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Designing the Distance Measurement System for a Mobile Robot

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***Abstract*—The paper presents the electronic design of the sensor control circuit for existing mobile platform with articulated robot. Sensor control unit, compatible to the existing electronic layout, is developed to create the necessary conditions for the autonomy of the mobile platform relating to its mobility. With the sensor equipped platform, inter alia, the problem of self-localization can be tackled and solved. In particular the sensor type and the electronic circuits are exemplified which are used in the application. Additional, the sensor principles, the electronic subsequent treatment procedure of the sensor signals, their provision for the connected bus system as well as the special programming requirements are explained. Concluding, the experimental results and the experiences which are won with the present test construction are highlighted.**

Key words: I2C, Mobile robots, distance measurement

I. INTRODUCTION

The mobile platform used in this application which is including the articulated robot IR50 p with 5 with rotary joints mounted on the platform, has dimensions 900mm length x 600mm width x 700mm height. The height of the platform includes the joint height of the robot, thickness of the mounting plate and the sprawled articulated robot. As energy source two 12 V auto batteries, in each case, with capacity of 96Ah, are used. To generate different required voltages, DC/DC voltage converters are integrated in the mobile platform. The movement control and the signal processing of the platform and of the articulated robot are realized by usage of sensors and actors, centrally managed by commercial personal computer. As actuators are used two brushless motors, which are both mounted in the front wheels of the mobile platform. Rotation of the platform and the forward and backward movement are realized with the precise adjustment of the motion speed. Motion speed is directly proportional to the direct current voltage used as an input signal for the electronic drive unit. The platform outline with the main components is presented in the following figure:

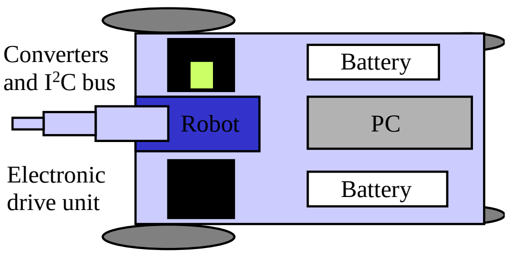

Fig. 1. Lay-out of the mobile platform with articulated robot

The engine control of both motors is mounted in the front side of the mounting plate of the robot. The control of the direct current voltage used as an input signal for the electronic drive unit is realized over an I²C bus system [1]. Multifunction-robot arm is placed also in the front of the mobile platform, so that the centre of the mass is optimally calculated. The mobile platform has already a module for the capture of temperature and humidity. These are measured in order to determine the temperature thresholds of the components and to determine, for instance the appearance of the incoming reign, for the case that the robot is moving outside.

Fig. 2. Prototype of the mobile platform with articulated robot without ultrasonic measurement lay out

The existing electronic system is to be extended with the ultrasonic sensors in order to realise the hardware layout as a prerequisite for the design of the autonomous mobile platform. Subsequently, such system can be used for the realisation of the self-localisation problem or for solving of robot learning problems as described in [2, 3]. Measurement principle is simple, consisting of an ultrasonic transmitter and an ultrasonic receiver. The transmitter sends out an ultrasonic impulse which is reflected by the objects in the environment. The reflected signal is received by the receiver. On account of the, time the reflected signal needs to reach the receiver, conclusions about the distance to the object which has caused the reflection, can be drawn.

II. ULTRASONIC MEASUREMENT LAY OUT

To equip the mobile platform with the possibility to shape a relatively clear “picture” of its environment in front and in the back, it was consequential to equip it, in the front and in the back, with ultrasonic sensors in each case. The ultrasonic sensors on the robot platform should be mounted as follows:

