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Design and Construct of an Elevator Demonstration Device

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Abstract In recent years, a new disease emerged and took the world by storm. The COVID-19 pandemic forced everyone to change their lifestyles. Necessary measures were taken to curb its spread. An example of such a measure, in Indonesia was the replacement of pushbuttons in elevators with proximity sensors. Nevertheless, due to its public nature, it was observed that eventually these sensors came into direct contact with a lot of individuals, and thus it became the very thing it was meant to prevent. In this research, a miniature elevator was constructed. It was designed to be accessible to individual smartphones via mobile Wi-Fi. It is hoped that this could further limit contact only to personal smartphones. As an additional feature, the device was also designed to be capable of energy recovery to raise environmental awareness during the global focus on the pandemic. It was calculated and measured that energy recovery up to 75% was possible.

Keywords: Alternative, constructed, contact, demonstration, designed, environmental, limit, miniature, personal, public.
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Introduction

According to Lubomír Janovský, an elevator is defined as a fixed transportation device that serves two or more floors by moving its cabin between and along a set of stiff rails vertically up to fifteen degrees of deviation [1]. Even though the elevator seems to be a modern invention, its conception was traced back to Archimedes in 236 B.C. and first took its modern form that we know today in the 1800s. It was not in widespread use due to the lack of safety measures until Elisha Graves Otis created the very first elevator safety system in 1852 A.D [2]. Today, the elevator is in common use. It is powered by electricity, automated by programmable logic controllers, and is classified into several types based on the different methods used to move its cabin [1].

Elevator installations are mostly public in nature. During the pandemic, the elevator is a high-risk area where the disease could easily spread through various means. One of those means was through contact with surfaces contaminated with respiratory droplets from infected individuals ([3], [4]). The utilization of proximity sensors in Indonesia to replace pushbuttons was not ideal as it was observed that eventually it came into direct contact with various individuals either accidentally or intentionally.

The goal of this research was to design a miniature elevator capable of wireless control via mobile Wi-Fi and energy recovery [5] for demonstrational purposes, showing an alternative method of access that further limits contact to personal smartphones thus lowering chances of transmitting COVID-19 through contact of contaminated surfaces while raising environmental awareness.

Design and construct

This section explains the steps taken to the completion of this thesis paper.

1) Preliminary research: to gather the necessary information to design, assemble, and program the demonstration device, preliminary research was conducted in the form of observation which helped identify the problems present in the field and gave ideas and motivation for the research, interview with Mr. Edi Susanto, an elevator expert that helped guide the research, and literature review that contributed further understanding not found from both observation and interview.

2) Problem identification: based on the observation made during preliminary research, it was found out that even if elevators in Indonesia utilized proximity sensors in hopes to limit contact, these sensors will still come into direct contact with many individuals

and potentially spread pathogens if one of them was an infected. With the solution of utilizing wireless technology to further limit contact to individual smartphones comes yet another problem, and that was the lack of a demonstration device to communicate the idea to the public with for the client – in which the client is none other than the Department of Industrial Engineering of Pelita Harapan University. As an additional feature, since what was designed and constructed was an elevator demonstration device that could potentially be used in educational settings, it is an invaluable opportunity to also raise environmental awareness with said device. An additional idea to add energy recovery capability was proposed, and the same problem was encountered – the lack of a demonstration device to communicate to the public with for the client.

3) Determination of research objectives: based on the problems identified, the goal and limitations of this thesis paper were determined. The goal was to design and construct a miniature elevator for demonstrational purposes capable of wireless control and raising environmental awareness. The research was limited to an allotted time and budget.

4) Literature review: information necessary for the completion of this research that was lacking in the previous steps was studied.

5) Design and Implementation: concept of the design was first determined alongside its limitations, components needed to assemble the device was listed and its purchase was planned, steps for implementation was also planned out. The 3D model and technical drawing of the device was made alongside its bill of materials. Construction and programming were then carried out according to what was previously determined. Feedback was continuously given by experts to help verify the progress of the project and solve any problems that arose during this step.

6) Evaluation and analysis of the demonstration device: after the device was deemed ready within its set of limitations, data concerning energy recovery was taken with the help of an oscilloscope, processed with Minitab to determine whether the data qualify, then with Microsoft Excel to calculate the energy conserved before an overall analysis was made.

7) Conclusion and suggestions: the device was handed over to the university and several suggestions were made.

The materials and methods section should contain sufficient detail so that all procedures can be repeated. It may be divided into headed subsections if several methods are described.

