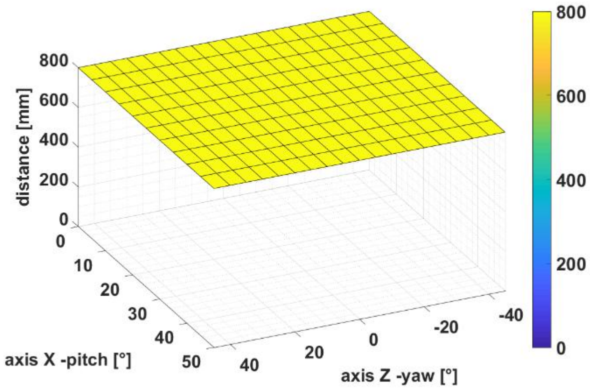

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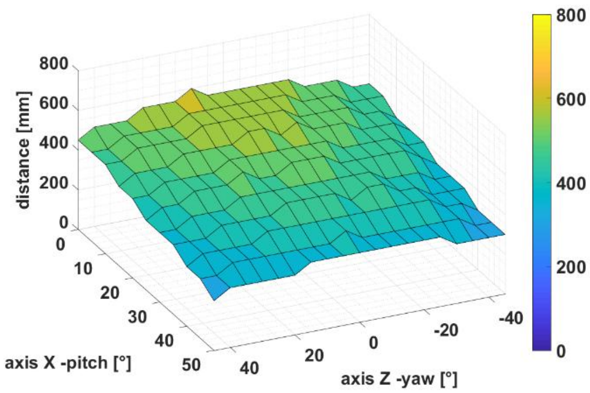


c)

Figure 6. Measurement results for a white surface: a) sensor Keyence, b) sensor Wenglor, c) sensor TSOP.

The wenglor sensor (Fig. 6b), sending a beam of light to a white surface, detects it at every distance and at every angle of inclination in the test. Identical results are for the Keyence sensor (Fig. 6a).

The TSOP sensor (Fig. 6c) is not able to detect the surface from the maximum distance within the test range. Its detection starts at 600 mm, but only at the 10 ° position for the horizontal axis and 0 ° position for the vertical axis. It can be assumed that its detection starts at 500 mm in the range from -30 ° to 30 ° on the horizontal axis and from 0 ° to 15 ° on the vertical axis. For a 45 ° position in the horizontal axis and 50 ° in the vertical axis, the sensor detects the surface at a distance of 200 mm, which is the smallest distance from which the sensor detects the test object in a given position. The best detection is in the range of 0 ° to 25 ° in the vertical axis, while for the horizontal axis the detection decreases with an increasing inclination in the X-axis in the range from -10 ° to 15 °. The smaller the tilt in the vertical axis, the better the detection of a given surface. If the tilt in this axis begins to increase, the detectability decreases for larger angles in the horizontal axis, and the sensor needs shorter distances from the tested object to detect it.

Of all sensors, Wenglor and Keynce ones are the best. The TSOP sensor works the worst because it does not detect the surface in all positions, and its maximum detection distance is smaller than the above-mentioned sensors.

Due to the easy detection of white surfaces by sensors, so as not to facilitate the detection of robots, no white surfaces are used in the robot casings.

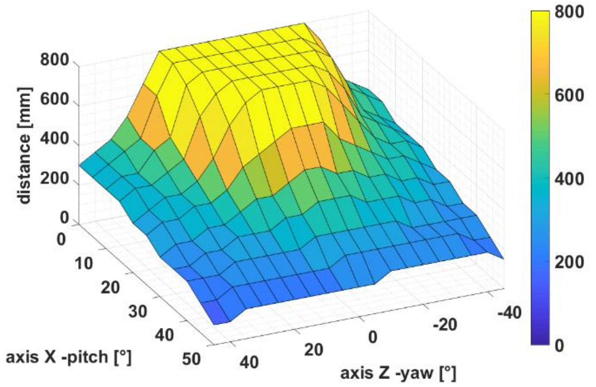
B. Black Surface

The black surface is very difficult to detect by the tested sensors. This is due to the absorption of light by black Surface, which makes it difficult for the sensor to detect the reflected light. An additional difficulty is the changing tilt angles of the surface being tested.

