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A Modular and Programmable Elevator System

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Abstract

This research is about the design, development and implementation of a small scale elevator. The main work was split into three major categories for the development process. The first stage focused on the mechanical structure of the elevator and involved combining the two server racks together to hold the components. The components were then mounted and cable trays were run through the server racks to keep the wiring clean and out of the way. The next stage involved the electrical wiring. The controls for the elevator were run through the cable trays and connected to terminal blocks, which were then wired to the PLC. Finally, the software components were integrated with the system. Two HMI's were designed to assist users with the operation of the system. The first HMI is hosted locally on the operator laptop and is used for testing the floor sensors and for jogging the system when it is stuck between floors. The second HMI provides information about the system and can be accessed from anywhere in the world.

Keywords: *Small Scale Elevator, PLC Control, Human Machine Interface, Modular and Programmable, Elevator Server*

1. Introduction

The main types of elevator used today are hydraulic and traction. Many factors need to be considered before selecting which type of elevator to use. Cost, safety, and reliability are important factors that will determine which type of elevator should be adopted. Hydraulic elevators are mostly used in smaller buildings (less than 8 stories) and have some great benefits compared to traction elevators. Hydraulic elevators do not require reinforcement and are generally cheaper than traction elevators. In the event of a line break, a hydraulic elevator will not fall faster than the oil can escape. According to [1], a major detriment of hydraulic elevators is the possibility for environmental contamination due to leaking oil. In fact, some companies have stopped producing hydraulic elevators due to these concerns. The second type of elevator used in industry is the traction elevator. Traction elevators are the most common type used today and work through the use of steel ropes attached to a motor and the elevator carriage [3-4]. These elevators can be used in buildings of any height and do not have the negative environmental impacts associated with hydraulic elevators [4-5]. Traction elevators are divided into two major types: gearless and geared. Geared traction elevators are controlled using motors attached to a worm and gear unit. Geared elevators are slower than gearless types. However they do not require as much power. Gearless elevators are faster than geared elevators and can be used in buildings of any height. Gearless elevators are also extremely reliable and rarely need to be replaced [6-7]. Our project aims to incorporate a number of the technologies including but

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not limit to Modbus, PLC programming, web technologies, and OPC. The core project focuses on controlling a simple elevator with a Siemens PLC. The elevator has 3 floors and is controlled through pushbuttons. The elevator cart is connected to a simple pulley system, which is raised and lowered using a Siemens motor. The entire project, as shown in Figure 1, is built modularly with reconfigurable features. The first addition to the project is a web based monitoring system. The webpage collects data sent by the PLC and displays statistics about the total operating time, most requested floors, and total downtime. The second addition is a human machine interface (HMI) which has multiple purposes, such as displaying the elevator's current floor and serving as a maintenance panel for when the elevator needs to be serviced.

Figure 1. The proposed elevator system

2. Objectives and Functionalities

The development of this project began with the physical construction of the elevator. Two server racks were bolted together to create the housing for the project. A support beam was then added to the top to increase the stability and strength of the system. Finally, cable trays were added to house the wiring and holes were drilled to mount the DIN rails.

The second stage involved the mounting and wiring of the electrical components. Two relays were added to the DIN rail to control the forward and reverse motion of the elevator. The relays were activated using a 24VDC signal from the PLC and upon activation sent a 10VDC signal to the motor driver. The elevator controls were wired through the cable trays and connected to the terminal blocks. These wires were then connected to their respective I/O ports on the PLC.

The final stage of development focused on the design of the PLC program, web based HMI, and operator HMI. The PLC program was developed using Siemens TIA portal. It is responsible for all of the logic in the system and provides the data needed to populate the web based HMI. The program connects to KEPServer, which then connects to Cogent DataHub to send the PLC values to the database. The operator HMI was also developed using Cogent DataHub and communicates with KEPServer to provide information about the floor sensors. It contains three lights that become active whenever the elevator cart is near a floor sensor. There is also a jog function for manually controlling the movement of the elevator. Finally, the web based HMI is hosted on 1and1.com and provides instant access to the elevator's data, as shown in Figure 2. Operators or owners can view this website and be provided information about the system, such as the total maintenance time or most requested floor. More data can easily be sent to the database using the PLC program.

