


Design and Implementation of a Prototype of Elevator Control System: Experimental Work

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Abstract Elevator is very important in the real life, and it is considered as an interesting and wonderful means of transportation. This paper designs and implements a prototype of an elevator control system. The mechanical design of this prototype is presented, where the dimensions, sizes, weights, calculations, and analysis of each part are considered. Based on some calculations, the servo motor of type MG996R High Torque Metal Gear Dual Ball Bearing is selected to operate the elevator's prototype. The control circuit for the developed elevator is designed using the Arduino Uno as the main controller and the 4x4 Matrix Membrane Keypad to be the component for human interface. An experimental work is investigated with the elevator's prototype using different loads (0.3 kg, 1.0 kg, and 2.5 kg) to check and investigate its effectiveness. The results show that the performance of the developed elevator is good and satisfactory whether in the upward or downward movements.

Keywords: *Elevator; Mechanical Design, Arduino Based Controller; Servo Motor; Experiments*

1 Introduction

Elevators are very important in our life because their applications and usage are every day for moving the goods or the peoples vertically in the high buildings e.g., the shopping centers, the working offices, hotels, hospitals, and so on. In addition, they shorten the time required to move

the people or the goods to the desired floor or level.

The main components of the elevator are the Car, the hoistway, the drive system, the control system, and the safety system. The main objectives of the elevator control system are bringing the elevator's car to the desired floor, minimizing the time of travel, and ensuring the safe speed limit for travel. Most of previous researchers used the programmable logic controller (PLC) to control their developed elevator as in ref. [1]–[4], and few of them proposed the microcontroller or Arduino as in [5], [6]. Yang et al. [1] used PLC as a controller and a parallel connection dispatching rule depending on the minimum waiting time for running two elevators in parallel. In their approach, LC series AC contactors were used, and PLC was programmed based on the ladder diagram. The type of their used motor was not stated. In [2], PLC was used to control an elevator, and programmed by ladder diagram. They used the DC motor for the elevator's operation, and H-bridge for changing the motor's direction. Also, S7-300 PLC was used in [3] to be the elevator's control system. Balug and his group [6] proposed methods to regulate the speed and position of the cabin of the elevator, for traffic control's purposes. They used the DC motor and H-bridge and the control circuit used Arduino Pro Mini board. In [5], an elevator based on Arduino Uno controller, was constructed. For the operation of the elevator, the stepper motor was used. In [7], an elevator group control system was designed. The passenger-based viewpoint was proposed for providing more information so as to make good elevators' schedules.

In this paper, a prototype of an elevator control system is

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developed. The mechanical design of this prototype is carried out using SOLIDWORK's software and then it is implemented in reality. In this work, we do not follow the traditional idea using the DC motor which needs a component to change the motion's direction and the floor's sensor to send the feedback's signals. Instead of that, the servo motor which has the feedback is used for operating the elevator's prototype. The control circuit of the elevator is designed using the Arduino Uno as the main controller which is simple and easy to be used and programmed. The elevator prototype is investigated and checked by doing some experiments with different loads.

The rest of the paper is composed of the following sections. Section 2 presents the mechanical design of the elevator and the selection of the used servo motor. In section 3, the controller circuit and its components are showed and discussed. Section 4 illustrates some experiments performed with the elevator to check its effectiveness. Finally, section 5 summarizes the main important points in this paper and gives some future work.

2 Mechanical Design

This section presents the details about the performed calculations and the mechanical design of the elevator's prototype that simulates the real one. In addition, the selection of the used servo motor is presented.

2.1 Prototype's Design

The designed prototype is composed of three levels or floors: the ground, the first, and the second floors. The wood is selected to be the material of the proposed elevator because it is cheap compared with other materials such as Aluminum or steel. In addition, the wood has the light weight and is easy to use. The dimensions of the elevator are selected to be as follows: the height is 120 cm and the wide is 30 cm. The height of every floor is 30 cm and the remaining 30 cm is used to fix the motor, pulleys, Arduino unit, and the other parts. Two shafts from irons are used and put on both sides of the car to assure the well fixing and to help the car moving upward and downward smoothly. At the back of the car, a slot is done for the Counterweight to make a balance with the load of the car and its contents. The dimensions of the car and the well and the calculations for the counterweight are obtained as follows:

- 1) The dimensions of the car are selected to be as 26 cm (width), 26 cm (depth), and 30 cm (height).
- 2) The dimensions of the well are selected to be as 30 cm

(width), 30 cm (depth), and 120 cm (height).

