

# Off-the-Shelf Electronics in Rescue Robotics

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## ABSTRACT

The design and manufacturing methods of rescue robots with different locomotion principles are explained in the literature in detail. However, the design and realization of electronic circuits of a rescue robot still pose a great challenge, especially for the academics with mechanical background, who know how to design and build the mechanics of the robot but do not know how to make the robot work and make the right choices for the electronic parts, such as selecting a microcontroller or drivers. This research reports the methodology of building an electronic system for a mobile robot with off-the-shelf products.

## CCS Concepts

• Applied computing → Electronics.

## Keywords

Off-the-shelf electronic, robot prototyping, electronic system design.

## 1. INTRODUCTION

Rescue robots can come in different mechanical shapes such as tracked, wheeled or snake-like structures [1, 2, 3, 4, 5 and 6]. Robots with different drive trains have advantages and disadvantages for mobility on rough surface but they need similar electronic circuits to be able to drive, communicate, measure with sensors and control the trajectory tracking errors generated during motion.

The contribution of this research is to explain the use of off-the-shelf electronic parts by building the electronic system of a search and rescue robot. The mechanical body of the robot can change; however, most of the electronic system design principles can be used universally.

In order to overcome any fault in the hardware, it is advantageous to use off-the-shelf products. Compared to building the boards from integrated circuits, it might be cheaper to use off-the-shelf products (when the cost of labor also taken into consideration); moreover, with this method building the electronics turns into system level design and it is faster and more reliable.

In the rescue robot design process, when the expectations of the

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robots are given, the mechanical designers work on the mechanisms and the general shape and the placements of the mechanical and electrical components. The motor speeds and necessary torque values are calculated and required sensors are chosen. This information determines the necessary electronics of the robot.

Building the circuits from scratch requires extensive knowledge of circuit design and it is time consuming [7 and 8]. Off-the-shelf electronic products are designed and built to make the electronic system design of machines simpler, where the designer does not need to have any knowledge of building electronic circuits, rather the system engineering is carried out. However, the designer must still know which electronic parts to use inside the mechanical system for different purposes. Compared to designing and building the electronics, it takes fraction of time to order the necessary boards. Off-the-shelf electronics are more expensive than custom-made electronic boards, but when the labor cost is included, it becomes cheaper to use off-the-shelf products at the prototyping level.

Off-the-shelf products are used especially in the classroom environment where prototyping needs to be completed in a short time period. Different hardware choices exist, such as mBed, FEZ and Arduino [9 and 10]. The purpose of this research is not to compare any hardware to each other or to present one brand as better. Instead, the main idea is to show how the electronics can be assembled fast and easy for prototyping purposes. When this information is also used at the design stage, mechanical engineers can have an idea about the size and weight of the electronics and how they should be placed inside a robot. However, 3 tables are provided in this paper to explain the basic properties of development boards, drivers and wireless control modules to give the readers an understanding of these common electronic elements.

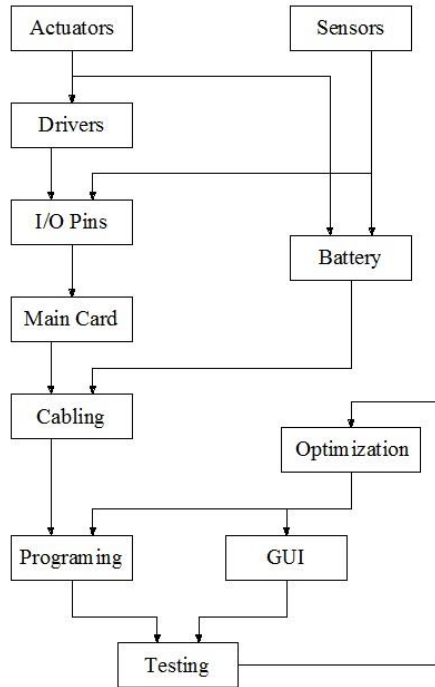
In the following sections the electronic design stage with off-the-shelf products is explained. Finally the properties of the off-the-shelf products are presented: their advantages and disadvantages are explained. The test results are provided to show the effectiveness of the off-the-shelf electronic system design and construction.

## 2. ELECTRONIC DESIGN STAGE

After the mechanical design is completed, the designer knows the necessary number of motors, their types and their power ratings, including the voltage and ampere requirements. Motor drivers are selected with the voltage and ampere ratings information of the motors. Moreover, drive methodology such as pulse width modulation (PWM) and required feedback from the motor driver (current feedback) helps the designer to select the motor driver.