Results

A. 3d model and technical drawing

The following are the 3D model created and its technical drawing generated with the help of Creo Parametric.

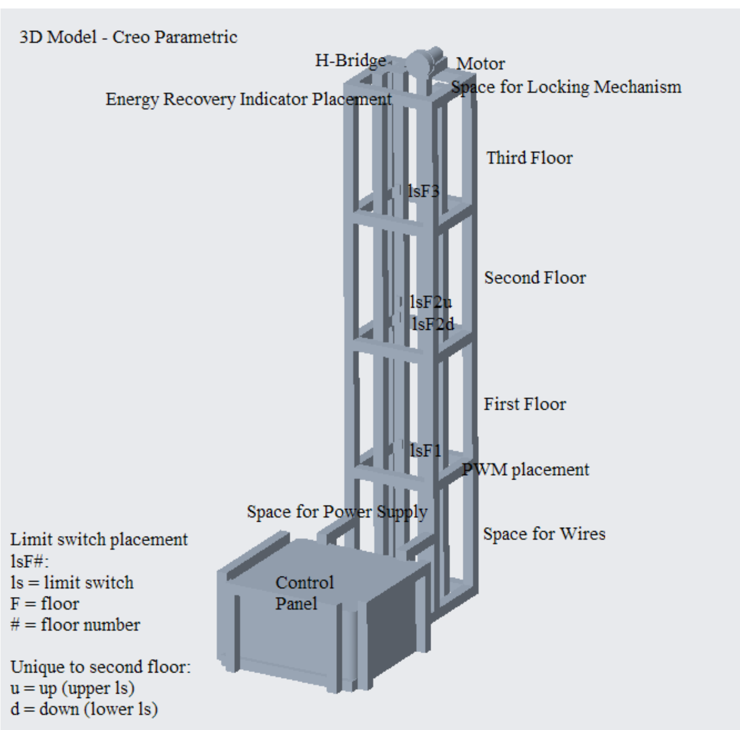

Figure 1. 3D Model

Since the device is a miniature, the model was designed to consider behaviors that will never line up exactly as it should on a regular elevator. Taking a closer look on Figure 1 and Figure 2, there are a total of four vertical rails, each 1000 mm in height installed within the elevator shaft. One served to hold the limit switches which are as sensors telling the microcontroller the location of the cabin in place, and the other three served as the cabin's railway.

