Design and Development of a Wireless Emergency Start and Stop System for Robots

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Abstract: This paper develops a wireless communication system that connects robots with many remote control devices used by many different users. The most important issue of this system is safety. To get high safety level a quick and efficient communication system is required. The emergency system and its communication system must work in parallel and independently of the main control of the robot. The robot must react to an emergency signal, but as a previous step, it must make sure that the security system is enabled and it so must also have some knowledge of how many remote control devices are related and if any of them has lost the wireless connection. Besides all the research and design stage to develop the communication system, the system has been implemented and tested. To build it, a microcontroller Arduino Fio and a radio frequency module Xbee has been used. Finally, the system has been tested in order to characterize the communication system, settling, connection time and the battery life.

1 INTRODUCTION

The Robotics world not only helps industry in manufacturing processes but it also helps people in their everyday life tasks or chores, for example a vacuum robot or Maggie Robot (Gonzalez *et al.,* 2011), used as an experimental platform for this work.

Although, these robots might look like harmless and little hazardous, it must not be forgotten that they are still machines. Some control must be taken over these machines and also these machines, at any given time must be halted or stopped (Morisawa, *et al.*, 2005). The reason for this is not only because they can cause people physical damage, but also for the robots own sake, just in case the robot loses control and it can fall, crash or impact with another object.

For this reason, in order for the robot to start moving and to perform its scheduled tasks, it will be necessary that someone has control over the robot, especially in the training period. This way, a person will be the one to turn the robot on and off wirelessly.

To make Maggie work a two relay system must be turned on. These two relays will be enabled separately, each one independently. Therefore, the robot will only move or perform its tasks when both relays will be switched on.

The system also has a third relay which will stop the robot when there is an emergency stop. The activation of the emergency stop can be activated in two different ways. The first one of them is that the base, where the robot motors and batteries are placed, will approach an object then this object will be captured by proximity sensors enabling the emergency stop. The second reason why the robot could stop is that the user presses the emergency push button of its remote control. This last system works with an infrared transmitter, similar to the remote control used for opening doors. These remote control devices are not always 100% reliable, even on many occasions it is necessary to point towards the goal in order for the transmitted signal to be sent correctly.

In this work the design and implementation of a wireless activation and emergency stop system is accomplished. This system works in a wireless transmission medium that can control several robots, using small microcontrollers and XBEE RF (Radio Frequency) modules that will solve any connectivity problem and that will make the robot control system safer. For the emergency system design the following specifications have been brought up:

- Mobile Robotics needs a 100% reliable

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emergency stop system.

- It must satisfy the manageability and usability requirements for an autonomous vehicle in terms of, the non-dependence of wires and its size in order to integrate them in the robot.
- It must have a fast response.
- It must be a two-way communication system that will allow having feedback information on the real receipt of the emergency signal by means of the robot.
- It must consider the possibility of having different emergency emitters on a same robot and even on different robots.
- As a result of these specifications, an emergency system is presented that allows:
- Wireless emergency stop pushbutton switch with two-way communication, endowing the robot with more intelligence, integrating both at hardware and software level with the robot's current architecture.
- A flexible system that allows several emergency stop pushbutton switches and when used they can be set up for each robot.
- Add while the robot is performing a task, new emergency stop pushbutton switch and new robots to the safety system.

The proposed system is based on the Xbee, communication technology (Micea *et al.*, 2012). This system has been chosen over the traditional RF technologies with conventional remote control devices since it fulfils the proposed specifications. This two-way communication and multipoint technology minimizes the effects of loss of signal. It can distinguish among different situations in which the robot does not receive the signal or the emergency system is out of batteries and other common mobile robotics situations. XBee, in addition, provides a two way protocol layer which considerably makes easer its implementation, allowing multi-point broadcast communication (Laudon and Laudon, 2012).

2 SYSTEM DESCRIPTION

2.1 General Overview

The proposed system consists of a network of emergency stop pushbutton switches and robots interacting among themselves. The emergency stop pushbutton switches will be integrated in the robot working in parallel with other emergency systems and with the robot's own control system, although in an independent way. Figure 1 shows the implemented emergency management system diagram. Each emergency stop pushbutton switch can be connected to any robot, but not at the same time. This is indicated by the dotted line.