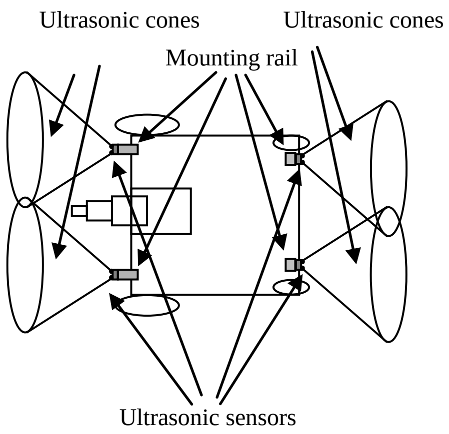

Fig. 3. Design of the ultrasonic measurement system

Both ultrasonic sensors in the front should be fixed with mounting rails to bring the ultrasonic cones further forwards, so that no influencing of the robot arm originates. Both back sensors are mounted only with short mounting rails on the mounting plate. The ultrasonic module used in the application is so called SRF04 [5]. This ultrasonic module is a combination of the ultrasonic transmitter; ultrasonic receivers and a small evaluation electronic module are completely mounted on a board. The decision, to use this sensor was made on account of the compact construction of the module, fitting technical data and because of the favourable price. The ultrasonic module SRF04 allows the measurement of the distance up to the first sound-reflective object. Besides, the distance is made available as an equivalent impulse length on the output of the module and can be determined with a suitable microcontroller or electronic layout. The object to be measured must be at a distance of 3 cms to 3 ms of the module. Besides, the distance is given always to the first object (the shortest distance), repeated echoes (further objects) are not taken into consideration. The module is presented in the following picture:

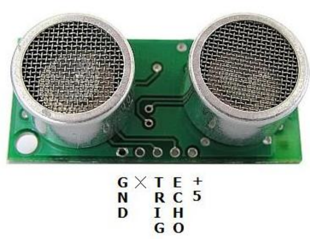

Fig. 4. Ultrasonic sensor module

In order to begin a measurement, a TTL impulse with the duration of min. 10µs is connected to the trigger input of the ultrasonic module (Fig.5). The module is clocked by the sequence control unit (PIC) with 200µs (8 cycles, 40 kHz) signal. The so called echo output of the module is then set on High logic level. The first incoming echo switches the echo output again to Low logic level, so that impulse originates which is directly proportional to the distance of the object. The trigger impulse should last no longer than 200µs; however, it must be set anyway, before the end of the echo impulse, on Low logic level again. The distance can be mathematically determined as a product of sonic velocity (343.8 ms/s) and the length of the echo impulse [4]. Because the distance is covered by the sonic signal twice, the result is to be divided by factor 2:

$$s[m] = 343{,}8\,m/s \bullet t_i / 2 \qquad (1)$$

Following figure presents the impulse timing diagram:

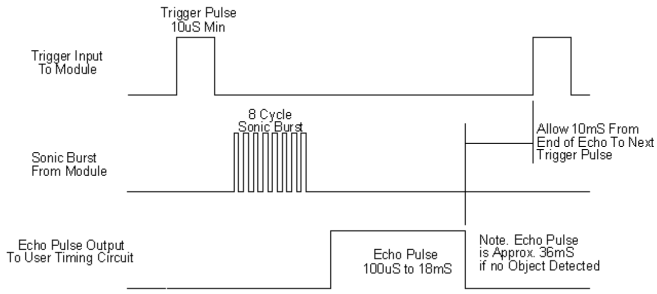

Fig. 5. Ultrasonic sensor module impulse timing diagram [5]

For the reason that the voltage converter for the ultrasonic transmitter during the echo signal receiving is switched off, it must still be waited after the end of the echo pulse at least 10ms up to the next trigger impulse, in order that the operating points stabilize again. Then, the next measurement procedure can be started.

III. EVALUATION OF THE SIGNALS OF THE ULTRASONIC SENSOR AND THE REQUIREMENTS FOR THE ELECTRONIC CIRCUIT

The echo signal lasts depending on distance of the object, between 18ms and 100ms. Some controllers are too slowly to measure the length of the source impulse directly. Through the electronic circuit, the digital impulse must be transformed in the equivalent voltage. The mobile platform has available I²C bus controller which is evaluated over the main computer. Currently the electronic drive unit and the mentioned module for the analysis of the temperature and humidity are already coupled to this bus. The aspiration was to couple the ultrasonic sensors likewise to this bus system to guarantee a consistent and standardized software evaluation of the signals by using of the main computer, as well as the compatibility of all signal processing components. The I²C bus has been developed to allow a simple communication between different devices in the entertainment electronics, like television sets, CD player etc. It is bidirectional, 2-wire bus which allows serial, synchronous data transfer, in 8-bit blocks, with transfer rate up to 100kBit / s in the standard mode and 3.4 MBit / s in the High speed mode, by using of the cable lengths up to several meters [6]. Besides, a great number of the identical or different I²C integral circuits can be connected to the I²C bus because every integral circuits have available an own, adjustable address. In the standard mode the I²C bus works in the Master-Slave procedure [7]. Besides, the communication of the I²C components is steered over a master component.