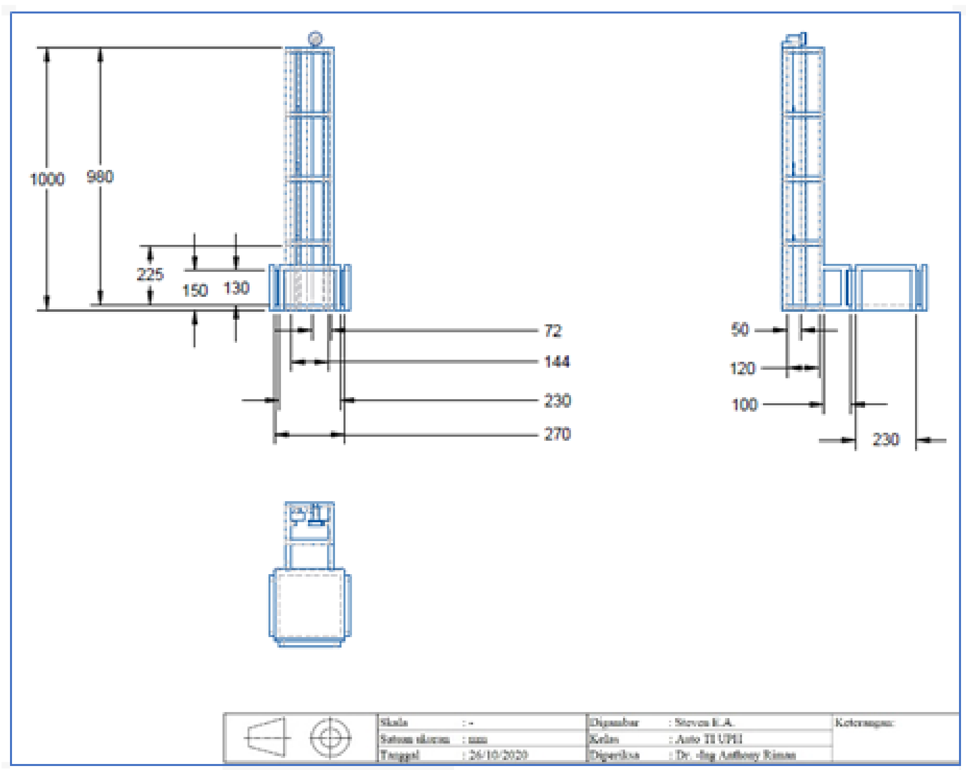

Figure 2. Technical Drawing

None of these rails are for the counterweight as no counterweight was used. This is because of the energy recovery system explored in this research, where it is not just a reduction of electrical usage for the motor when the cabin is to move downward but instead a total cut off so that any kind of downward movement will solely rely on gravity and in turn generate electricity. The presence of a counterweight which will balance the cabin [6] in that event was deemed more of a hindrance due to the balancing act it will provide and thus it was not utilized in this research.

The elevator shaft itself was designed to be split into four levels. The first level is not considered a floor, but instead space for wires. First floor starts at the second level, then the second floor on the third level, and finally the third floor on the fourth level.

The H-Bridge is the component responsible for controlling the direction of rotation of the motor by changing its polarity [7]. It was placed on top next to the motor instead of inside the control panel to easily set up its connection to the motor. Additionally, since the H-Bridge has heat sink fins and will indeed release heat, it would adversely affect the performance of other electrical components if it were placed inside the control panel as resistance varies with temperature.

The elevator locking mechanism consisting of a solenoid and a relay was placed next to the motor on the opposite side of the H-Bridge while LED indicator for energy recovery was placed in front of the motor.

Between the control panel and the elevator shaft was a thin strip of space with a platform designed for the placement of the power supply. Next to it, on the side roughly on the same level with the control panel is placement of the Pulse Width Modulator or PWM responsible to control the speed of the motor and the relay tasked to cut the motor off from its power source whenever the cabin is told to move downwards.

The control panel itself was placed at the lowest level in front of the shaft. This placement and that of PWM was designed considering that the device was intended to be placed on top of tables for use and display. The placement itself will provide ease of access to the control panel as it will roughly be on the same level as the abdomen, at least of the local population, while the entirety of the elevator shaft itself will be visible without causing much discomfort. Ergonomic calculations [8] were, however, not applied. Instead, it was just a rough estimation based on comfort during construction and feedback.

Within the control panel are microcontrollers, specifically Arduino Mega 2560 and ESP32. These function as PLC master units tasked to store and run programs as well as connecting inputs and outputs [9]. A four-channel relay to control pilot lamps and a breadboard for ease of wiring is also present within the control panel.

A detailed table of the bill of materials created after the 3D model and technical drawing was provided in the thesis paper.

B. *Wiring and Programming*

The following are the circuit diagram (Figure 3) made with the help of Fritzing, a sample of the main program created in Ladder Logic Diagram running in a simulation in LDmicro (Figure 4) which also is the integrated development environment software used to create the main program, and the program for mobile user interface created in Blynk as shown in Figure 5.

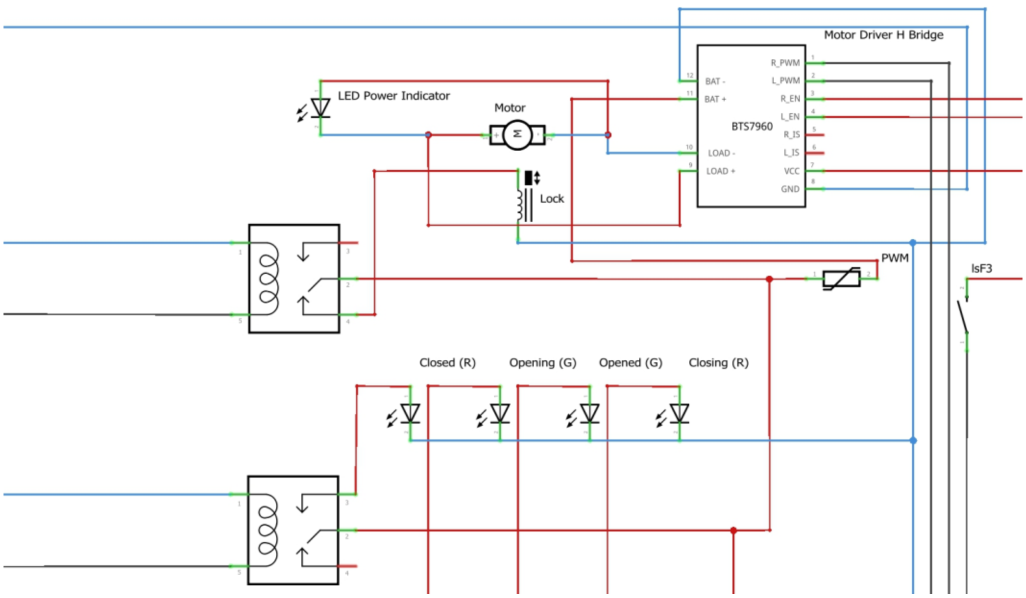

Figure 3. Circuit Diagram (partially shown here, motor control circuit)