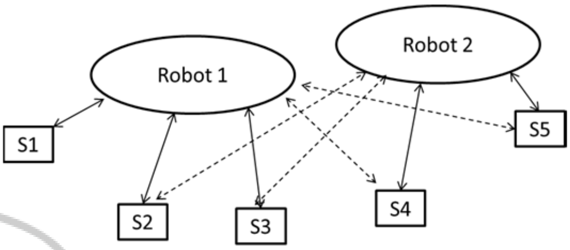


Figure 1: Proposed emergency system.

2.3 System Parts

The full system, Figure 2, consists of two modules: the emergency stop pushbutton switch and the on board robot module, that is, the hosted module.

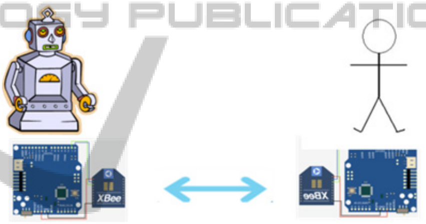


Figure 2: Architecture general scheme.

2.3.1 Emergency Stop Pushbutton Switch

The emergency stop pushbutton switch is the way by which the user can control the robot. The user can turn it on or off when needed and always in the safest possible way, since this operation can be performed wirelessly.

The system functions will be among others of automatic response when a robot sends the connection signal or the emergency stop pushbutton switch refresh and the reading of the pushbuttons position and signal sending to the system hosted in the robot in order for the robot to change its state.

2.3.2 Device Hosted in the Robot

The device hosted in the robot forms the central node of our communication system. This node will act as coordinator, that is, it will get the packages sent by all the system pushbutton switches and this node will tell the following command or task the system will perform.

Its main functions are the receipt of packages, package analysis and action on the robot to operate it or stop it, depending on the chosen pushbuttons on the emergency pushbutton switch.

3 EMERGENCY PUSHBUTTON SWITCH

The emergency pushbutton switch is the system component by which the user interacts to create the emergency signal on the robot. Therefore, it is the element that links both the user and the robot. Its design and communications system has been implemented having this fact in mind.

3.1 Hardware Implementation

For the hardware design and implementation both the required communication restrictions and limitations of size have been considered. All the hardware components must be located inside a remote control device, that must fulfill the ergonomic conditions allowing the way of holding it and handling by the user. In Figure 3 a components outline included in the hardware system is shown.

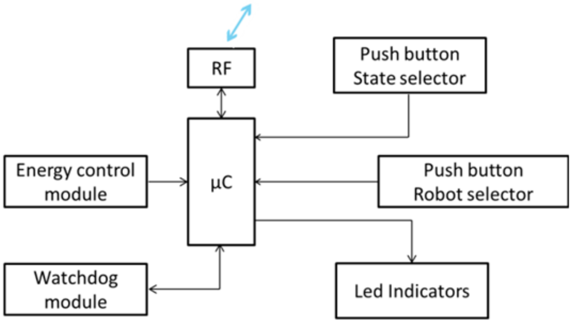


Figure 3: Emergency pushbutton switch electrical schematic.

This device is based on an Arduino Fio microcontroller (Arduino, 2013) with an Xbee radio frequency module, as well as the robot. But, for this implementation it can choose to which robot to be connected, joining one or another network. The microcontroller inputs and outputs are connected to pushbuttons allowing operating with the emergency stop pushbutton switch (three buttons to command the emergency status) and two LEDs that show the robot connection status.

3.2 Software Implementation

Figure 4 shows the emergency stop pushbutton switch software management diagram with the main resources used by the microcontroller. The system manages the use of analog and digital inputs and outputs that enables the LEDs and it also uses the Arduino FIO EEPROM memory to write and read two important parameters for the system; one is the PAN ID to which it will be connected and the other parameter is the pushbutton switch address. This last parameter is used to calculate the delay time of each pushbutton switch, due to each pushbutton swith has a unique address.

