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Mobile robot turned on by sound and directionally controlled by an external light source

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Article Info	ABSTRACT
	This paper presents theoretical, numerical, and experimental tests of a mobile robot, which starts on the emission of a strong sound, like an applause, and the direction and speed of the vehicle is controlled by an external pulsed light source (PWM signal). The simulation is performed in MATLAB-Simulink; electrical circuits and the experiment are shown in detail. The results show that the vehicle speed can be controlled with a PWM signal from an external light falling on the LDR sensors. Besides, the circuit was designed to consume less than 1 ampere with the four motors moving at full speed, which can easily be powered by lithium battery.

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1. INTRODUCTION

Due to the constant advancement of technology and the extensive development of automated control systems, numerous methods have been developed to control devices through external physical quantities [1]. Industrial robots are now commonly used in production systems to improve productivity, quality, and safety in manufacturing processes. Recent developments involve using robots cooperatively with production line operators [2]. The interest in cooperative systems arises when certain tasks are either too complex to be performed by a single robot or when there are distinct benefits that arise from the cooperation of many simple robots [3]. Robots have been used in explorations, underwater navigation, mining, and military settings for a variety of tasks. Depending on the application, mobile robots may require several conditions to be satisfied about their design and specifications [4]. The introduction of improved techniques allows for the introduction of more complex tasks [5] including wheeled mobile robot navigation, which have attracted the attention of researchers developing control motion automated systems and solving issues such as the acquisition and processing of sensor data [6].

In terms of motion control, one major problem is how a robot can pass well and robust trajectory in different environments; but under the situation in which existing environmental information such as map and GPS cannot be used, it is necessary getting the vehicle robot to work based on the available data [7]. When a wheeled mobile robot is navigating in an unknown environment, it relies on sensors to recognize the outside world and then estimate the state of the robot itself to achieve the task of autonomous navigation. Commonly used sensors include ultrasound, a laser range finder (LRF), vision sensor, and light sensors among others [8].

A vehicle turned on by sound and directed by a light source can be described as a merging of mechanics and electronics technologies. The transformation variables allow the vehicle to turn detected light or sound signals into electric pulses, generating motion [9, 10]. The technology for recognizing the location or direction of a sound source by using a microphone is well developed. To realize the location of a sound source, at least two sensors or microphones are required [11, 12].

The paper is organized as follows. Section 2 describes the proposed system. Section 3 shows the description of the mathematical model of the system. Section 4 presents the numerical results. Section 5 describes the experimental results and Section 6 concludes.

2. PROPOSED SYSTEM

The system consists of an omnidirectional microphone, two photoresistors, four DC motors, a lithium battery (V_{CC}), and electrical and electronic circuits to form a circuit of two stages as shown in Figure 1.
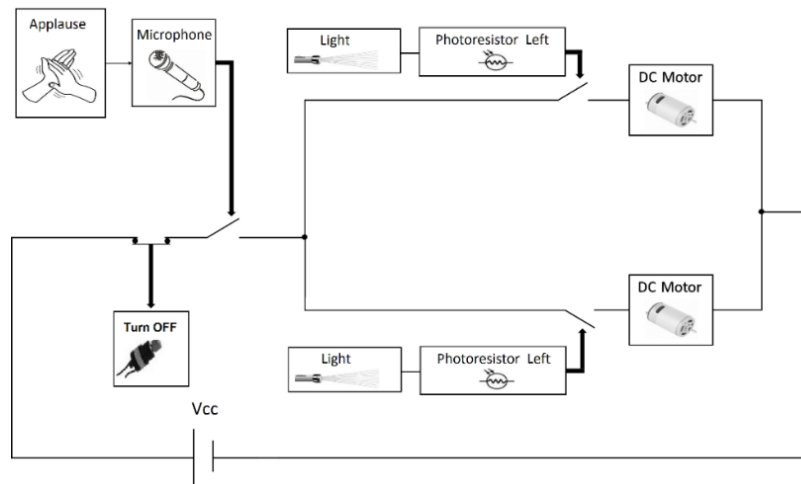