IV. Connection of the Ultrasonic Sensor to the Existing I²C Bus Circuit and Description of the Circuit Principle

For the connection of the ultrasonic sensor to the I²C bus an analog to digital (A/D) converter is used. It is able to convert the voltage value generated by the electronic lay out of the ultrasonic module and which can be measured over the capacity C2 (measurement point between resistance R2 and capacity C2), into a digital value (8 bits) and to carry out a connection to the I²C bus. As a suitable, A/D converter PCF8591 [8] of the Phillips company, is used.

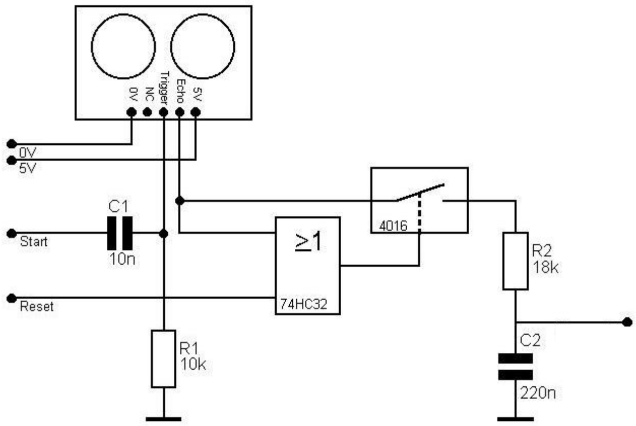

Fig. 6. Circuit principle

The measurement with the ultrasonic sensor begins with an impulse on the trigger input of the sensor module. This is shortened by using the RC element (R1/C1) which should guarantee that the trigger impulse don't last too long. As long as the echo output of the ultrasonic sensor is set on High logic level, the capacitor C2 becomes charged over the resistance R2. Now using the voltage value on which the capacity was charged, the length of the source impulse and therefore the distance to the obstacle can be determined. To prevent that the capacity C2 discharges again before the voltage was measured, a bilateral switch (IC 4016) is used which remains only opened, as long as the source impulse of the ultrasonic module is available and allows with it, the charging of the capacitor. To set the circuit, before the next measurement, into the origin state again, the capacitor C2 must be uncharged. In order to realise it, a logical High level impulse is generated at the Reset input of the circuit for at least 20ms. Due to it, the bilateral switch gets open. Through this action the capacitor C2 can discharge. To allow the opening of the bilateral switch for the charging and discharging procedure, OR gate is used, at whose inputs echo source impulse and the Reset impulse are connected.

V. Derivation of a Formula for the Identification of the Mutual Dependence Between the Voltage Value and Distance

The derived formula serves to calculate the measured voltage on capacity C2, so that one can identify the distance based on voltage. The later evaluation procedure is carried out by using of software algorithm.

$$U_{C2} = \left(1 - e^{\frac{t}{-R_2 * C_2}}\right) * 5V \qquad (2)$$

$$for\ \frac{t}{2} = \frac{s}{v_{Sonar}} \Rightarrow t = \frac{2*s}{v_{Sonar}}$$

$$U_{C2} = \left(1 - e^{\frac{2*s}{-R_2 * C_2 * Vsonar}}\right) * 5V$$

$$it..follows:$$

$$\frac{U_{C2}}{5V} = 1 - e^{\frac{2*s}{-R_2 * C_2 * Vsonar}}$$

$$e^{\frac{2*s}{-R_2 * C_2 * V_{Sonar}}} = 1 - \frac{U_{C2}}{5V}$$

$$\frac{2*s}{-R_2 * C_2 * v_{Sonar}} = \ln\left(1 - \frac{U_{C2}}{5V}\right)$$

$$2*s = \ln\left(1 - \frac{U_{C2}}{5V}\right) * (-v_{Sonar}) * R_2 * C_2$$

$$s = \ln\left(1 - \frac{U_{C2}}{5V}\right) * \left(\frac{-v_{Sonar}}{2}\right) * R_2 * C_2 \qquad (3)$$

The formula for U_{C2} which is referring to voltage of the capacity is the formula for the identification of the capacitor C2 charging voltage. The time t, is the time which passes during the go-and-return way of the ultrasonic signal. Therefore, the time t was taken into consideration only for the midway, means t was divided with factor 2.