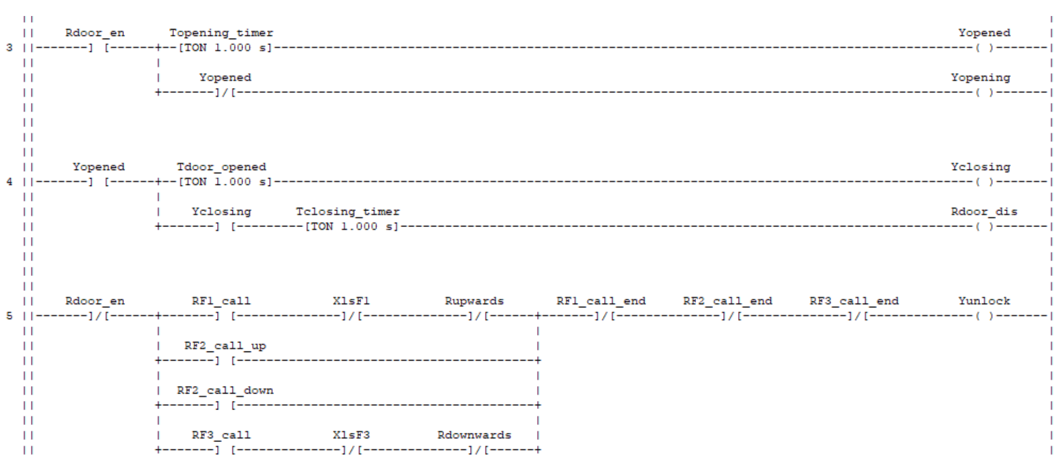

Figure 4. Program Simulation using Ladder Logic Diagram (partially shown here)

Figure 5. Mobile user interface programming

C. Energy Recovery

To be able to find out how much power was used and produced by the motor, its resistance must first be known. It is known that the that motor used was designed to require 12 V and 0.3 A to operate. Using Ohm's Law,

$$R = V / I \qquad (1)$$

where V is voltage in Volts (V), I is current in Ampere (A), and R is its resistance in Ohm (Ω).
Divide 12 V with 0.3 A and we get the resistance of the DC motor or R_{motor}, which is 40 Ω.
Meanwhile, it is known that the energy recovery indicator circuit or $R_{circuit}$ has a resistance of 220 Ω.

Data taken by the oscilloscope is the voltage used by the LED circuit shown in Fig. 6. connected to the motor or $V_{circuit}$ and not that of the motor itself. Therefore, the true value of the voltage produced by the motor follows the equation to solve for the electromotive force of a battery,

$$V_{motor} = I \text{ x } R_{eq} \qquad (2)$$

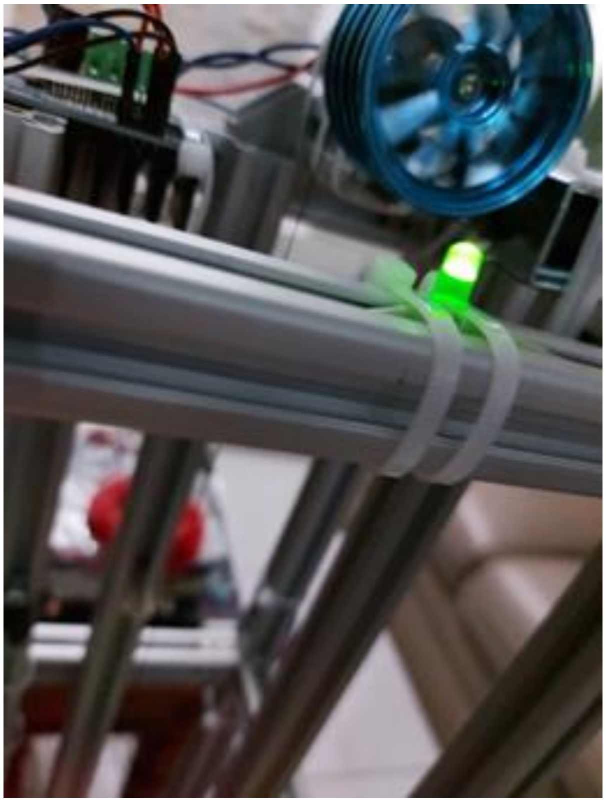

Figure 6. Energy recovery led indicator

where V_{motor} is the true value of voltage produced by the motor, I is its current, and R_{eq} is the total resistance in the series circuit which is 260 Ω,