The Keyence sensor (Fig. 7a) can see an object from a large distance only at very small defection angles, up to 10 ° for the vertical axis and from -5 ° to 5 ° for the horizontal axis. At larger angles, the range of the sensor decreases significantly. When the angle of deviation from the vertical axis exceeds 20 °, with a small angle of deviation from the horizontal axis, the sensor can only detect from a distance of 300 mm. The sensor detects the surface from a distance of 100 mm when the tilt angle in the horizontal axis exceeds 15 ° and when the tilt angle in the vertical axis does not exceed 30 °. With large deviations from the vertical (over 30 °) and horizontal (over 15 °) axes, the sensor no longer detects the surface.

For the Wenglor sensor (Fig. 7b), the best detection occurs when the tested surface is in the 0 ° position in the vertical axis (pitch) because the sensor detects it at the largest tested distances. This state, however, begins to decrease drastically, because, at an angle of inclination of 15 ° (yaw) for the horizontal axis, the distance from which the surface is detected begins to decrease and decreases to about 400 mm. In addition, when the surface is tilted in the vertical axis above 5 °- 10 ° the detectability decreases successively and at slopes close to 50 ° the surface is detected at very short distances (approx. 100 mm). The best detection for this sensor with black surfaces is in the angles from 25 ° to -25 ° on the horizontal axis and in angles from 0 ° to 20 ° on the vertical axis. The values shown on the graph are distributed symmetrically.

The TSOP sensor (Fig. 7c) only begins to detect a black surface at a distance of 200 mm in a small range (from -10 ° to 10 ° on the horizontal axis and 0 ° on the vertical axis). At a distance of 150 mm, specific results appear, because when the surface is positioned vertically, it is not detected, but when tilted by 10 ° in the vertical axis, the situation changes. Changes in horizontal skew cease to be relevant for distances less than 150 mm. With a greater slope of the surface in the vertical axis, the detection begins to decrease until the situation where the sensor cannot detect the surface in any position on the horizontal axis.



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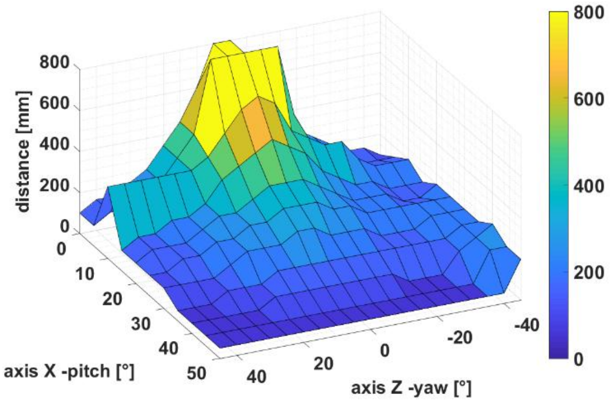

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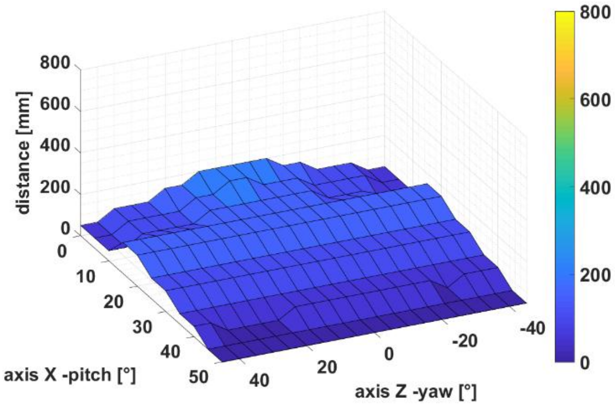

