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Performance Comparison of Infrared and Ultrasonic Sensors in Distance Measuring

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Abstract: **Ultrasonic and infrared sensors are widely used for contact-less mid-range distance measurements, in navigation systems, robotics and vehicle related applications.**
This paper showcases the performance analysis of infrared and ultrasonic sensors in distance measuring for obstacles made of different types of materials such as: sponge, cardboard, wood, plastic, metal and glass, materials with different textures, thickness, colors and reflexion. Navigation systems are using both sensors for locating as well as for avoiding different types of obstacles.
Aspects of weight, dimensions, costs, accuracy, response times, and others make sensors widely accepted in all areas. It is extremely important to choose the best sensor specific to a particular measuring environment but at the same time that sensor that can calculate the distance for different types of obstacles. The analysis carried out during this paper aims to provide guidance in choosing the appropriate sensor for a certain type of obstacle.

Keywords: sensors; infrared; ultrasonic; distance; time of flight; atmega.

I. General Aspects About Distance Measuring

A. The concept of measurement

Measurement is a practical (empirical) process, an act of quantitative and qualitative knowledge of reality, objects and the environment in which we operate. It is completed by directly or by computing the values of the sizes we are interested in.

A dimension may be any common property, any manifestation or element of characterization of a class of objects, phenomena or real processes, which in various circumstances may have several states, values or nuances.

Unfortunately, not all natural quantities can be measured, but only the subset of measurable sizes, in conjunction with observable sizes and reference quantities, as suggested in the Venn diagram of Figure 1.1.

The observable sizes are those sizes on which qualitative and / or quantitative discrimination can be found: the measurable quantities are those that are orderly and on which measurement scales can be built, and measurable sizes - those for which effective measurement techniques .

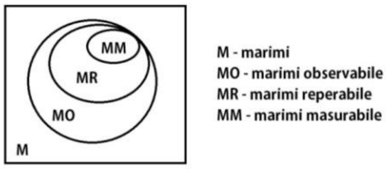

Figure 1. Submultiples of measurable quantities

Measurement can be treated and interpreted in several ways. From a mathematical point of view, the measurement is regarded as an experimental process of comparing the size to be measured, x with another magnitude of the same nature, called the unit of measurement um, to obtain a numerical result in the form:

$$n = \frac{x}{u_m} \qquad (1.1)$$

From the technical point of view, the measurement is regarded as a process of acquiring and subsequently transforming information about a certain size in order to compare it with a conventional scale or unit of measurement and use the result of this operation in various activities. It therefore interests not only the result obtained but also the form in which it is provided because it is to be used either by man or by various equipment in production, design, research, and so on.

From an informational point of view, the measurement is regarded as an experimental process of removing a nondetermination over a measured x-size, by determining (locating) a narrowest range of that magnitude.

In cybernetic terms, the measurement is regarded as a process that takes place in a system in which the measurement size x is subjected to successive transformations to obtain an x-dependent y-size at its output. (Bucur [1])

Any measurement process is accompanied by errors, including *absolute* and *relative errors*. (Paraschiv [2])

Absolute error is defined as the difference between the measured value and the actual value:

$$e_{abs} = x_m - x_r \qquad (1.2)$$

The relative error is defined by the absolute error and the measured value according to the relationship:

$$e_{rel} = \frac{e_{abs}}{x_m} .100 \qquad (1.3)$$

B. Electronic distance measurement

This method is based on the principle of measuring the propagation time, on the return path, of a light wave modulated between an emitter and a receptacle, placed on the same vertical and a reflector placed in the second end of the alignment under the measurement. But instead of modulated light, radio waves can also be used. In both cases the distance D is given by the relation:

$$D = \frac{v*t}{2} \qquad (1.4)$$

where $\boldsymbol{v}$ is the propagation velocity of the wave (light or radio), and $\boldsymbol{t}$ is the propagation time on the return path. But as the wave propagation time is measured with large errors, it is determined indirectly by measuring the phase shift between output and input modulation.