Figure 1. Proposed system

The first stage includes a circuit for polarizing the microphone, which amplifies the signal to a voltage that excites the thyristor and drives current through the same signal continuously as shown in Figure 2. The second stage, which only works if the thyristor is excited, comprises two circuits that turn the vehicle's motors on or off through two photoresistors; that is, when the photoresistor has captured the light signal it turns the motor on. Each photoresistor controls both wheels on one side of the vehicle; therefore, if only one of the photoresistors is excited, then the vehicle will turn toward the light source. The microphone captures the external signal, amplifying it through the polarizer inverter circuit (because the transistor Q_1 inverts the signal voltage V_1) and this amplified signal drives the thyristor SCR U_1 that enables the vehicle to be turned on.
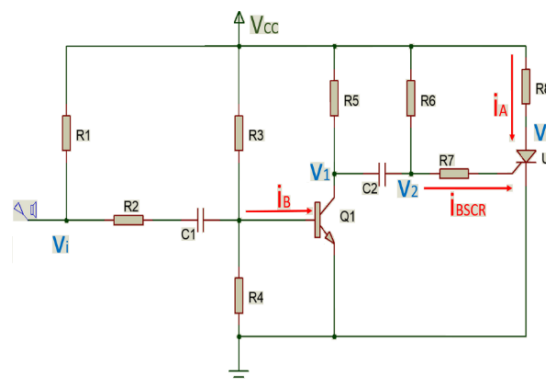

Figure 2. First stage: polarizer microphone circuit and vehicle on/off controller

3. MATHEMATICAL MODEL

Equation (1) is obtained from Figure 2, where V_i is a column vector $\begin{bmatrix} 1 & 0 \end{bmatrix}^T$ in the binary space, where the logic level "1" denotes a voltage greater than zero and less than V_{CC}, and logic level "0" denotes a voltage around zero [13]. Thus, i_B is also a column vector whose values indicate the base current values of the transistor Q_1 in the saturation or cutting region, respectively, with the order of the components of i_B:

$$i_B = \begin{bmatrix} \frac{V_{CC}}{R_3} - 0.7\left(\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}\right) \\ \frac{V_{CC}}{R_3} - 0.7\left(\frac{1}{R_3} + \frac{1}{R_4}\right) \end{bmatrix} + \begin{bmatrix} \frac{1}{R_2} & 0 \\ 0 & 0 \end{bmatrix} V_i. \tag{1}$$

To obtain (1), it is necessary to analyze the system's behavior in the following situations:
(1) No current through the capacitor C_1, and
(2) High signal frequency as shown in Figure 6.

The above conditions are satisfied because the sound captured by the microphone (applause) to turn the mobile robot on, is a high-frequency signal; therefore, although this sound is not generated, the base current i_B is too small. Equation (2) shows the possible values for the amplified and inverted voltage of the microphone signal in the cut and saturation regions, which depends directly on h_{FE}, which is the current gain in the collector relative to the base current i_B:

$$V_1 = V_{CC} - h_{FE} R_5 i_B. \tag{2}$$

By making a similar analysis for capacitor C_2, it follows that

$$V_2 = V_1. \tag{3}$$

Thereby the current in the gate of the thyristor $SCR \ U_1$ can be calculated as shown in (4), where the difference $V_{CC} - V_1$ inverts the signal, again due to the pull-up resistor R_6:

$$i_{BSCR} = \frac{V_{CC} - V_1}{R_6}. \tag{4}$$

The current through the anode of the thyristor $SCR \ U_1$ can be calculated using (5) obtained from the two-transistor model, where I_{CBO1} and I_{CBO2} are leakage currents of the model's transistors, and α_1 and α_2 are the collector's current gains relative to the emitter's current of each:

$$i_A = \frac{\alpha_2 i_{BSCR} + I_{CB01} + I_{CB02}}{1 - (\alpha_1 + \alpha_2)}. \tag{5}$$