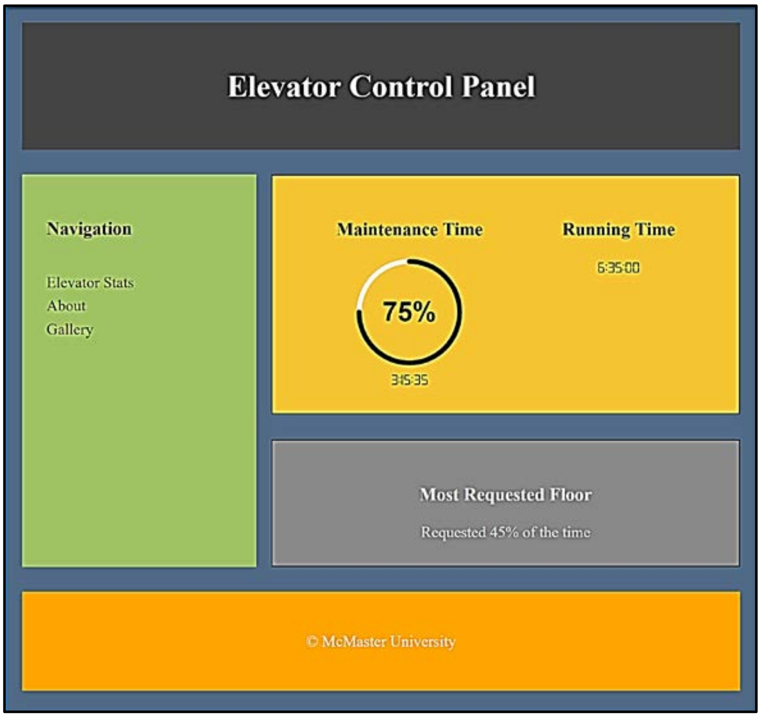

Figure 2. Website prototype

3. Mechanical Design

One of the objectives of this elevator model was for it to be easily moved from one place to another without any disassembling. For it to be easily moved, a frame was designed and constructed out of two one-post server racks. The racks have wheels on them which allow it to be wheeled with minimal effort. To make the two racks as one, a metal beam was secured to the top of each rack, connecting them securely and providing rigidity to the structure. To further secure the two together, a bottom aluminum plate was attached to give further support and gap closure. With these fabrications, a two-post server rack was constructed with space for all components to be secured to all while being able to be mobile.

The construction of components within the frame is comprised of two main parts, the controls and the elevator carriage. For organization and functionality, one half of the frame is dedicated for the PLC, motor driver, power bar and all wiring components, while the other half acts as the shaft of an elevator which houses the carriage.

In order for the carriage to ascend and descend straight, a guide rail was fabricated. Two 7’, 1” diameter aluminum pipes were used as the rails. They were secured in place through pre-existing holes on the top of the rack and holes were drilled to secure it from the bottom. To connect the carriage to the guide rails, attachments were designed and 3D printed to allow one side to be fastened to the carriage and the other side to allow the guide rail to be inserted to.

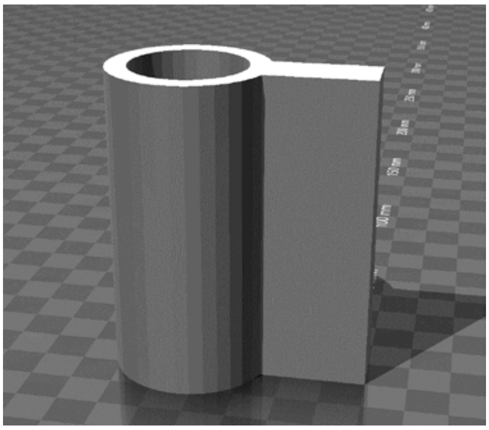

Figure 3. Guide Rail

For the carriage to be controlled by the motor, one end of a 25’ ⅛” cable is connected to the carriage and the other end is attached to the spool connected to the motor. To allow the carriage to be lifted or lowered from above two pulleys are used to redirect the movement of the cable. One pulley is mounted on the top supporting beam right above the motor. The other pulley is mounted to the top beam on the other side of the frame above the carriage. The location of pulleys allows the motor to be mounted on the base of the frame and the carriage to be lifted or lowered from above.

3. Electrical Design

The distribution of power to the motor, PLC and components is controlled through one power bar mounted at the top of the frame. There are two power cords into the power bar. One is for the 24 VDC supply to the PLC and components and the other is the 120 VAC to the motor driver. Each has its own switch on the power bar to control the on/off of each independently. The identification of each power cord and switch is labeled on the power bar underneath where it is plugged in.

To control the circulation of DC power to the buttons and PLC, two 40-pole common terminal modules are used, as seen in Figure 17 below. One module is for -24 VDC and the other is for +24 VDC. Each of these modules is supplied its power from the 120VAC to 24 VDC power supply. One connection from the power supply is made to each module which allows the remaining terminals in that module to be supplied with that designated power.

The wiring of the components use 20 AWG stranded wire and are categorized using three different color codes. Red wires represent +24 VDC, black wires represent -24 VDC and grey wires represent communication signals. Each pushbutton is supplied with one red +24 VDC and one grey communication input signal wire. The LED light bulb in each pushbutton is also supplied with one red +24 VDC and one grey communication output signal wire. On the connection sides of each wire is a crimped ferrule terminal end. Ferrules are used to provide a neat, secure connection point to prevent from possible loose connections in the future. Following figure shows the control panel of the proposed system.

Figure 4. Control box

The wiring of all communication signal wires to the PLC is organized using two terminal blocks, as seen in Figure 5 below. One terminal block is designated for inputs and the other is designated for output. The use of terminal blocks provides the user with a visual representation of what input/output corresponds with the input/output terminal address to the PLC. Terminal blocks also provide an easier way to diagnose a problem if one were to arise and also for the ease of implementing additional inputs/outputs.