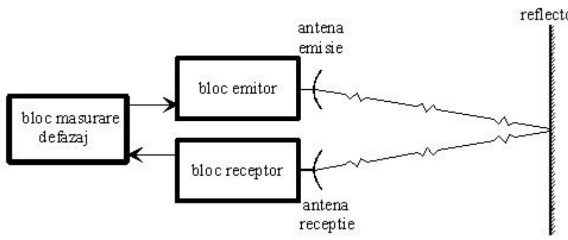

Figure 2. Measuring principle (wave propagation)

II. Designing The System

A. Block diagram, structure and system operation

The measuring system consists of the two proximity sensors HC-SR04 and SHARP GP2Y0A21YK0F, an ATmega328P-PU microprocessor and a 16x2 character LCD display for displaying the results. The microcontroller continuously scans all entries, like a programmable machine, processes the information according to the code in the bootloader and transmits the results to the display.

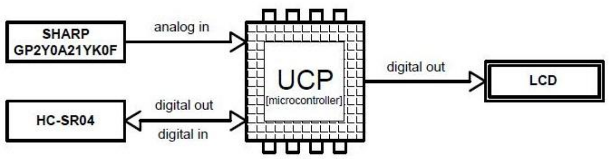

Figure 3. System Block Diagram

B. Principles of operating sensors

The ultrasonic sensor or sonar uses the Time Of Flight method for distance measurement, which represents the time of a pulse from the transmitter to the observed object and back to the receiver. .
To initiate the measurement, the "Trig" pin is switched to high (5V) for 10 microseconds. The sensor then transmits 8 pulses of 40kHz and waits for the reflected signal (echo). When detected within 150uS to 25ms, the sensor will shift the "Echo" pin to high (5V) with a delay proportional to the distance. The real distance is obtained by measuring this delay according to the formulas:

distance(cm)=Time(uS)/58
distance (inch) = Time(uS) / 148

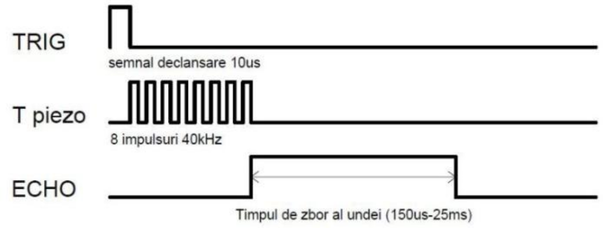

Figure 4. The operating principle of the ultrasonic sensor

The infrared sensor is based on the detection of a light wave emitted by an IR luminous diode. The distance can be measured based on the intensity change of the received light by the triangulation method and is returned as a voltage level between 0.4V and 3V. The voltage is then converted into digital signal using the analog-to-digital converter of the microcontroller. The feature is not a linear one, so changes in distance are not proportional to the output voltage. For a more accurate estimate, algebrical equations are used:

float Volts = analogRead * (5.0/1024) (conversion factor from 5V to 10 bits)

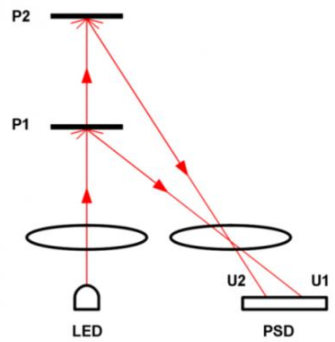

Figure 5. Infrared sensor operating principle

Figure 6 shows that the output voltage level is inversely proportional to the distance. The maximum distance measured is limited by two aspects: the decrease in the reflected light quantity and the difficulty of the PSD photodiode to record the small changes in the position of the reflected wave. When measuring too distant objects, the output voltage remains approximately the same as that corresponding to the maximum measurable distance. The minimum distance is also restricted due to the constructive limitations of the Sharp sensors below 50mm, the output voltage dropping sharply to 0V, meaning that for the same voltage there may be two measured distances, but the problem can be avoided by making measurements in the field indicated in the data sheet.