Once the number and type of motor drivers are known, the necessary input and output pins for the microcontroller are calculated, both analog and digital. The number of sensors and their types also help the designer to calculate the number of input and output pins for the sensors.

When the total number of input and output pins and their types as analog or digital are known the microcontroller is selected. Meanwhile, processing speed, memory size, power requirements, physical size and weight also play a role in the decision process. Moreover, when communication between the operator and the robot is achieved by wireless units, input/output pins are also required. Figure 1 shows the design process of the electronic system of a rescue robot.



**Figure 1. Design procedure of the electronic system of a mobile robot.**

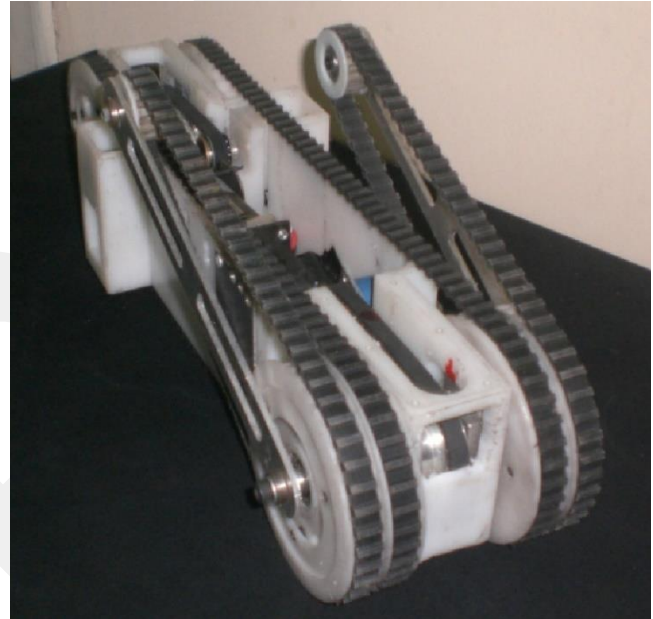
A rescue robot is considered as an example which is shown in Figure 1. Considering the working conditions defined at the mechanical design stage, the robot is expected to move its tracks at both sides and lift the arms at the front of the robot. 3 DC motors are used in order to make the robot perform these movements. Two of the DC motors are attached to the tracks and they are identical, so that they provide the same amount of rotational speed and torque. The velocity and direction of each motor is controlled by motor drivers. Additionally there is one multi-turn potentiometer, one power LED, one light dependent resistor and a wireless unit.

### 3. DESIGN PROCESS WITH OFF-THE-SHELF ELECTRONICS

In the design process with the off-the-shelf electronics, the decision of the electronic parts is made and input/output pin numbers and their types are determined. Table 1, 2 and 3 show the most common off-the-shelf electronic parts as microcontrollers, motor drivers and wireless units respectively. By using the Tables 1, 2 and 3 the designer chooses the components to be used on the robot.

When Table 1 is examined, it is seen that the development boards come in all different sizes. Also their computing capacity and input/output vary. The application dictates which board should be used. For a robotic application, when a board is chosen, the following parameters are taken into consideration: processor

speed, number of pins, memory size, programming language and price. If the application requires heavy computing processes to be done in a short period of time, such as using a Kalman filter on the sensor data, the clock speed of the processor should have a high priority. If the code sketch is significantly long and has a relatively larger size in bytes, memory size should be considered. Code sketch size becomes relatively big, if there are “if” and “for” commands in the program. The programming language can differ with the preferences of the coder, if the coder is more familiar with Arduino than C++ or Python; the language becomes a deterministic factor. The number of I/O pins required on the board can change with the application, more intricate designs may need a higher number of pins on the board. Price is self-explanatory, lower is usually preferred.



**Figure 2. The rescue robot prototype.**

In a rescue robot application, the size of the board and cabling also becomes important. The space inside the robot is very limited, a smaller board takes less space and if a shield can be used to attach the equipment such as Xbee wireless shield to eliminate cabling, this board becomes very advantageous. Another issue with the cabling, when a shield is used there is no risk for cables to detach.

If high computing power is required, a board using an ARM process can be chosen, since it has enough computing power to achieve even image processing on board. In this research an Arduino board is selected for its small size, sufficient capacity, low cost and market availability.

The motor drivers are chosen for their voltage and continuous current capacity, Table 2. The peak current refers to the current which is drawn when the motor is stalled. Even though it seems quite straight forward to select a motor driver, the PWM drive capacity and current feedback output are important features of motor drivers and should be taken into consideration. PWM frequency shows the level of accuracy of the applicable voltage and current feedback is used for calculating the generated torque by the motor. For simple applications, voltage and current ratings are taken into consideration and for control applications PWM and current sense capabilities as well as voltage and current values must be considered. In this project MC33887 motor drivers are

selected for their voltage and current ratings and the PWM control is used to adjust the rotation of the robot.