However, for practical purposes, these leakage currents are considered negligible, leaving the anode current of the thyristor as the product of a gain equivalent to "α" with the gate's flow of the thyristor i_{BSCR} as shown in (6):

$$i_A = \alpha i_{BSCR}. \tag{6}$$

Thereby, the anode's voltage V_O (7) of the thyristor U_1, which turns the vehicle off or on is finally obtained:

$$V_O = V_{CC} - R_8 \alpha i_{BSCR}. \tag{7}$$

Figure 3 shows the second stage of the system, which corresponds to the on/off controller of the vehicle's motors. This circuit is controlled by the circuit of the first stage as shown in Figure 2, which only work when there is a difference of appreciable potential between V_{CC} and V_O, which occurs only after the microphone has captured a loud sound.
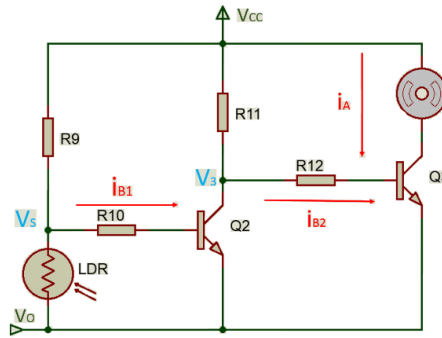
Figure 3. Second stage of the system related to the on/off controller of the vehicle's motors

Equations (8)–(11) are easily obtained from Figure 2 in order to calculate the current through the motor at the time of having excited the photoresistor with an external light source:

$$i_{B1} = \frac{V_S - V_O - 0.7}{R_{10}}. \tag{8}$$

$$V_1 = V_{CC} - h_{FE}R_{11}i_{B1}, \tag{9}$$

$$i_{B2} = \frac{V_3 - V_O - 0.7}{R_{12}}, \tag{10}$$

$$i_M = h_{FE}i_{B2}. \tag{11}$$

The motor speed is directly dependent on the current of the supply system.

4.   SIMULATION

The overall system can be summarized in a truth table as shown in Table 1. The circuit is only turned on after sensing a sound of high intensity (applause) and the movement of motors is controlled by the sensed light intensity. The signals sensed by the electret microphone, which are amplified by a polarizer circuit transmitting an inverted signal with higher voltage, were simulated using a MATLAB-Simulink interface as shown in Figure 4. The outcome of the simulation is shown in Figure 5, where the highest peaks are each sound amplification with high external current (applause) sensed by the Simulink's microphone and where the amplitude reaches about $4\ V$, enough to excite the thyristor and turn the system on.

Table 1. Truth table of the system

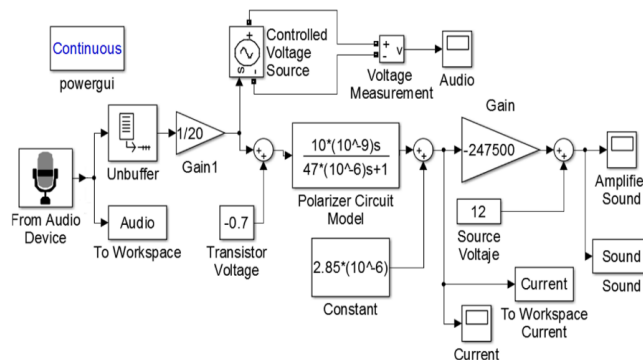| Applause	Light	System	Motor
0	X	0	0
1	0	1	0
1	1	1	1