- 3) The counterweight is given by the following equation and by selecting the car empty weight to be 3.0 kg,

$$\begin{aligned} \text{Counterweight} &= \text{car empty weight} + 1/2 \text{ rated load} \\ &= 3 \text{ kg} + 0.5 \times 0.5 = 3.25 \text{ kg} \end{aligned} \quad (1)$$

The prototype is designed using SOLIDWORK's software and it is implemented in reality in the Mechatronics laboratory, Faculty of Engineering, South Valley university in Egypt. The design of this prototype is shown in Fig. 1. The parts found in the upper part of the elevator such as the servo motor and the used pulleys are presented in Fig. 2.

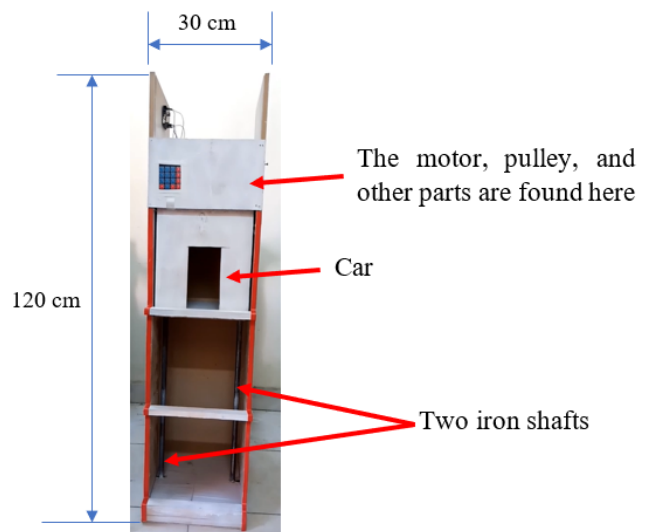


Fig. 1 The implemented design of the prototype of the elevator.

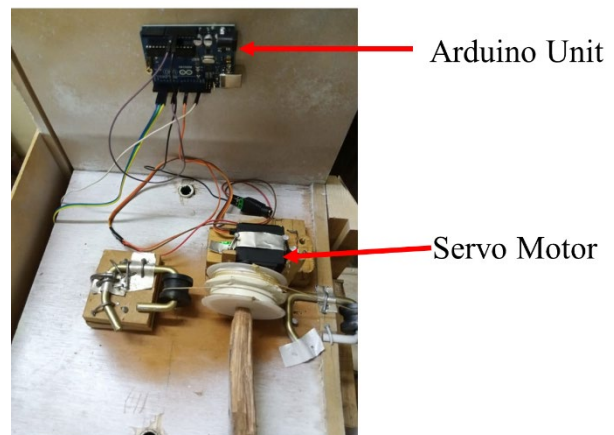


Fig. 2 The components found in the upper part of the elevator such as motor, pulleys, and Arduino unit.

2.2 Servo Motor Selection

As presented from Fig. 2, the motor is coupled to the car by the use of the belt system for ensuring the upward and downward movement for servicing the floor request. Coupling is done by a belt drive mechanism. The calculations that are the basis for selecting the motor are presented by the following equations.