VI. Graphic Representation of the Connection Between Pulse Length, Capacity Voltage and Distance

An example curve for a sonic velocity of 343.8 ms/s, R2=18kOhm, C2=220nF:

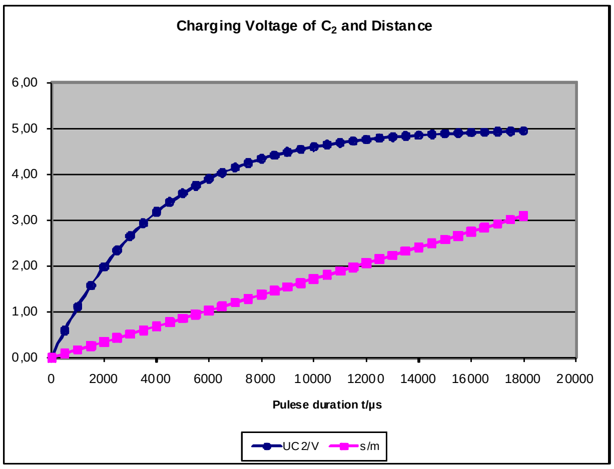

Fig. 7. Pulse duration, Charging Voltage and Distance Interrelation

The blue curve (circles) shows the interrelationship between the pulse duration of the ultrasonic signal and the voltage in the capacity. The magenta colored curve (rectangles) shows, by using formula (2) for calculation of Uc_2, the interrelationship between the pulse duration of the ultrasonic signal and the distance.

VII. Control of the Sensors by Using of a Counter

As already explained, the control of the modules, the Trigger and the Reset signal are required. Unfortunately, only one output pin is available with the PCF8591, what requires integration of the additional logic circuit in the whole concept. With the new logic circuit, the possibility for the disconnection of the output of the PCF8591 must be developed. The main idea is to integrate the counter, which increments with every output signal of the PCF8591. Now, with the help of the signals of the counter, the output signals of the PCF8591 can be used by using of the suitable gate circuits at different positions of the electronic layout. It becomes apparent, that the counter with the first output impulse of the PCF8591 increments (counts up) the first time and that the least significant bit (LSB) of the counter output is set on the High logic level. The LSB of the counter in conjunction with the output signal of the PCF8591 produce together with one AND gate the Trigger signal for the sensors. Now, after the produced Trigger signal, the measurement procedure of the sensors is started. The second output impulse of the PCF8591 increments the counter again, so that the second bit of the counter is set on the High logic level. The output signal of the PCF8591 together with the second bit of the counter resets the sensors for the next measurement by using of the AND gate. A measuring cycle is closed with it. To reset the counter again, the third impulse is sent over the PCF8591. This impulse sets the LSB and the second bit of the counter on the High logic level. The LSB and the second bit of the counter are in conjunction over AND gate and they reset the counter itself.

TABLE I. SIGNAL STATES

		QB	QA
Initial state	Waiting on Trigger signal	0	0
1. Counting	Trigger	0	1
2. Counting	Reset	1	0
3. Counting	Counter reset	1	1

Fig. 8. Signal overview and the true table

Remark: only both least significant bits of the counter are used. The used counter is steered through falling edges.

VIII. Complete Electronic Layout of the Sensors Including the Connection to the I²C Bus

Electronic layout:

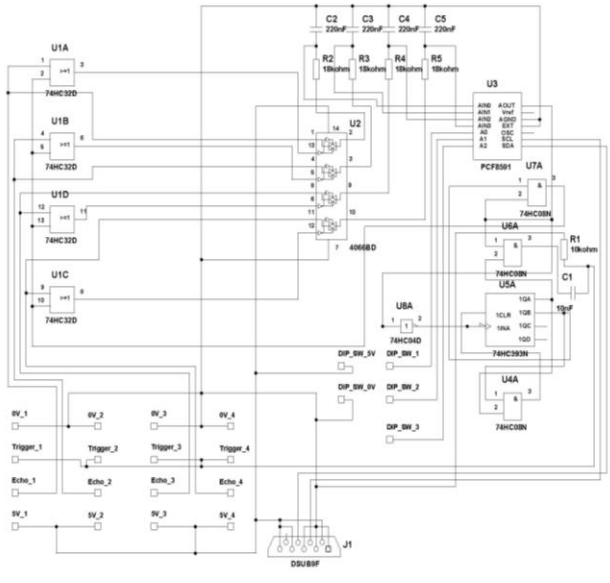

Fig. 9. Complete electronic layout

The inverter (U8A) on the input of the counter (U5A) is used to invert the pulses on the AOUT (U3), because the counter is activated by falling edges. In addition is to be noted, that the PCF8591 is, according to hardware layout, encoded over the inputs A0 … A1. These are fixed, in contrast to the layout, to the address 011 and not variable over the dual in-line package (DIP)-switch. The measuring points, at which the voltage is to be evaluated, are connected in each case on the input of the PCF8591 (U3). These can be individually sampled over the I²C bus. Over the I²C bus, a High logic level is generated on the output AOUT of the PCF8591. With the rising edge on the output of the 1QA of the U5A, the High logic level is also generated. This High logic signal is connected together with the signal on the AOUT of the PCF8591 by using of AND gate (U6A) and it steers the Trigger input of the ultrasonic module. The whole signal duration for the Trigger input should last 10 µs and is determined by the software. After it, the signal on the AOUT is set for approx. 100ms on Low logic level. This time is enough to memorize and to read all logic level on the AIN0 … AIN3, however, the time length can be changed if required, because the time is to be determined only experimentally in dependence to how long reading and memorizing of the signals lasts and how long the logical level on the AIN0 … AIN3 is stable. In the third step the RESET of the ultrasonic sensors must be realized. This step is realized by generating of the High logic level on the AOUT. The output 1QB of the U5A is therefore set on High logic level and it connected by using of the AND gate (U7A) with the High logic level on the AOUT. On the output of the U7A a RESET signal is consequently generated. The High logic level on the output of the U7A must last for 20ms in order to discharge the capacitors. Afterwards the AOUT is switched again to Low logic level. Additional the counter must reset itself. For this purpose a short impulse is generated on the AOUT of the PCF8591. By using of the AND gate (U4A), which is connected with 1QA and 1QB outputs (U5A), the RESET impulse is generated and switched on the RESET input (1CLR) of the counter. Now a new measurement and the whole cycle can be started again. The impulse and time diagram additionally illustrates the operating mode.

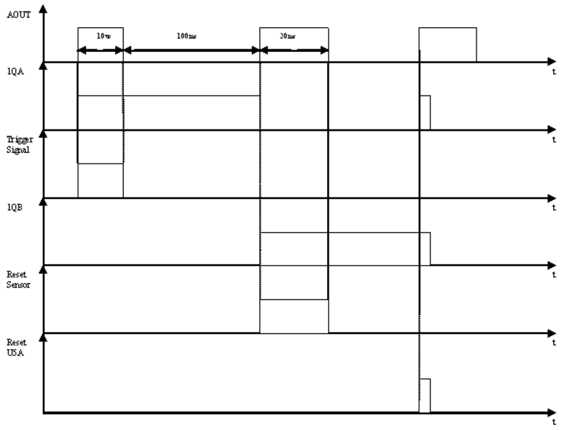

Fig. 10. Impulse and time diagram

IX. SPECIAL PROGRAMMING REQUIREMENTS

They are, from the current point of view, important programming requirements they must be fulfilled in order to enable a successful functionality of the electronic circuit. First, the PCF8591 must be taken up in the Master-Slave hierarchy of the existing I²C bus. In addition its address (011), must be announced to the master module. Necessary 3 impulses for Trigger of the sensors, a RESET of the sensors and a RESET of the counter, must be generated by the software. First a 10µs signal must be generated on the AOUT of the PCF8591 for the Triggering of the sensors. After the Triggering, 4 analogous inputs of the PCF8591 must be sampled. These inputs are AIN0… AIN3. The PCF8591 generates from the measured voltage value an equivalent 8 bits digital string. This string corresponds to the distance of a respective object in front of the sensor. The task of the software is to assign the digital value which is suitable to the distance and it must be calibrated, perhaps, experimentally. Besides, it is helpful to use the mentioned connections between pulse length, capacity voltage and distance. After 4 inputs were sampled, the RESET signal can be sent to the sensors. In addition a 20ms signal must be given on AOUT of the PCF8591. Finally the counter must be reset. Another short signal on the AOUT of the PCF8591 can be used for it.

X. CONCLUSION

To explain and to analyze learning and localization principles of the mobile robots, these must be designed with the appropriate hardware and software layout. In this paper presented sensor control unit represents, in consideration of its extensive properties and compared to similar systems, a low-cost and high-performance solution. The use of I^2C based ultrasonic sensor control device fits in the existing communication structure consisting of the mobile platform with mounted articulated robot. The system presented allows any research centre to design and use a simple sensor environment, which may be administered in an easy-to-use basis. Future work will address the development of the software solution for the system and the development of the appropriate robot's learning algorithm.

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