The rest of the resources used by this system are relative to the Xbee RF module configuration, to the communication with the robot and to a serial port added for its configuration and testing.

The overall pushbutton switch operation consists of waiting and listening until a message reaches the robot. Once the package is received, the pushbutton switch will answer the robot. The response package will be different according to the buttons pressed in the pushbutton switch.

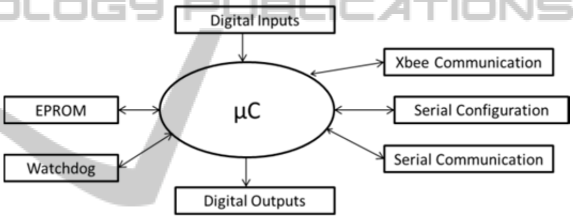


Figure 4: Software resources used for the system hosted in the pushbutton switch.

In Figure 5 the main pushbutton switch control flow chart is shown. When the program is run the first thing that has to be carried out is the microcontroller and the Xbee module configuration (Foste, 2011). To accomplish this task the data transmission frequency will be specified, 57600 baud in this case, and also the robot to be controlled will be chosen.

Additionally, in the setup the delay time this pushbutton switch must have is calculated. Every pushbutton switch has a different address and the system will own up to 10 pushbutton switches and directions will go from 2 to 9 and from A to B with a representation in the hexadecimal system.

Once the system is configured, all the variables involved in the main loop will be initialized. Next, the reading an package management is carried out. The received package is saved in a variable that stores the pushbutton switch state, there are three possibilities:

- State 0: There are two possibilities, one that no robot has been yet detected, being in the search state, so the green LED will slowly blink, or the second possibility the refresh has not been yet accomplished to tell which pushbutton switches are connected, in this case the LED will quickly blink.

- State 1: It means that a robot has been detected, telling that it can connect to it. The green LED will quickly blink. It is worth mentioning, if this state is received it means that the robot is not even moving.
- State 2: This states means that the robot in addition to being connected is in motion, so besides having the green LED blinking quickly, the blue LED will be now turned on.

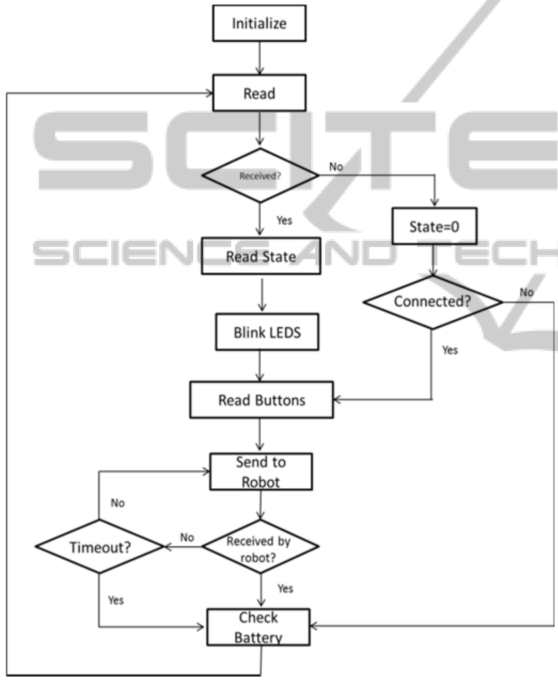


Figure 5: Main pushbutton switch control flow chart.

The next step is to read the pressed buttons from the pushbutton switch and based on them, send an answer or another. It is at this moment when the delay time will be introduced, in which each pushbutton switch will have different delays. For this reason, we will ensure that the communication between the pushbutton switch and the robot is correct. Finally, the pushbutton switch state will be sent as a reply to the connection or as a refresh to the robot's message.

3.3 Push Button Switch Design and Construction

Last, the design and construction of the housing for the emergency stop pushbutton switch is done. It has been taken into account during this stage that it will protect the microcontroller and the internal circuits before any impact as well as its handling and gripping by the end user.

The pushbutton switch has been made from ABS plastic which is light, hard, strong and low cost. The technique used in this work to create the pushbutton switch housing is a 3D printer (Bassoli *et al,* 2007) (Figure 6).