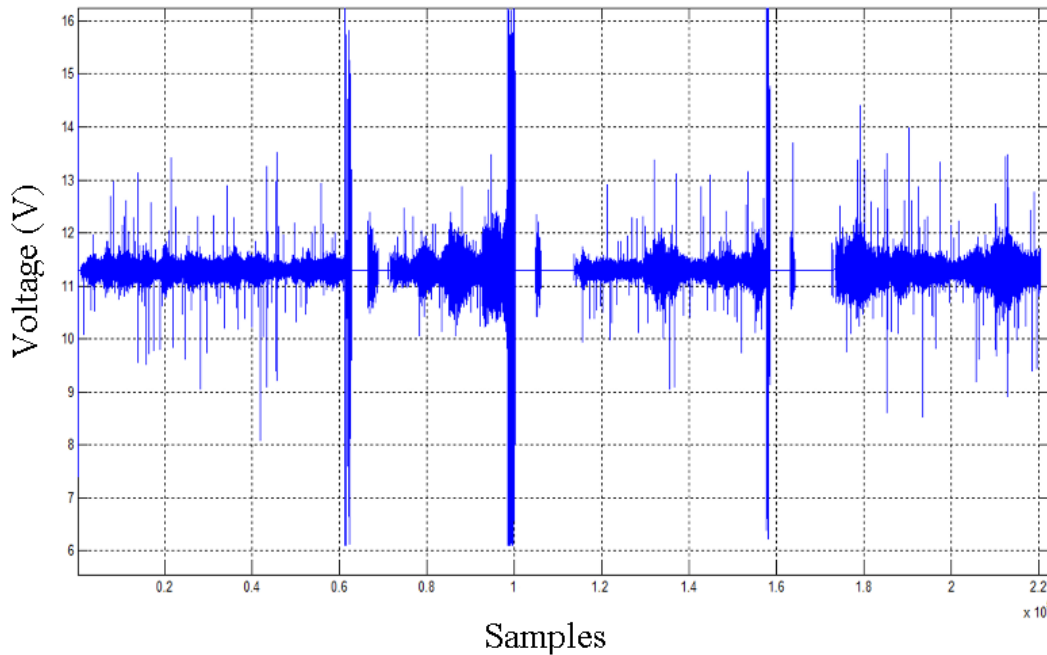Figure 4. Simulation in MATLAB-simulink

Figure 5. Amplified and inverted simulated signal

5.   EXPERIMENTAL RESULTS
All results were obtained using the values of resistors and capacitors as shown in Table 2.

Table 2. Parameters for simulation and experiment

Symbol	Name	Value
V_{CC}	Supply voltage	12 V
R_1	Microphone's resistor pull-up	3.3 $k\Omega$
R_2	Microphone's polarization base resistor	4.7 $k\Omega$
R_3	High impedance polarization resistor to V_{CC}	2 $M\Omega$
R_4	High impedance polarization resistor to ground	250 $k\Omega$
R_5	Transistor collector resistor Q_1	3.3 $k\Omega$
R_6	Pull-up resistor amplified signal	5.1 $k\Omega$
R_7	Thyristor base resistor U_1	100 Ω
R_8	Thyristor base resistor U_1	200 Ω
R_9	Pull-up resistor, photoresistor	100 $k\Omega$
R_{10}	Transistor base resistor Q_2	1 $k\Omega$
R_{11}	Transistor collector resistor Q_2	1 $k\Omega$
C_1	Capacitor microphone polarization	10 nF
C_2	Polarization capacitor, amplified signal	100 nF

5.1. First stage: circuit to turn the vehicle on and off
The circuit of Figure 3 amplifies and inverts the signal sensed by the microphone, being more sensitive to sounds of higher intensity as shown in Figure 6 and the amplification reaches 3 V. The highest peaks correspond to each sound's amplification (applause) generated externally: the very short period indicates high-frequency signals.