The most important features of a wireless unit are the range, data rate and frequency. The application dictates the range of the unit and the amount of data required to be transmitted determines the data rate. Since only operator commands are transferred in the current design, a pair of Xbee units was sufficient. The Xbee units can be used with Xbee shield which allows the designer to attach the unit directly to the Arduino board without cables. The programming simplicity of the Xbee boards and their compatibility with an Arduino board was the reason for selecting them in this project. Since the dimensions of the units are similar to each other, this property is not taken into consideration.

When a rescue robot is considered, there are 3 main parts of the electronics a designer can choose from: a microcontroller board, a motor driver and a wireless unit. The sensors are not added into this list since each robot will require a unique set of sensors.

An Arduino board is used for its low cost, ease of programming and availability on the market [11]. The wireless communication is achieved by a Xbee wireless module, which is placed on top of the Arduino with a Xbee shield [12], because the Xbee shield eliminates the necessity for cabling, a Xbee module is preferred. The motor drivers (MC33887 model) are used to control the velocity and direction of the motors [13 and 14].

**Table 1. Microcontroller development boards**

Name of the Board	Arduino Uno	Arduino Due	Arduino Mega2560	Raspberry Pi	Basic STAMP 1
Processor speed	16 MHz	84 MHz	16 MHz	700 MHz	4 MHz
RAM size	2 KB	96 KB	8 KB	512 MB	16 bytes
Power requirement	7-12V	7-12V	7-12V	3.5 W	6 ?-15V
Programming language	Arduino	Arduino	Arduino	BASIC, C, Perl, Python	PBASIC
Program loading method	USB	USB	USB	microUSB socket	USB
Number of input output pins	20	66	70	15	8
PWM output	6	12	14	NA	16
Number of analog input/output	6	12	16	NA	16
Number of digital input/output	14	54	54	NA	16
Size (mm)	75 x 54 x 15	68.6 x 53.3 x 15	108 x 53 x 15	85.6 x 53.98 x 17	35.8 x 10.2 x 3.81
Weight (g)	25	46	40	45	32
Price (\$)	29,00	49,95	58,95	35,00	29,00

Name of the Board	FEZ Domino	mBed NXP LPC1768	STM32F4 DISCOVERY	MAPLE	Gumstix Chestnut43
Processor speed	72 MHz	100 MHz	168 MHz	72 MHz	600 MHz
RAM size	62 KB	64 KB	192 KB	20 KB	256 MB
Power requirement	7V -12V	4.5-9V	1.8 - 3.6 V	3.0-12V	3.5-5 V
Programming language	C++	C++	C/C++	C	C
Program loading method	USB	Ethernet, USB OTG	USB OTG HS/FS	USB	USB
Number of input output pins	43	40	100	55	40
PWM output	6	6	NA		6
Number of analog input/output	7	6	NA	16	6
Number of digital input/output	36	20	NA	39	6
Size (mm)	68 x 53 x 15	14 x 14 x 1.4	97 x 66	52 x 53	118 x 67
Weight (g)	65	100	78	34	41
Price (\$)	37,95	49,95	40,95	44,00	79,00

#### 4. EXPERIMENTAL RESULTS

In order to test the performance and reliability of the electronic system of the robot, a test field is used and the performance of the off-the-shelf part manufactured electronic system is reported as follows:

**Time:** It takes significantly less time to order the off-the-shelf products rather than designing and manufacturing the boards.

**Cost:** Cost of an off-the-shelf product seems higher when only the microcontroller or motor driver cost is considered. However, when the time and man power are taken into consideration to design and manufacture the electronic boards, off-the-shelf products are cost effective at the prototyping level, but not in mass manufacturing. Cost details are given in the introduction section.

**Space:** Since off-the-shelf parts are double sided boards with micro resistors and LEDs, the boards take less space when compared to custom made electronic parts.

**Capacity:** As a result of off-the-shelf products using the same microcontroller, motor driver or wireless unit as custom-made units, there is no capacity problem. If necessary, higher capacity elements can be found.

**Heating:** The battery, motor driver, gearbox and the motor are tested for 30 seconds stalled condition and the temperature increase of these components are measured as 0, 1.3, 4.4, and 8.5 °C respectively. The heating of the motor is not significant enough to cause any damage.