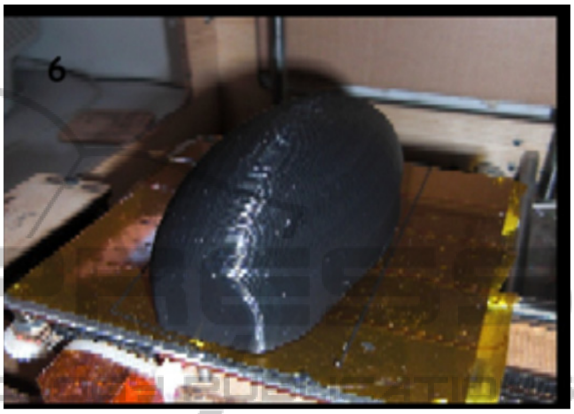


Figure 6: Emergency stop pushbutton switch final aspect.

4 SYSTEM HOSTED IN THE ROBOT

The device placed in the robot forms the communication system central node, so it will be its own coordinator. It will see all the packages sent by all the pushbutton switches in the system and it will tell the following command or task the system will perform.

Its main functions are the receipt of packages, package analysis and action on the robot to operate it or stop it, depending on the chosen pushbuttons on the emergency pushbutton switch.

4.1 Hardware Implementation

The most important components in order for the communication to be correctly established and that each pushbutton switch will communicate with the desired robot are: the Xbee RF module along with the microcontroller that coordinates these communications and that performs the operation that modifies the robots' state.

Each robot will create a different network, which will be defined with a network ID different from a robot to another (PAN ID). Robots will have a unique address and pushbutton switches must change the PAN ID according to the robot to which they are connected. To make these adjustments in the system hosted in the robot the Xbee RF modules will need to configure using the X-CTU program.

On the other hand, this system should change the robots state depending on the type of message received, either by putting it into operation or by stopping it. To do so, it will be necessary to act on the relays that feed the robots' motors. There are three relays, one for the emergency stop and the other two for the robot activation. Two activation relays are used as a security matter, since a single button could accidentally be pressed. For this reason until both relays are not pressed at the same time the robot will not start working.

To turn on these relays it will require that it is done through a transistor, which will act as a switch, since the current provided by the microcontroller output pins is not enough for the relays to be set (Moham *et al.,* 2003)(Barrado and Lázaro, 2001)(Torres, 1994).

Figure 7 shows the scheme of the robot´s activation and stop of the robot module.The Arduino FIO microcontroller is represented in the middle of the image. The LED indicators are connected to the digital outputs of the Arduino to visualize that the system placed in the robot has received a package that would modify the robot's state. The robots' activation and stop relays are connected to the Arduino. The EPROM module is used to store the push button switch IDs. Xbee is used as RF module.

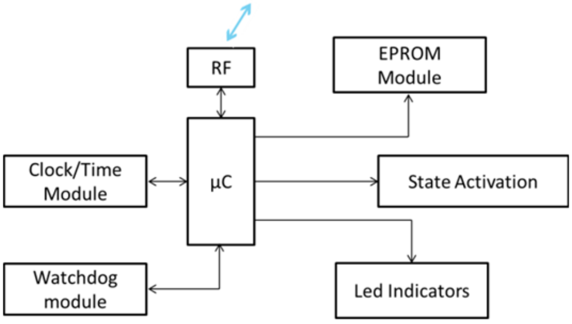


Figure 7: Robot´s system electrical schematic.

4.2 Software Implementation

Figure 8 shows a diagram of the resources used in this system. In the centre stands the microcontroller that will act on certain digital outputs. At the same time it will also have connection with the XBee module using the serial connector, for its initial configuration, and a new SoftSerial module in order to visualize communications behaviours, since the serial connection included in the microcontroller is in charge of the the XBbee RF module.

Figure 9 shows the flow chart of the main management program of the system placed in the robot. The first step is to adjust the configuration of the inputs and outputs and of the XBEE RF module parameters.