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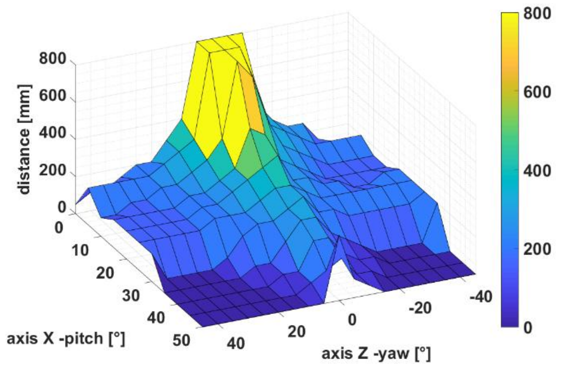
Figure 7. Measurement results for a black surface: a) sensor Keyence, b) sensor Wenglor, c) sensor TSOP.

The Wenglor sensor has the best detection among the tested sensors. Its detectability is characterized by the largest range in the case of the maximum distance from the tested surface, and the decreases in this aspect are not so significant.

In the case of a black surface, its detection by sensors decreases significantly. For this reason, it is common practice to wrap the front walls of the robot with black foil, and its casing is made of plastic or metal in shades of black.

C. Reflecting Surface

This surface has properties such as the mirror surface. It reflects light very well, but in different directions depending on the angle of incidence.



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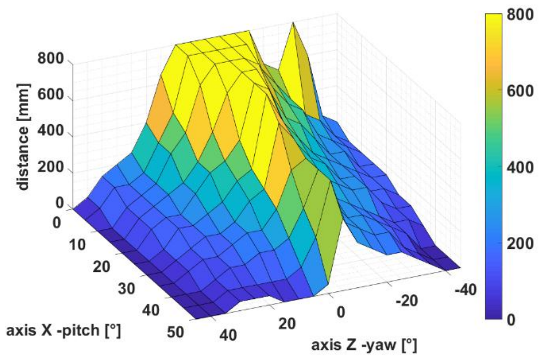

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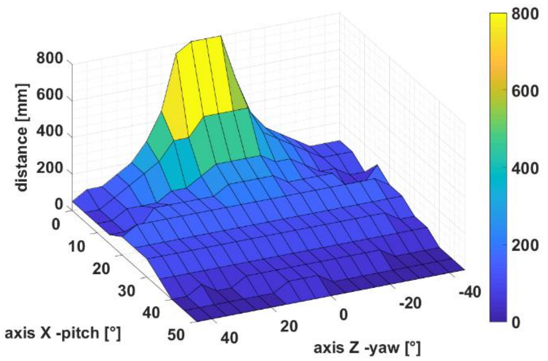

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Figure 8. Measurement results for a reflecting surface: a) sensor Keyence, b) sensor Wenglor, c) sensor TSOP.

The Keyence sensor (Fig. 8a) can see an object from a long distance only with very small deflection angles, up to 10 ° for the vertical axis and from -5 ° to 5 ° for the horizontal axis. At larger angles, the range of the sensor decreases significantly. When the angle of deviation from the vertical axis exceeds 20 °, at a small angle of deviation from the horizontal axis, the sensor can detect from a distance of 300 mm. The sensor detects the surface from a distance of 100 mm when the tilt angle in the horizontal axis exceeds 15 ° and when the tilt angle in the vertical axis does not exceed 30 °. With large deviations from the vertical (over 30 °) and horizontal (over 15 °) axes, the sensor no longer detects the surface. For the Wenglor sensor (Fig. 8b), the best position at which the surface is detected is from -10 ° to 10 ° on the horizontal axis. As the vertical angle increases, the detectability decreases almost from the very beginning of the tilt. The graph is relatively symmetrical, but there is one deviation in the form of surface detection in the position -10 ° for the horizontal axis and 0 ° for the vertical axis. From ranges around 10 ° to 45 ° and from -45 ° to -10 ° on the horizontal axis and from 35 ° to 50 ° on the horizontal axis, the sensor does not detect the surface. From the graph can be noticed a certain relationship: if the surface is in the 0 ° position on the horizontal axis, then its detectability is the highest. However, any tilt in the vertical axis eliminates this condition and detectability drops suddenly. Thanks to these properties, the best detectability occurs when the surface is in positions close to being perpendicular to the sensor beam because the beam is then best reflected (towards the sensor).