Figure 7 illustrates the behavior of the thyristor when the system is off (there has been no detection of sound), when it is turned on (it has detected a sound), and when the anode's voltage is abruptly grounded. In such a case, the anode's voltage when the system is off is 10.6 V, so the current flowing through the anode is too small, allowing the system to remain off and preventing the LDR (photoresistor) from turning on the motor. Moreover, when the system is on (has detected sound), the voltage is 3.8 V, allowing an appreciable current flow through the thyristor's anode and feeding the motor circuit controlled by the LDR. Finally, when the anode voltage of the thyristor is connected to ground, the current flow is stopped and the system returns to its initial state of 10.6 V, that is, the system is off.
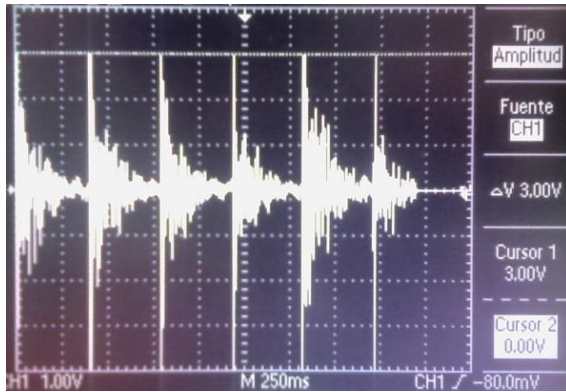
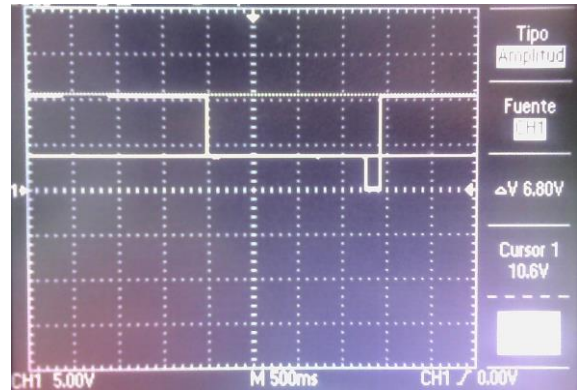Figure 6. Amplified and inverted signal by the polarizer circuit for the microphone

Figure 7. Anode voltage of the thyristor when there has been no sound (is off) and when the system is on

5.2. Second stage: controller to turn the motor circuit on and off

The motor voltages when the LDR detects light (or not) are reported in Table 3. Table 4 lists the voltages of the photoresistor when the light signal is detected (or not). This stage of instrumentation is very sensitive to changes in light intensity as shown in the Table 4; i.e., an LDR of only 0.11 V is needed to turn the motor on.

Table 3. Motor voltages

Light	Voltage
ON	5.32 V
OFF	0 V

Table 4. LDR voltage

Light	Voltage
ON	0.11 V
OFF	0.7 V

5.3. Vehicle

The photographs in Figures 8 and 9 depict the vehicle with the implemented circuits, where the electret microphone is projecting toward the top and the LDRs are forward, allowing the vehicle to always move toward the light source.
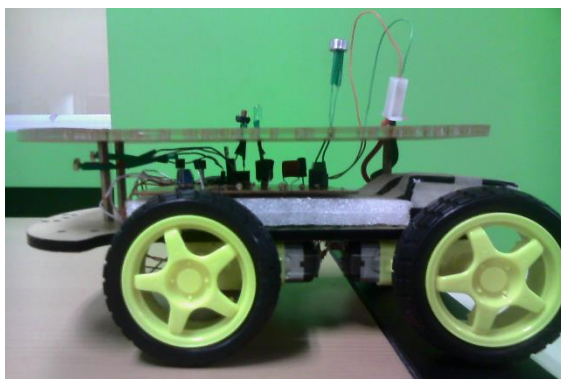