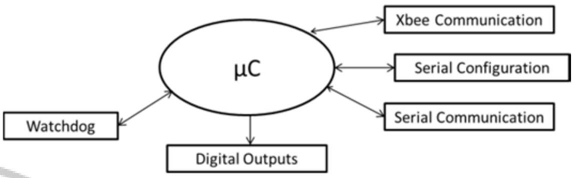


Figure 8: Software resources used for system placed in the robot.

Then, a broadcast is sent (to all the pushbutton switches), in order to connect to the robot.

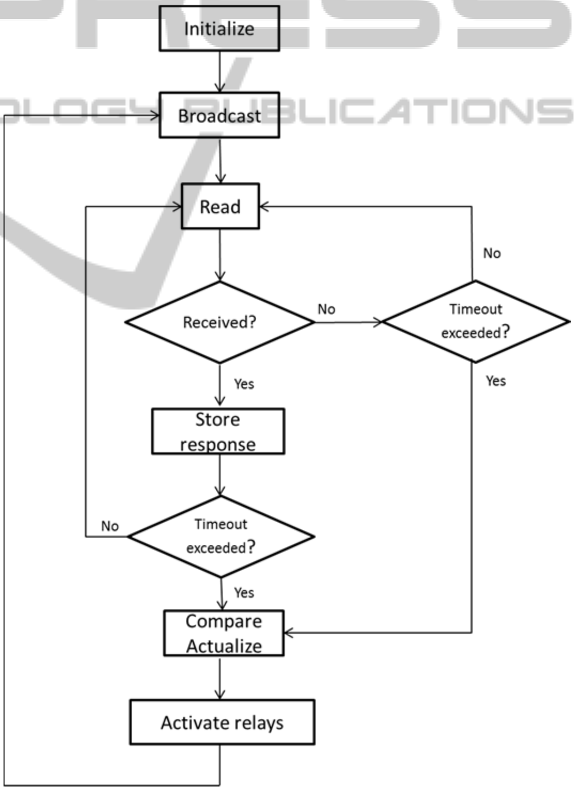


Figure 9: General flow chart of the system placed in the robot.

Once the broadcast is sent, the robot will wait for the pushbutton switches answer. So the next step is to read from the Xbee all the answers from each pushbutton switch. Once the Xbee reading is carried out, it now checks if it is the first time the system is running to initialize the connections.

If it is not the first time the program is run, then the number of connections that were in the previous loop with the current one must be compared, considering that new pushbutton switches could have been connected. If connections are lost, the robot will stop.

4.3 Design and Implementation of the System Hosted in the Robot

Figure 10 shows the final system placed in the robot. The microcontroller is mounted on a board, which incorporates all the hardware components required for the emergency stops management, the communication modules and the robots' power supply connection.

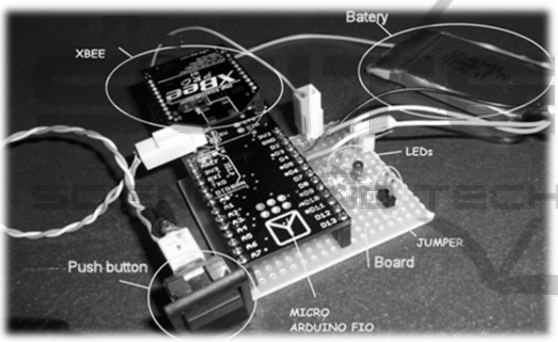


Figure 10: Emergency module placed in the robot.

5 EXPERIMENTAL TEST

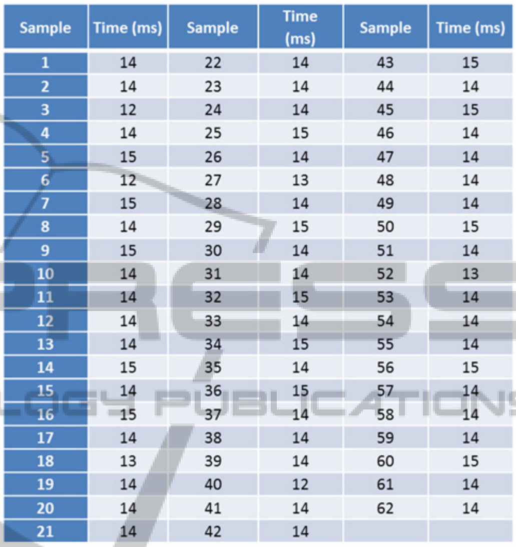
For the system validation several tests have been carried out. These tests evaluate the connection times and the battery life, which are the main factors to determine the usability of the proposed system.