Figure 5. Terminal blocks

The motor and motor driver is directly connected to each other using a four-conductor wire. Each conductor is colored black, white, red and green. The designation of each conductor on both the motor and motor driver side is:

Black - T1
White - T2
Red - T3
Green - Ground

To power the motor driver it is supplied with 120 VAC via a 14 AWG three conductor power cable. One side of the power cable is connected to the power bar and the other goes to the motor driver. To protect the driver from possible damage, a 10 Amp slow blow fuse and holder is used. The line conductor is connected to one side of the fuse holder and the other goes to the motor driver. The Neutral and Ground conductors are connected straight to the driver. The designation of each supply power conductor into the motor driver is:

Black - Line

White - Neutral

Green - Ground

The function of controlling the motors forward and reverse operations are done through the motor drivers digital inputs. On the motor driver, digital input 1 (DI1) controls the forward movement and digital input 2 (DI2) controls the reverse movement. The input of these signals is routed from the outputs of the PLC using relays. One relay is used for each digital input.

4. Software Design

4.1 PLC Program

The PLC was connected to the PC using PROFINET. The program was built using TIA Portal V14 and the programming language used was ladder logic. There were a total of 19 rungs in the PLC program. It also had 8 inputs and 7 outputs. There were many memory bits that were used during the programming too. The program allows to the elevator to move three floors and executes the maintenance mode when needed. Ten tags from the PLC Program was read by KEPServerEX so that it can be written to the database and used by the HMI.

4.2 Operator HMI

The HMI was web based and created using Cogent DataHUB. This HMI is accessible only if the user is on the same network. The tag values collected on KEPServerEX were read by Cogent DataHUB. These tags were then bound to the lights and buttons on the HMI for operation

4.3 Web Based HMI

The web based HMI is used as a data historian and includes information on the most requested floors, total operating time, and total maintenance time. The page also includes information on the developers for this project and also includes links to the GitHub repository, YouTube video, and a link to this technical report. The HMI, as shown in Figure 6, is mobile responsive to provide operators easy access from any device. It was hosted at 'www.4tr3.space'.

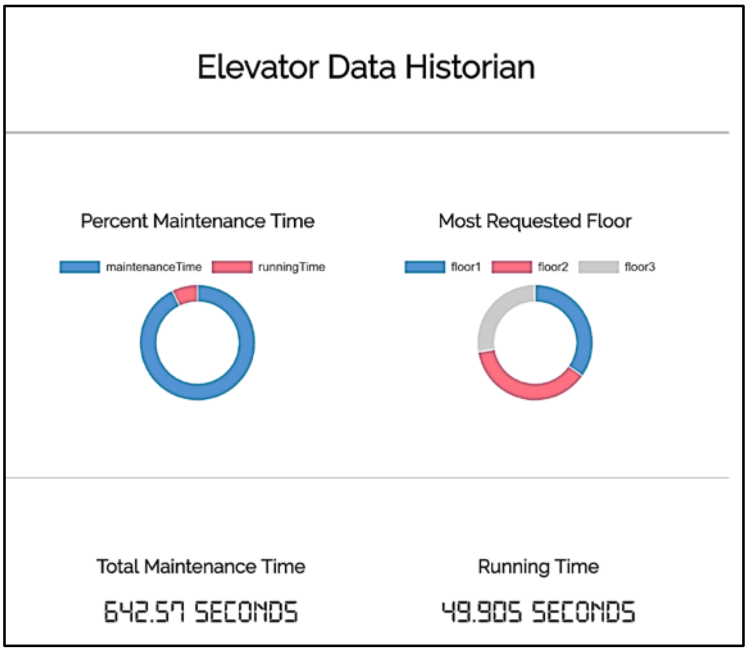

Figure 6. Data hisrian

The HMI was developed using HTML, CSS, and JavaScript for the front-end, and PHP for the back-end. A JavaScript repository called Chart.js was used to visual the data. AJAX and JSON were used to bridge the data between JavaScript and PHP. The data is hosted on Amazon Web Services using their Relational Database Service. The database was made using MySQL and contains one table with 6 rows: ID, floor1Count, floor2Count, floor3Count, maintenanceTime, and runningTime. A PHP script queries this database to retrieve the relevant information. The request is then converted to JSON to make it accessible from JavaScript script. The JavaScript program then fetches this data and adds it to the Chart.js function to display the data.

Conclusions

The purpose of this technical project was to develop a modular, PLC controlled elevator. The elevator design is based on a Siemens motor and Siemens PLC. The elevator is contained within two server racks, which act as a foundation and housing for the entire project. The elevator shaft and pulley system operate between the two racks and all major components are mounted on the back of one server rack. On the other rack, it has left space for a number of pushbuttons to control the elevators movement and maintenance modes. The elevator is purposefully built with modularity. Each component of our elevator can easily be added or taken away to provide extra functionality for the elevator depending on the situations it is used in. The elevator is equipped with a connection to a web based HMI and data historian. However, this component can be easily shut off to focus on the physical control of the elevator.

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