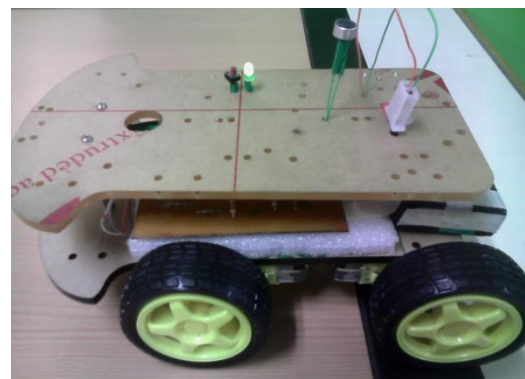
Figure 8. Vehicle with the implemented circuits

Figure 9. Vehicle ON

6. CONCLUSIONS

This article presented theoretical, numerical, and experimental tests of a mobile robot, which starts on the emission of a strong sound, like an applause, and the direction and speed of the vehicle is controlled by an external pulsed light source. The simulation was performed using the software MATLAB-Simulink and the circuit was implemented to compare the results. The system implemented two types of sensors to control the basic functions of a vehicle: (1) ignition and movement of the motors and (2) sensitivity to high-intensity signals, such as a loud noise or light from a common light bulb. Sensitivity can be adjusted simply

by varying the values of the pull-up resistors of each sensor. The circuit consumes less than 1 A of current with the four motors moving at full speed; thus, this is a low-power system that can easily be powered by lithium battery. Vehicle speed can be controlled with a PWM signal from an external light falling on the LDR sensors (pulsed light), which is a future goal.

REFERENCES

[1] S. Nurmaini and B. Tutuko, "Intelligent Robotics Navigation System: Problems, Methods, and Algorithm," *International Journal of Electrical and Computer Engineering (IJECE)*, vol/issue: 7(6), pp. 3711-3726, 2017.
[2] A. A. Jaber and R. Bicker, "Wireless Fault Detection System for an Industrial Robot Based on Statistical Control Chart," *International Journal of Electrical and Computer Engineering (IJECE)*, vol/issue: 7(6), pp. 3421-3435, 2017.
[3] M. R. M. Sapiee and K. A. M. Annuar, "Synchronous Mobile Robots Formation Control," *TELKOMNIKA Telecommunication Computing Electronics and Control*, vol/issue: 16(3), pp. 1183-1192, 2018.
[4] H. Ahmad, *et al.*, "A Solution to Partial Observability in Extended Kalman Filter Mobile Robot Navigation," *TELKOMNIKA Telecommunication Computing Electronics and Control*, vol/issue: 16(1), pp. 134-141, 2018.
[5] G. M. Z. G. Morales, "Análisis de Circuitos Electricos en DC," Van Nostrand Reinhold Company, 2005.
[6] J. H. Han, *et al.*, "Sound signal following control of a mobile robot with the estimation of the sound source location by a microphone array," 2005.
[7] Hwang, *et al.*, "Sound direction estimation using artificial ear," *International Conference on control, Automation and Systems*, pp 1900-1910, 2007.
[8] M. C. Jesús, *et al.*, "Diseño y construcción de un robot seguidor de línea controlado por el pic16f84a," *8° Congreso Nacional de Mecatrónica*, pp. 816-821, 2009.
[9] Y. W. Jung, *et al.*, "Adaptative microphone array system with self-delay estimator," *Korea information and communications society*, vol/issue: 30(1C), pp. 54-60, 2005.
[10] D. K. Kim, *et al.*, "An accidental position detection alforithm for high pressure equipment using microphone array," *The Korean institute of electrical engineers*, pp. 2300-2307, 2008.
[11] D. Nagahara, *et al.*, "A method of trajectory generation to vehicle robot under unknowm environment," World Automation Congress, TSI Press, 2010.
[12] Y. T. Wang, *et al.*, "Calibrated kinect sensors for robot simultaneous localization and mapping," 2014.
[13] A. Wibowo, *et al.*, "Parallel cascade fuzzy interference system at the environment changes, case study: Automated guide vehicle robot using ultrasonic sensor," *The International Conference on Advanced Computer Science and Information System*, 2012.

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