**Table 2. Motor drivers and basic features**

Name	VNH5019 Motor Driver	MC33926 Motor Driver	TB6612FNG Dual Motor Driver	DRV8833 Dual Motor Driver
Motor Channels	1	1	2	2
Min. Operating Voltage	5,5	5	4,5	2,7
Max. Operating Voltage	24	28	13,5	10,8
Continuous output current per channel	12	2,5	1	1,2
Peak output current per channel	30	5	3	2
Current sense	0.14 V/A	0.525V/A	NA	NA
Max. PWM frequency	20 kHz	20kHz	100kHz	NA
Reverse voltage protection	YES	YES	YES	YES
Running motor type	Brushed DC motor	Brushed DC motor	Brushed DC motor	Brushed DC motor
Over current protection	YES	YES	YES	YES
Size (mm)	38 x 27	25.4 x 30	15 x 20	13 x 20
Weight (gr)	6,5	4	3	1
Price(\$)	34,95	17,95	8,45	6.95

**Table 3. Wireless communication units and basic properties**

Name	XBee® ZB	XBee-PRO® ZB	Programmable XBee-PRO® ZB	Wixel	Wifly	pyXY
Processor Name	ZB	Pro ZB	Prog Pro ZB	RW-PL-1336	GSX 802.11b/g	Synapse SM700
Speed	1200 bps - 1 Mbps	1200 bps - 1 Mbps	1200 bps - 1 Mbps	350 Kbps	1 Mbps	10 Mbps
RAM Size	N/A	N/A	32 KB Flash / 2 KB RAM	29 KB Flash and 4KB	128KB	96KB
Supply Voltage	2.1 - 3.6VDC	2.7 - 3.6VDC	2.7 - 3.6VDC	2.7 V - 6.5 V	3.3VDC	3.3V
Transmit Current	35 mA / 45 mA boost mode @ 3.3VDC	205 mA	220 mA	30 mA	40-240 mA	193mA
Receive Current	38 mA / 40 mA boost mode @ 3.3VDC	47 mA	62 mA	30 mA	40 mA	30mA
Frequency Band	2.4 GHz	2.4 GHz	2.4 GHz	2.4 GHz	2.4 GHz	2.4GHz
Size (mm)	23 x 33	23 x 33	23 x 33	18 x 38	28.5 x 37	25.4 x 36.5
Range (m)	40	90	90	15	200	2800
Price (\$)	17,00	21,00	35,00	19,95	49,95	69,95

**Wireless Communication:** Xbee 2.5 module has no reception problem below 120 meters in an open field. However, in the hallways of a building, the reception dropped down to 22 meters. The received signal quality changes due to the way the robot and the control unit are placed. An antenna should be used to increase the signal quality for higher distance reception.

**Connection Cables:** With off-the-shelf products, cables with male and female headers are used to connect the pins to each other. These cables eliminate the need for soldering and allows easy connection. Moreover, the designers can always solder the wire to the desired pins to ensure the connectivity of the cables in a rough environment where vibration might cause cables to disconnect.

## 5. DRAWBACKS OF OFF-THE-SHELF ELECTRONICS

When the electronic system design for a mobile robot is achieved with off-the-shelf electronics, there are also some drawbacks of using these products, such as cost, capacity, level of availability, redesign, and software compatibility.

The cost of off-the-shelf products is higher than electronic elements on the board. In the prototyping level, considering the man power to design and manufacture a board, it is cost efficient to use off-the-shelf products. However, if the robot will be mass manufactured, off-the-shelf products will not be cost efficient.

Since off-the-shelf products are mass manufactured, they are sold at different levels of capacity and if a user wants to buy the product, i.e. a motor driver, at an exact size, it might not be possible to find the appropriate size. All the electronic parts, especially sensors do not have off-the-shelf counterparts. An ISD board is not commonly used in robotic applications, so it is not easy to find this board.

If the robot is manufactured with off-the-shelf products and later it is decided to be redesigned with custom-made electronics to save money or to use specific parts, the designer must resolve both hardware and software compatibility issues.

## 6. CONCLUSIONS

This study summarizes the system level design of the electronics with off-the-shelf products for a rescue robot. Using off-the-shelf products decreases the prototyping time drastically and provides reliable hardware. In the decision making of using off-the-shelf products not only the price, but also the time to design, manufacture and assemble the electronic circuits should be considered. Moreover, the hardware reliability is one of the biggest advantages of off-the-shelf products, as well as their adaptability. Especially for prototyping purposes off-the-shelf products are very practical and easy to use. This technology can also be used in other remote controlled robotic applications as well as testing equipment.

## 7. ACKNOWLEDGMENTS

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