1) The motor torque is given by

$$\text{Force} = m \times g = 8 \text{ kg} \times 9.81 = 78.5 \text{ N} \quad (2)$$

$$\text{Torque } (T) = \text{Force} \times \text{radius of pulley} = 78.5 \times 3 \text{ cm} = 235.5 \text{ Ncm} \approx 2.4 \text{ Nm} \quad (3)$$

2) The angular speed in *rad/s* is assumed to be

$$\omega = \frac{2\pi \times 250}{60} = 26.167 \text{ rad/s} \quad (4)$$

3) Therefore, the power *P* of the motor is calculated by

$$P = T \times \omega = 2.4 \times 26.167 = 62.8 \text{ watt} = 0.08 \text{ hp} \quad (5)$$

Based on these calculations, the servo motor of type MG996R High Torque Metal Gear Dual Ball Bearing [8] is selected. This motor is shown in Fig. 3 and its technical specifications are presented in Table 1.

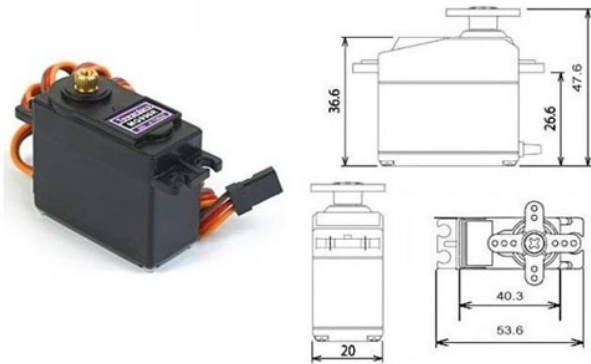


Fig. 3 The used servo motor of type MG996R High Torque Metal Gear Dual Ball Bearing [8].

Table 1 The technical specifications of the used servo motor in the presented work.

Parameter	Value
Weight	55 g
Dimension	40.7 x 19.7 x 42.9 mm approx.
Stall torque	9.4 kgf·cm (4.8 V), 11 kgf·cm (6 V)
Operating speed	0.17 s/60° (4.8 V), 0.14 s/60° (6 V)
Operating voltage	4.8 V a 7.2 V
Running Current	500 mA – 900 mA (6V)
Stall Current	2.5 A (6V)
Dead band width	5 μs
Stable and shock proof	double ball bearing design
Temperature range	0 °C –55 °C

3 The Control System

In this section, the discussion of using the controller for the elevator’s work, the type of the used controller, the matrix membrane keypad, and the design of the control circuit are presented.

3.1 Elevator’ Work Based on The Controller

The elevator’s work based on the control system is presented in Fig. 4. In this figure, the input sends signals to the controller which processes these signals and determines the required action. The taken action by the controller depends on the command issues at the input and the input signal that received from the motor and car e.g., the information about the car level or floor and the position and speed of the motor. Therefore, all the logic operations are performed by the controller to enable up and down elevator motion and to determine the priorities in servicing the requests. The input refers to the sent data to the controller through an issued command from a particular component device. In this case, the sent commands to the controller are from push buttons as described in Fig. 5.

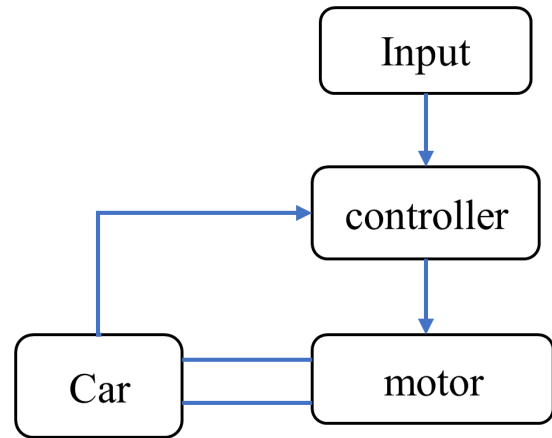


Fig. 4 The work of the elevator’s prototype based on the controller.

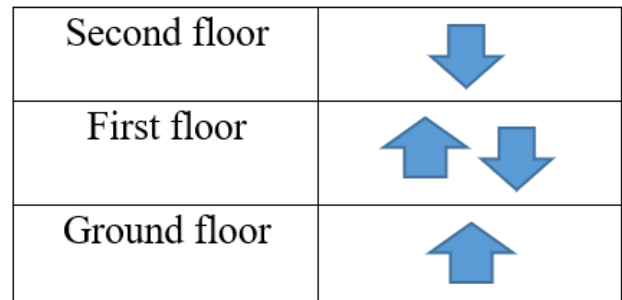


Fig. 5 The used push buttons to send commands to the controller.