5.1 Establishing Time Two Way Communication

This test measures the elapsed time since the emitter sends a package until the receiver receives the message and it send the confirmation message when the package has correctly been received. This is very important since it is the basis to estimate the time that it takes for a pushbutton switch to connect, as well as to allow to set the delay time so that another pushbutton switch tries to connect. Also, it reports the time that would take for a pushbutton switch to send a signal to the robot to stop it. This signal should arrive in the shortest time possible since it is the most critical and important signal that the pushbutton switch can send to the robot. The total elapsed time between the activation of an emergency button and the robot's response should depend on the number of remote connected switches and must take into account the results for the worst times.

Table I shows the time results of the 62 samples obtained, ranged from 12 to 15 milliseconds

Table 1: One package receipt time.



Sample	Time (ms)	Sample	Time (ms)	Sample	Time (ms)
1	14	22	14	43	15
2	14	23	14	44	14
3	12	24	14	45	15
4	14	25	15	46	14
5	15	26	14	47	14
6	12	27	13	48	14
7	15	28	14	49	14
8	14	29	15	50	15
9	15	30	14	51	14
10	14	31	14	52	13
11	14	32	15	53	14
12	14	33	14	54	14
13	14	34	15	55	14
14	15	35	14	56	15
15	14	36	15	57	14
16	15	37	14	58	14
17	14	38	14	59	14
18	13	39	14	60	15
19	14	40	12	61	14
20	14	41	14	62	14
21	14	42	14		

Performing a subsequent statistical analysis, along with Figure 11 plot, the average data obtained is 14,079 milliseconds.

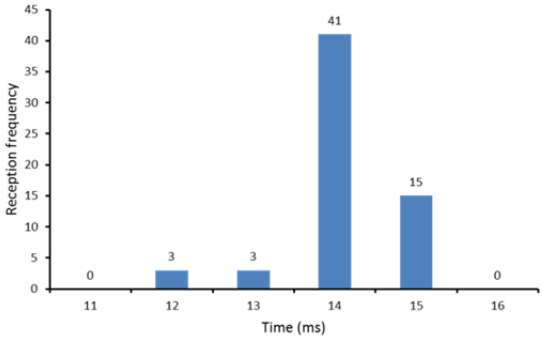


Figure 11: Bar chart of the mesaures obtained in the package receipt time test.

In addition, other statisticians have been used as the medium, and the result obtained is 14 milliseconds and the mode that is also 14 milliseconds. With all this data it can be concluded and estimated that the time needed to send a package and to get the confirmation message that the package has been received, is 14 milliseconds.

5.2 Battery Characterization with Pushbutton Switch Standard Use

This test will be performed with the use of a power supply source with voltage regulation. The Arduino Fio will use this power supply source. The voltage will be decreased little by little until the microcontroller stops working.

Samples are taken every 5 mV up to the 3.7 volts and from the 3.7 V samples will be taken every 2 mV to have more data from the battery voltage and thus characterize the system. Figure 12 shows the results obtained.

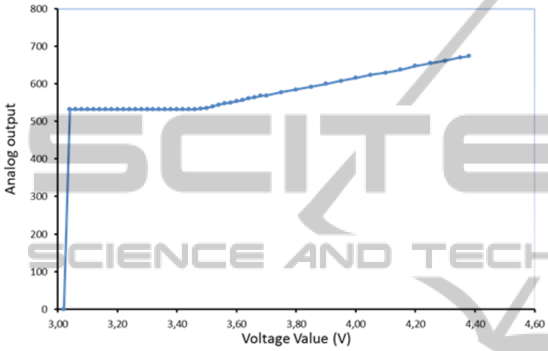


Figure 12: Power supply voltage from source vs voltage value obtained.