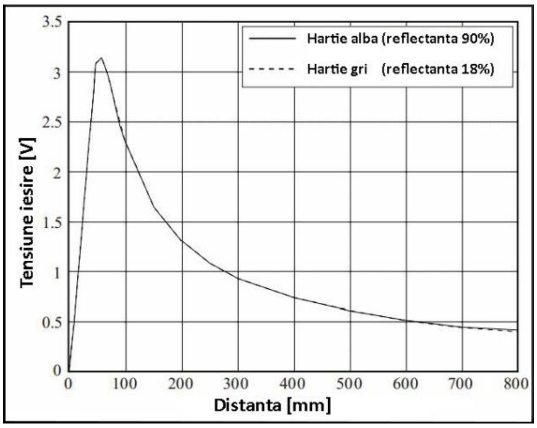

Figure 6. Distance-tension dependence

III. System Implementation

Data collection and processing will be taken over by an ATmega328P-PU chip, commonly used in Arduino development boards, but will be mounted separately on a test board together with a 16MHz quartz crystal, two 22pF ceramic capacitors, a 10K resistor and optionally a reset button.

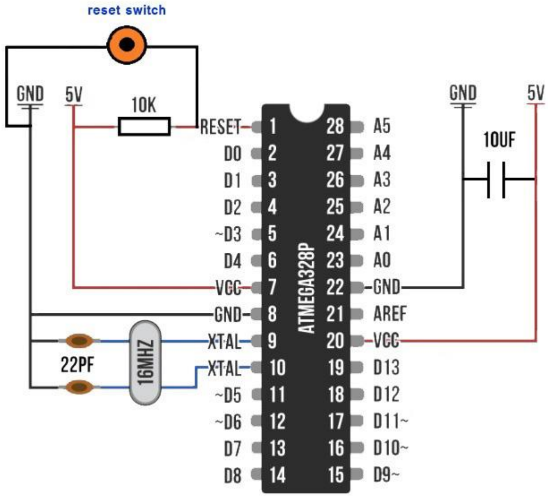

Figure 7. Mounting schematic and chip legend for ATmega 328P-PU

For powering the chip as well as the sensors and the display, a 5V continuous voltage is needed so that the initial 9V supply voltage will be limited by a LM7805 regulator that has an output voltage of 5V with a maximum current of 1A. It can be replaced by the L78L05 which has a smaller size, but it has a much smaller current than 0.1A. The schematic also contains a 1N4004 diode and two electrolytic capacitors of 100uF and 10uF, respectively.

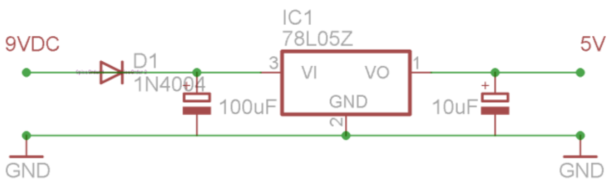

Figure 8. 9V to 5V C.C. voltage regulator schematic

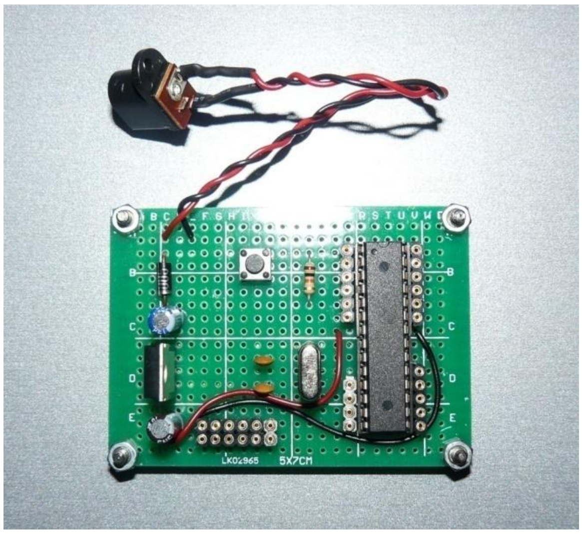

Figure 9. Base plate (CPU) after planting

The diagram below details the connections between the sensors and the microcontroller. After this configuration, both the operating tests and the programming of the microcontroller were performed.