$$I = V_{circuit} / R_{eq} \qquad (3)$$

$$R_{eq} = R_{motor} + R_{circuit} \qquad (4)$$

A hundred data were taken for each of the following cases: cabin movement from floor 1 to floor 2, floor 2 to floor 3, floor 1 to floor 3, and the opposites of the previous three cases.

It was found that the voltage used to get the cabin to move upwards or V_{up} was always constant, and that value is 5.08 V. Knowing the equation for power where P is power in Watts,

$$P = V^2 / R \qquad (5)$$

The electrical power consumed for all upward motion or P_{up} is found to be 645.16 mW using the following equation,

$$P_{up} = {V_{up}}^2 / R_{motor} \qquad (6)$$

The electrical power produced for all downward motion or P_{down} on the other hand is,

$$P_{down} = {V_{motor}}^2 / R_{motor} \qquad (7)$$

Meanwhile, the voltage produced whenever the cabin moves in the opposite direction varies. To verify whether the varying data taken is valid, it was run through a series of statistical tests using Minitab.

At the 5% significance level using Grubb's test ([10],[11]), it was found that it has no outliers. Using the same significance level value, the data went through the Anderson-Darling normality test. With P-Values greater than 0.05, the data was concluded normal.
After the statistical tests, in Microsoft Excel, the data was run through equations 4, 3, and 9. Then, to get the percentage of electrical energy recovered from the opposing movement, in a simplified setup, where the upward and downward movement speed is adjusted to have equal speed, energy recovered can be calculated as following

$$\text{Energy Recovery Percentage} = 100 \text{ x } (P_{down} / (P_{up}) \qquad (10)$$

Regarding measurement uncertainty, it is known that the uncertainty of the voltage measured by the oscilloscope is ±0.004 V while other variables with no known errors were considered to have ±0 uncertainty. For any kind of addition and subtraction done, add the absolute values of each uncertainty. For any kind of multiplication and division, add the percentage of uncertainties before finding out the value of uncertainty. The results, both main calculation and that of the uncertainty, were then converted to milliwatts and their average values taken.

It was then known that whenever an upward movement consumed (645.16±1.02) mW of power:
- For an upward movement from floor 1 to floor 2:
  its opposing movement produced (485.81±1.02) mW of power and thus recovered 75.30% of the power used.
- For an upward movement from floor 2 to floor 3:
  its opposing movement produced (400.15±0.94) mW of power and thus recovered 62.02% of the power used.
- For an upward movement from floor 1 to floor 3:
  its opposing movement produced (457.81±1.02) mW of power and thus recovered 70.89% of the power used.

Conclusion

The elevator demonstration device was deemed ready at the end of the feedback process and its energy recovery results were satisfactory. A miniature elevator capable of demonstrating wireless control accessible using mobile phones to limit contact to personal smartphones and energy recovery whenever its cabin moves downward thus potentially able to pique interest on environmental awareness was successfully designed and constructed as shown in Fig. 7.

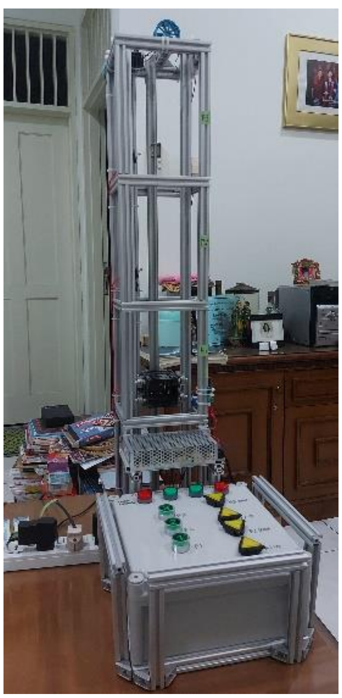

Figure 7. Elevator Demonstration Device

Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Acknowledgments

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