3.2 Arduino Based Controller

The controller is the responsible for coordinating all aspects of elevator service such as travel, speed, accelerating, decelerating, door opening speed, and delay and levelling. The used controller in the presented work is Arduino Uno. Arduino Uno [9], [10] is a microcontroller board based on the ATmega328. It has the following components:

- 14 digital input/output pins and 6 of them can be used as PWM outputs.
- 6 analog inputs.
- A 16 MHz crystal oscillator.
- A USB connection.
- A power jack.
- An ICSP header.
- A reset button.

Arduino Uno contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 programmed as a USB-to-serial converter. Uno means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Uno and version 1.0 will be the reference versions of Arduino, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform, for a comparison with previous versions. This type of controller is shown in Fig. 6.

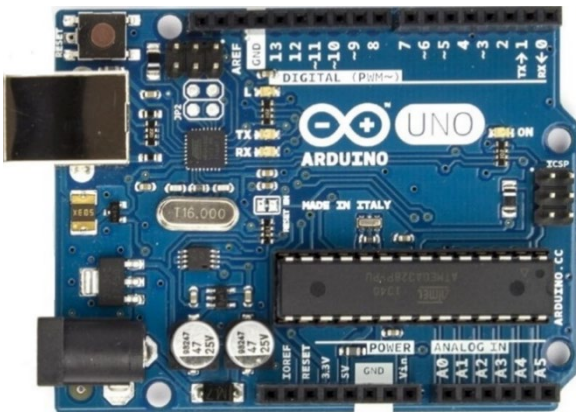


Fig. 6 The Arduino Uno. This picture is taken from ref. [9], [10].

3.3 4x4 Matrix Membrane Keypad

This keypad has 16 buttons, and it provides a useful component for microcontroller's projects which it is used to send commands to the controller. The convenient

adhesive backing gives the simple way to mount the keypad in various applications. This keypad uses a combination of four rows and four columns for providing the button states to the host device, typically the microcontroller. Underneath each key is a pushbutton; one end is connected to one row and the other end connected to one column. These connections with the keypad are presented in Fig. 7.

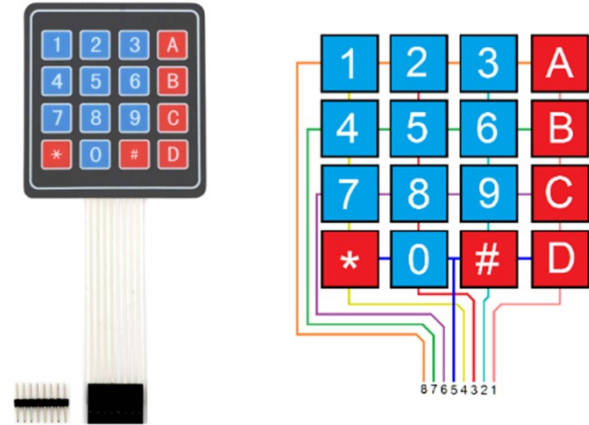


Fig. 7 The 4x4 matrix membrane keypad with its connections, [11], [12].

3.4 The Control Circuit Design

The components such as the Arduino Uno, the servo motor, and the matrix keypad are connected together to compose the control circuit of the elevator. This circuit is presented in Fig. 8.

The used servo motor gives a continuous rotational motion and does not give an incremental or stepper motion. To solve this problem, we design a flowchart diagram for the system. In addition, the Arduino Uno is programmed considering some values and symbols to determine each floor in which the car and the motor should be stopped. Figure 9 presents the flowchart diagram describing the design of the control logic involved in the elevator's operation. The elevator starts operating when the power is switched on. Under no use, the lift rests at the last floor serviced (last destination floor). The elevator keeps checking for the requests during the waiting to ensure fast serving of any request on any floor. The car moves on each level and keeps checking for requests and destinations in the direction, e.g., upward, or downward, depending on the direction of travel and motion. The elevator's car keeps checking the last and ground floor to ensure reverse of directions on those floors since they represent the highest and the lowest floors according to the design scope. Indeed, this prove the safety.