The TSOP sensor (Fig. 8c) detects a reflecting surface at a distance close to the maximum tested distance in the range from -10 ° to 10 ° on the horizontal axis and 0 ° on the vertical axis. With further increasing the angles, the detection begins to decrease significantly. Most results remain between 200 mm and 100 mm. Detectability decreases as angles on individual axes increase. The sensor stops detecting the test surface at tilting angles close to 40 ° and 50 ° on the vertical axis and almost any tilt on the horizontal axis.

The Wenglor sensor again is the best because of the largest range in which it can detect a mirror surface.

A polished reflecting surface is difficult to detect by reflective sensors due to the fact that the sent beam may not return to the sensor and reflect in a completely different direction. The reflecting surface is more difficult to detect than the black surface when it is tilted in the horizontal axis. For these reasons, reflecting the surface should cover the sidewalls that are set vertically and do not point the robot sideways to the opponent. However, one must be careful of mechanical damage and mirror surface contamination, as this leads to the detection of this surface by better sensors. This can be difficult to achieve in continuous sumo robot battles.

VI. Summary and Conclusions

Measurements showed differences in the detection of individual surfaces by the sensors. The white surface is the easiest to detect because it reflects light. For this reason, this color should be avoided in any area on the robot casing. The black surface is the hardest to detect from all surfaces because it absorbs most of the light emitted in its direction. That's why it's best to create black robot enclosures. The mirror surface is difficult to detect in cases where it is not perpendicular to the sensor because it reflects the light emitted by the sensor in such a way that it does not return back to the receiver in the sensor casing. This feature can be used by placing mirrored surfaces for example in the form of silver plaques on the walls, which for most of the fight will be at an angle to the sensor (for example, on the side walls).

In this case, however, avoid using damaged or soiled mirror surfaces, as these factors facilitate detection.

In the case of a white surface, the TSOP sensor proved to be the worst, detecting it only at a distance of 600 mm and depending on the angle of inclination, this distance fell to 250 mm. In contrast, Wenglor and Keyence sensors detected this surface in every possible position and at every possible distance.

For a black surface, the Wenglor sensor works best. It detected the surface from a distance of 800 mm in the widest range of tilt angles from all tested sensors. In the whole range of tested angles, the smallest distance at which the sensor detects the surface is a distance of 150 mm and also in this aspect is the best of all tested sensors.

For a reflecting surface, the Wenglor sensor works best again. For this sensor, the detection of this surface at the maximum distance takes place within the widest range of surface tilt angles from all sensors. With the Keyence sensor, there are more surface positions where the sensor detects nothing. The TSOP sensor has the smallest angular range in which it detects a surface from a maximum distance.

The best sensor is the Wenglor sensor, however, due to its high price, its implementation may be difficult. That is why the Keyence sensor is not much worse but a much cheaper alternative. Both of the above sensors are supplied by the manufacturer in fairly large housings, which, with limited space in Mini Sumo robots, significantly hinders their implementation in larger quantities. The worst is the TSOP sensor, but its purchase and implementation in the robot is extremely cheap, which is why it is often used. In addition, compared to previous sensors, the amount of space occupied by the TSOP sensor is much smaller, which allows to use more of these sensors, and thus improve detection and increase the detection field at a lower cost than in the case of previous sensors.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Mateusz Święcki was responsible for writing an article and he took part in preparing the research station and conducting measurements. Józek Szymelewicz prepared program for Arduino Uno wrote in C, took the main part in conducting the research and he was helping in preparing articles and research stations. Jerzy Matusiewicz took the main part in preparing research station and he was helping in writing an article and making readings. Rafał Grądzki was an originator of the subject of this article. He also assisted in the writing of these papers. All authors had approved the final version.

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