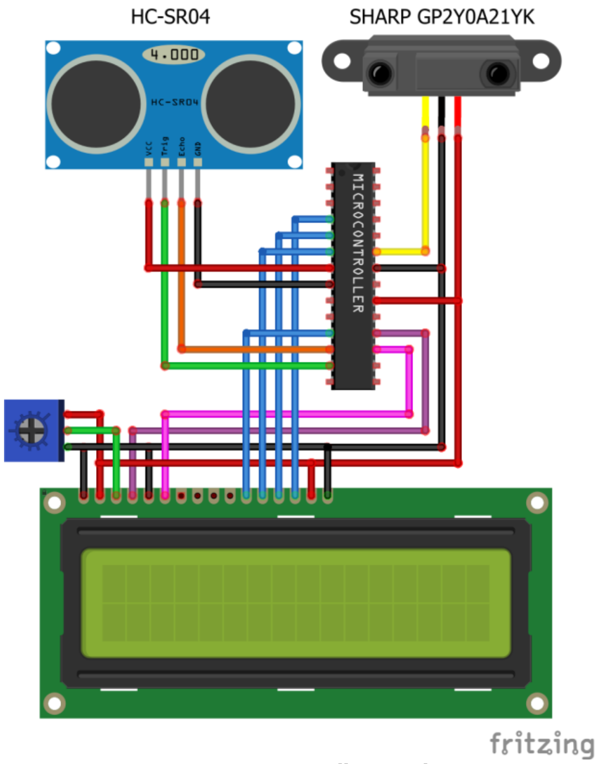

Figure 10. Equipment installation and testing

A 16-character 2-line LCD display with a 10K variable resistor for adjusting the contrast was also used to display the results.

	0,0	1,0	2,0	3,0	4,0	5,0	6,0	7,0	8,0	9,0	10,0	11,0	12,0	13,0	14,0	15,0
0	U	S	:		X	X	X	X		m	m					
1	I	R	:		X	X	X	X		m	m					
	0,1	1,1	2,1	3,1	4,1	5,1	6,1	7,1	8,1	9,1	10,1	11,1	12,1	13,1	14,1	15,1

Figure 11. LCD matrix [column, line]

The code was written in C language and implemented in the chip using an Arduino Uno development board as a "Arduino as ISP" (in-system programmer) transfer medium.

At start-up, the display shows for 2 seconds "Distance measurement system" introductory message followed by "STM 2017" for another 2 seconds. The measurement display begins immediately after that. For added accuracy, the system calculates for each sensor the average of 100 measurements each executed at 10ms intervals. The final result is then displayed in milimetres without decimals.

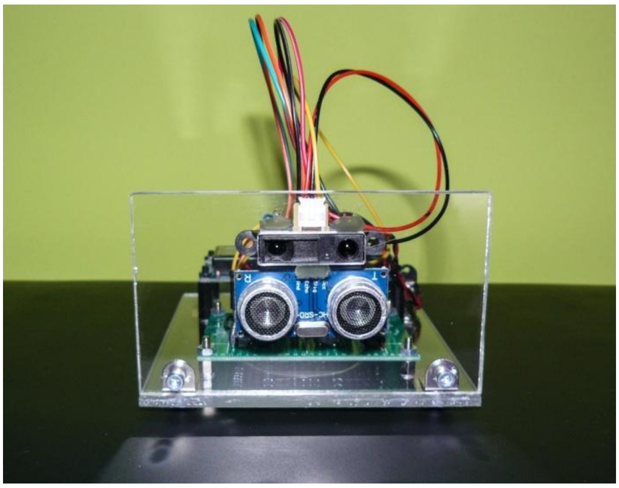

Figure 12. Measured system assembled and prepared for experiment

IV. EXPERIMENTAL RESULTS

For the comparative measurements, 6 plane obstacles were used, each representing a different type of material: sponge, cardboard, wood, plastic, metal and glass, materials with different textures, densities, colors and degrees of reflection. Because the action rays differ, experimental limits range from 200mm to 650mm in 10 steps of 50mm to accommodate both sensors. The experiment was performed simultaneously with both sensors under artificial light conditions at a temperature of 25 ° C and a 60% air humidity. Actual sensor-obstacle distances may include a margin of ± 2mm due to the difficulty of calibrating the transmitter point for each sensor.

Figure 13. Sensor action rays and experimental limits

In the following, the results obtained for each material will be described comparatively.