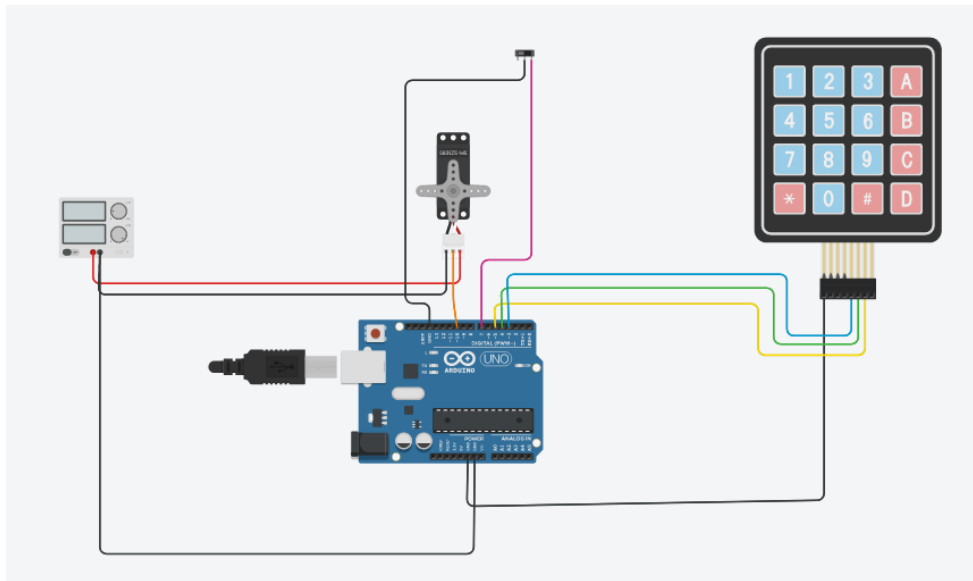


Fig. 8 The designed control circuit of the elevator’s prototype.