In the experiment the microcontroller does not read voltage values from 3.02 V since it does not have enough voltage to operate and a shutdown occurs. In the range between 3.02 V and 3.7 V, which is the voltage range where the pushbutton switch will operate, the turning point of the microcontroller voltage reading occurs, so from this voltage value on it could not be tell apart whether the battery voltage continues decreasing. For this reason, at a voltage value of 3.48 V the low battery warning point will be placed.

Finally, Figure 13, a test will be performed to estimate the battery life under standard operating conditions.

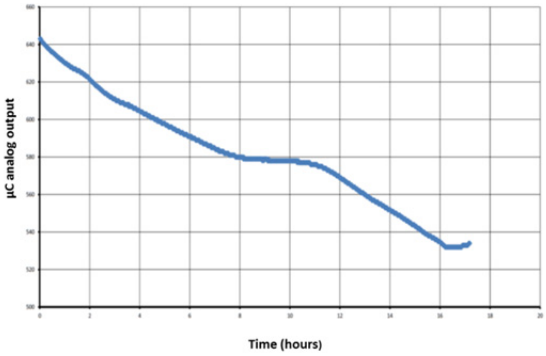


Figure 13: Battery dicharge curve (standard operating conditions).

In this test operations were carried out with the pushbutton switch together with the robots' system. The system works as it would usually do, that is, the robot would send the broadcast for pushbutton switch detection and the pushbutton switch answers back.

Going over the data obtained, the battery life when the system works under standard operation conditions is of 17 hours and 11 minutes.

6 CONCLUSIONS

This works presents a multipoint and bidirectional communication system for the start and emergency stop of robots. It allows working with greater safety since the robots control is under control at all times. Even if one of the pushbutton switches fails, the implemented system would detect it and stop the robot. Multiple robot can be controlled, but not at the same time.

Additionally, the operation system allows to work with distances greater than other emergency systems, about 25 meters, which is the Xbee RF module range of action and no direct line of sight between the pushbutton switch and the robot is necessary as in other wireless systems. Finally, the system allows to control several robots, that is, the user chooses which robot he wants to control.

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REFERENCES

Gonzalez, V., Ramey, A., Alonso-Martin, F., Castro-Gonzalez, A. and Salichs, M.A. (2011). Maggie: A Social Robot as a Gaming Platform. *International Journal of Social Robotics.,*vol. 3, No. 4, pp.371-381.

Morisawa, M. *et al.*, (2005). Emergency stop algorithm for walking humanoid robots. *Intelligent Robots and Systems, (IROS)*, pp. 2109-2115.

Micea, M. V., Stangaciu, V., Stangaciu, C. and Filote, C., (2012). Sensor-Level Real-Time Support for XBee-Based Wireless Communication. *Proceedings of the 2011 2nd International Congress on Computer Applications and Computational Science Advances in Intelligent and Soft Computing*, vol 145, pp 147-154.

Laudon, K. and Laudon, J. (2012). *Management Information Systems*. Ed. Prentice Hall. New Jersey, 12th edition.

Arduino. (2013). http://code.google.com/p/arduino/wiki/BuildingArduino. Last visualized 24/06/2014.

Foste, J. (2011). Xbee CookBook with 802.15.4r. (http://www.jsjf.demon.co.uk/xbee/xbee.pdf). Last visualized 24/06/2014.

Bassoli, E., Gatto, A., Iuliano, L. and Violante, M. G. (2007). 3D printing technique applied to rapid casting. *Rapid Prototyping Journal*, Vol. 13 Iss: 3, pp.148-155.

Moham, N., Undeland, T.M. and Robbins, W.P. (2003). *Power Electronics*. Ed. John Wiley & Sons. New Jersey, 2nd edition.

Barrado, A and Lázaro, A. (2001). *Power Electronichcs*. Ed. Pearson. Madrid, 1st edition.

Torres, M. (1994). *Microprocessors and microcontrollers applied in industry*. Ed. Paraninfo. Madrid, 3rd edition.