The sponge used, 50 mm thick, is a low density porous material and phono-absorbing properties. It is not the ideal obstacle for the ultrasonic sensor as it returns values far beyond the actual distance, apparently without any correlation between them.

The infrared sensor begins by detecting the sponge with a good accuracy of 3-10mm, but it will decrease to the end of the range.

TABLE I. The results obtained for the sponge

Distanta reala [mm]	200	250	300	350	400	450	500	550	600	650
Valoarea masurata ULTRASONIC	9791	3065	2364	2355	2353	2367	2367	2365	2370	2367
Valoarea masurata INFRAROSU	211	253	304	341	377	439	468	518	557	602
Eroarea absoluta ULTRASONIC	9591	2815	2064	2005	1953	1917	1867	1815	1770	1717
Eroarea absoluta INFRAROSU	11	3	4	-9	-23	-11	-32	-32	-43	-48

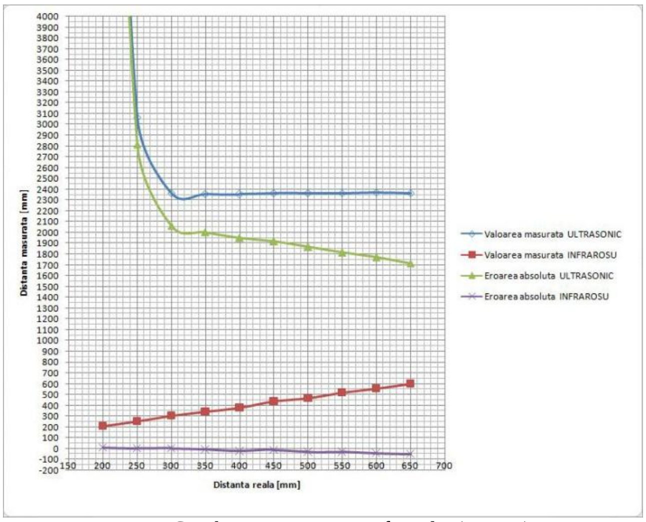

Figure 14. Graphic representation of results (sponge)

Packaging cardboard with a thickness of 3 mm is also a material with a relatively low absorption reflexivity. In the first half of the interval, both sensors have an accuracy of between 0 and 7mm, and in the second half their errors increase significantly.

TABLE II. The results obtained for the cardboard

Distanta reala [mm]	200	250	300	350	400	450	500	550	600	650
Valoarea masurata ULTRASONIC	200	254	307	366	800	910	1001	568	612	1295
Valoarea masurata INFRAROSU	204	252	298	340	377	420	467	500	537	558
Eroarea absoluta ULTRASONIC	0	4	7	16	400	460	501	18	12	645
Eroarea absoluta INFRAROSU	4	2	-2	-10	-23	-30	-33	-50	-63	-92

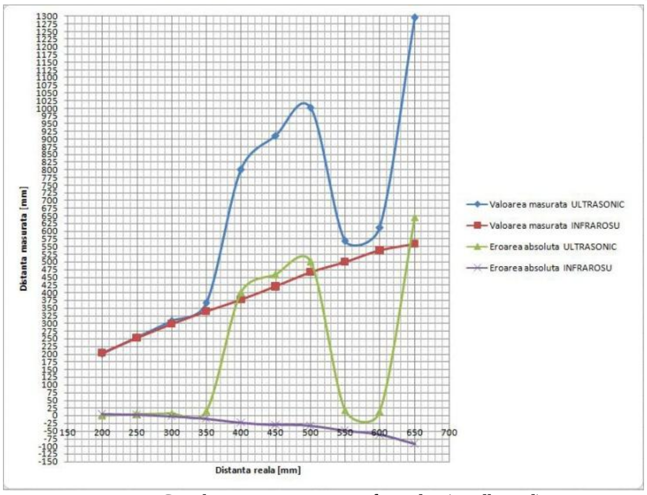

Figure 15. Graphic representation of results (cardboard)

In the case of wood, a 18 mm thick pine piece was used. The ultrasonic sensor reads the distance with a very good accuracy with an average error of 1.2mm, while the infrared sensor returns erroneous values after 400mm.