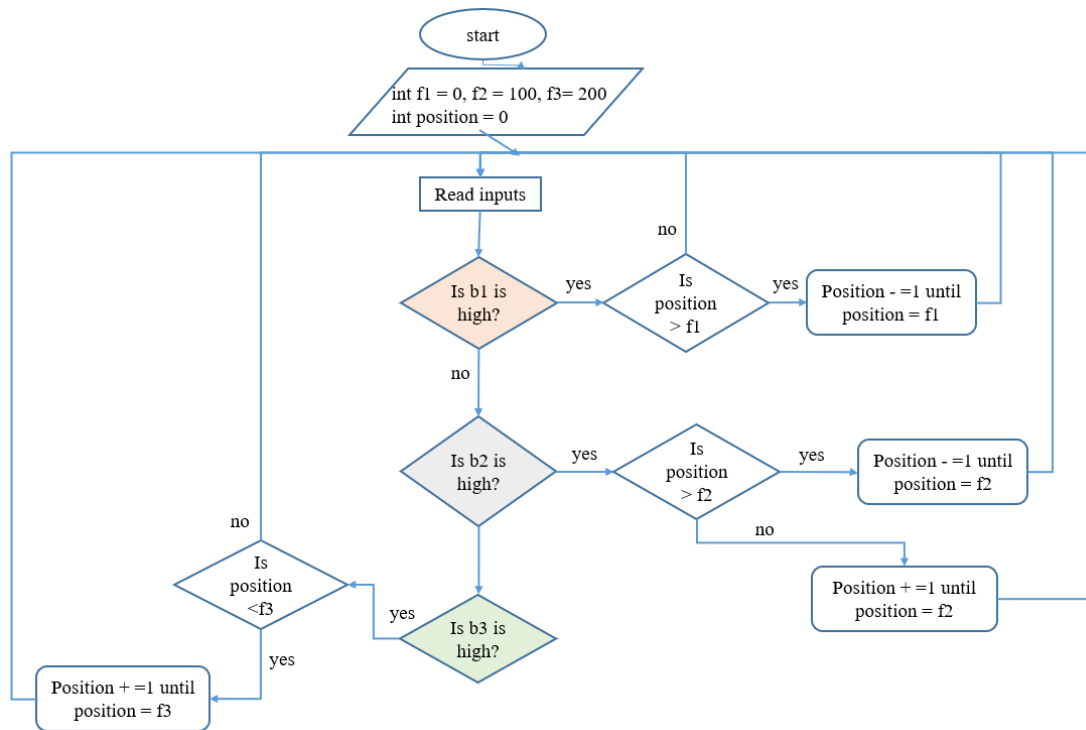


Fig. 9 The flowchart diagram describing the design of the control logic involved in the elevator’s operation. b1, b2, and b3 are the buttons.

The experimental work with the designed elevator control system is described in the next section.

4. Experiments

In this section, some experiments are carried out with

the designed prototype of the elevator control system. The servo motor is checked by connecting a plastic bottle to it via the belt and it is working very well. Three experiments are executed by the elevator: the first one is using a load of 0.3 kg, the second experiment is using a load of 1.0 kg, and the third one is using a load of 2.5 kg. From these experiments, we deduce that the elevator can lift the weight of 0.3 kg and 1.0 kg efficiently. In the case of the

load of 2.5 kg, the designed elevator works but with some difficulties. Although the elevator is designed to lift a load of 5.0 kg, the maximum weight that it lifts is 2.5 kg. This is actually because that the frictions between the elevator's parts are not considered in the previous calculations that presented in subsection 2.2 that are used for the motor selection. Figure 10 represents the car of the elevator in the three floors during the experiments. A video illustrating some experiments is available at the following link:

<https://www.youtube.com/watch?v=H5TCJJK7vJo>

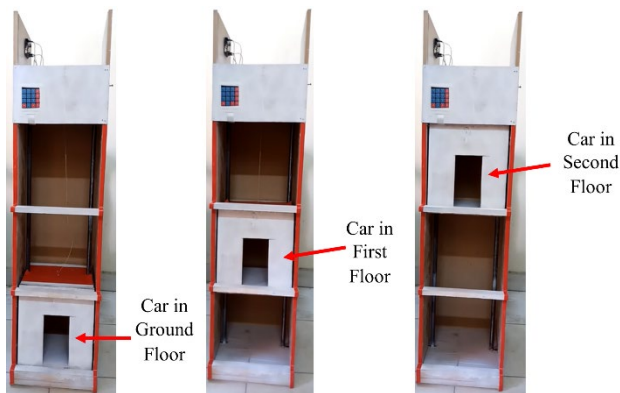


Fig. 10 Some snapshots from the experiments with the designed elevator control system during the upward and downward movements.

5. Conclusion and Future Works

In this paper, an elevator control system is designed and implemented. The mechanical design including the dimensions, sizes, weights, calculations, and analysis of the elevator's prototype, is presented. The servo motor is selected to operate the elevator, and the control circuit using the Arduino Uno as the main controller is designed. The used servo motor has continuous motion and is not incremental or stepper. To solve this problem and convert the servo motor's motion to incremental, a flowchart diagram is designed and followed during the programming of the Arduino Uno. Some experiments are executed with the elevator, and it is found that it can lift a load up to 2.5 kg although it is designed to lift a load of 5.0 kg. This happens because that the friction forces are not considered during the calculations and the selection of the motor. The performance of the elevator is good and promising.

In the near future, some points can be considered as follows:

- 1) Development of a more complex elevator having

more than 5 floors, where there are more conditions to test, calculate, and analysis.

- 2) The presented work is serving as First Come First Serve method (FCFS algorithm), and there could be a clever way of serving such as CPU scheduling algorithms. This point should be considered and investigated in the future work.
- 3) The requesting methods can be implemented using SMS remote request service or wireless requesting using the internet for the VIP or special cases.
- 4) The doors can be designed to automatically open to be more flexible.

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