TABLE III. Results obtained for wood

Distanta reala [mm]	200	250	300	350	400	450	500	550	600	650
Valoarea masurata ULTRASONIC	200	252	301	350	400	450	499	550	597	645
Valoarea masurata INFRAROSU	207	252	303	341	390	425	467	516	537	580
Eroarea absoluta ULTRASONIC	0	2	1	0	0	0	-1	0	-3	-5
Eroarea absoluta INFRAROSU	7	2	3	-9	-10	-25	-33	-34	-63	-70

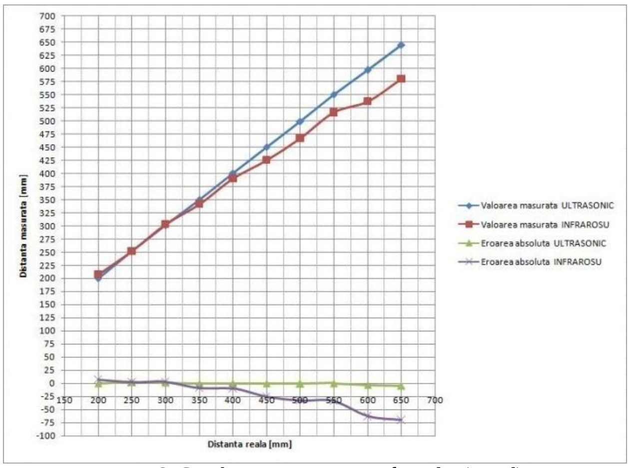

Figure 16. Graphic representation of results (wood)

As a plastic material, a 4mm black matt PVC piece was used. As with wood, a very good precision for the ultrasonic sensor with an absolute maximum error of 6mm. The ultrasonic sensor also has good accuracy up to the end of the chosen range.

TABLE IV. Results obtained for plastic

Distanta reala [mm]	200	250	300	350	400	450	500	550	600	650
Valoarea masurata ULTRASONIC	202	256	301	351	400	455	500	545	595	650
Valoarea masurata INFRAROSU	214	268	310	349	376	437	467	517	580	558
Eroarea absoluta ULTRASONIC	2	6	1	1	0	5	0	-5	-5	0
Eroarea absoluta INFRAROSU	14	18	10	-1	-24	-13	-33	-33	-20	-92

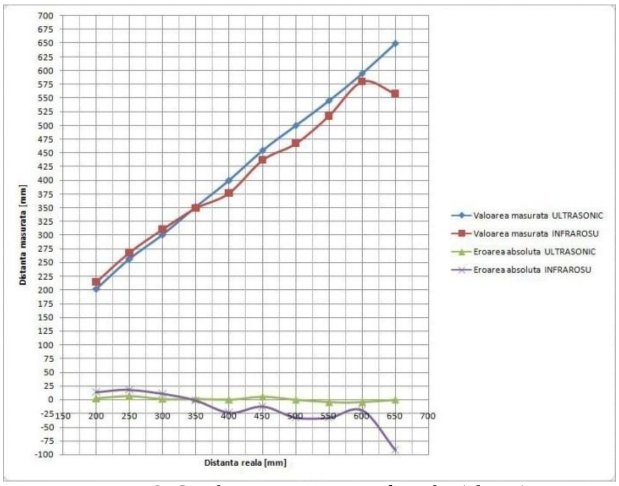

Figure 18. Graphic representation of results (plastic)

The metal used is a 3mm polished aluminum plate with increased reflexivity. The sonar accuracy is again very good, while the infrared sensor detects an increase in error after 300mm.

TABLE V. Results obtained for metal

Distanta reala [mm]	200	250	300	350	400	450	500	550	600	650
Valoarea masurata ULTRASONIC	205	253	300	350	398	449	495	547	594	645
Valoarea masurata INFRAROSU	217	262	297	318	333	367	390	425	466	426
Eroarea absoluta ULTRASONIC	5	3	0	0	-2	-1	-5	-3	-6	-5
Eroarea absoluta INFRAROSU	17	12	-3	-32	-67	-83	-110	-125	-134	-224

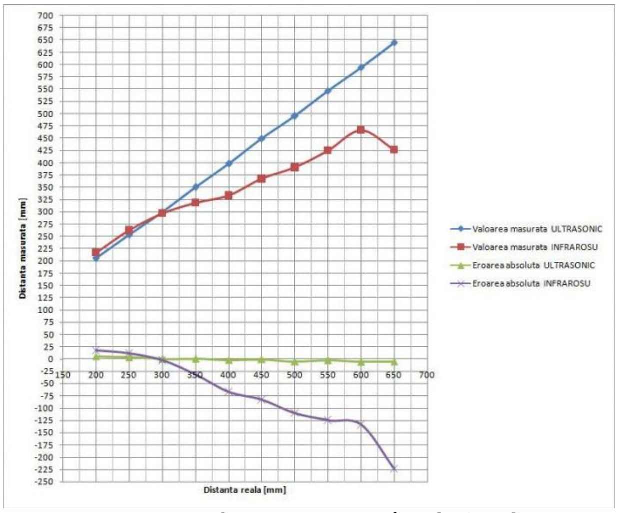

Figure 17. Graphic representation of results (metal)

The 4mm thick glass is also a barrier to the sonar. Due to its transparent nature, it can be seen that the infrared sensor can not correctly estimate the distance across the entire measuring range.

TABLE VI. Results obtained for glass

Distanta reala [mm]	200	250	300	350	400	450	500	550	600	650
Valoarea masurata ULTRASONIC	201	255	301	350	400	450	495	548	597	645
Valoarea masurata INFRAROSU	248	291	324	318	325	376	412	468	500	452
Eroarea absoluta ULTRASONIC	1	5	1	0	0	0	-5	-2	-3	-5
Eroarea absoluta INFRAROSU	48	41	24	-32	-75	-74	-88	-82	-100	-198

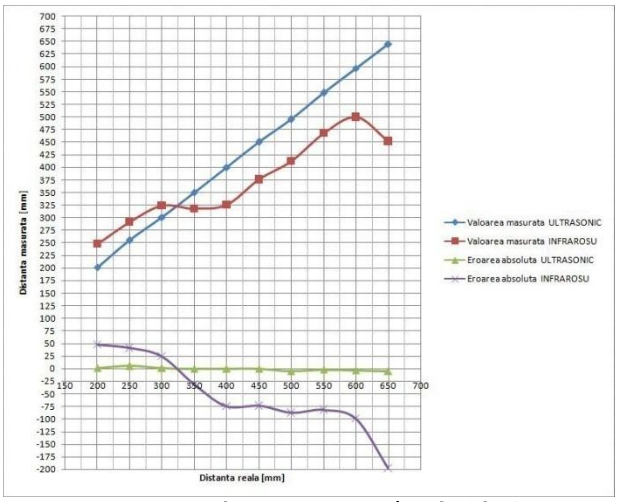

Figure 19. Graphic representation of results (glass)

V. Conclusions

The objective of this experiment was to perform a comparative analysis of ultrasonic and infrared sensors against different types of obstacles.

Therefore, for the particular case of this project, it appears that the ultrasonic sensor offers a more accurate representation of obstacle distances such as wood, plastic metal and glass while the infrared sensor is a suitable choice for obstructions such as sponges and porous surfaces where the sound is in mostly absorbed.

Although the optical sensor has a faster response time, dependence on the degree of reflection of surfaces and a nonlinear feature, it requires prior knowledge of the material properties while the sonar can be more useful in low light conditions and for transparent objects. Two sensors can be used in addition to detecting the type of obstacles and better appreciating the distances. Any improvements to the measurement system may include:

- A more efficient recalibration of the infrared sensor, with changes in the distance calculation equation;
- Mounting sensors on a mobile device and automatically acquiring data while moving it;
- Expanding the measuring range by replacing the infrared sensor with one having a larger range;
- Making measurements for objects of various materials, geometric shapes, colors and temperatures;
- Spectral analysis of temperature variation of the ultrasonic sensor using a thermistor;
- Inclusion of a laser sensor in the system of measurement and comparative analysis;
- Calculating the frequency response;
- Calculating the reflection coefficient of the analyzed materials and the stability of the system;

Acknowledgements

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