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Integration of Artificial Intelligence in Elevators

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First and foremost, we express our profound gratitude to ALLAH, whose guidance, blessings, and support have enabled us to complete this work.

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Abstract

In this work, a smart elevator system combining artificial intelligence and Schneider automation is proposed. A Raspberry Pi 5 is used for intelligent decision-making, facial recognition, and predictive maintenance, supported by DHT and MPU6050 sensors that monitor temperature, humidity, and vibration. A Schneider TM221CE16T PLC controls the motor, door movement, and essential elevator processes, while real-time data from the Raspberry Pi ensures accurate and safe operation. The system also includes a Magelis HMI programmed with Vijeo Designer to provide clear visualization and manual control. This integrated design enhances safety, reliability, performance, and user interaction within the smart elevator.

Résumé

Dans ce travail, un système d’ascenseur intelligent combinant l’intelligence artificielle et l’automatisation Schneider est proposé. Un Raspberry Pi 5 est utilisé pour la prise de décision intelligente, la reconnaissance faciale et la maintenance prédictive, en s’appuyant sur les capteurs DHT et MPU6050 pour mesurer la température, l’humidité et les vibrations. L’automate programmable Schneider TM221CE16T assure le contrôle du moteur, du mouvement des portes et des fonctions essentielles de l’ascenseur, tandis que les données en temps réel envoyées par le Raspberry Pi garantissent un fonctionnement précis et sûr. Le système intègre également un écran Magelis HMI programmé avec Vijeo Designer pour une visualisation claire et un contrôle manuel. Cette intégration améliore la sécurité, la fiabilité, la performance et l’interaction utilisateur dans l’ascenseur intelligent.

الملخص

في هذا العمل، يُقترح نظام مصعد ذكي يجمع بين الذكاء الاصطناعي وتقنيات الأتمتة من شنايدر. يتم استخدام Raspberry Pi 5 لاتخاذ القرارات الذكية، والتعرف على الوجه، والصيانة التنبؤية، بالاعتماد على حساسي (DHT) وMPU6050 لقياس درجة الحرارة والرطوبة والاهتزاز. ويتولى المتحكم المنطقي القابل للبرمجة Schneider TM221CE16T التحكم في المحرك، وحركة الأبواب، والعمليات الأساسية للمصعد، بينما تضمن البيانات الفورية المرسلة من Raspberry Pi دقة التشغيل وسلامته. كما يتضمن النظام شاشة Magelis HMI المبرمجة بواسطة Vijeo Designer لعرض المعلومات والتحكم اليدوي بوضوح. ويسهم هذا التكامل في تعزيز السلامة والموثوقية والأداء وتفاعل المستخدم داخل المصعد الذكي .

General introduction

In recent years, the rapid growth of urban populations and the increasing demand for high-rise buildings have created a strong need for efficient and intelligent vertical transportation systems. Smart elevators have emerged as a key innovation in this context, combining advanced control technologies, sensors, and artificial intelligence to improve performance, safety, and user experience. Unlike conventional elevators, which operate based on simple mechanical and electrical logic, smart elevators can analyze real-time data, optimize energy consumption, predict maintenance needs, and even identify users through biometric systems such as face recognition. These capabilities contribute to reducing operational costs, minimizing downtime, and enhancing passenger comfort and security. As cities continue to grow vertically, smart elevators play a crucial role in shaping the future of intelligent and sustainable building infrastructures.

In chapter one the fundamentals and evolution of elevator systems is presented. Hardware and software description is explained in chapter two. Design, realization, simulation and practical tests have been discussed in chapter three. In addition, results and discussions are given. Finally, a conclusion is given.

CHAPTER 1

FUNDAMENTALS AND EVOLUTION OF ELEVATOR SYSTEMS

I.1 Introduction

In recent decades, urban expansion and the vertical growth of cities have increased the demand for more efficient and intelligent vertical transportation systems. Elevators have evolved from simple mechanical systems into complex, electronically controlled smart systems, driven by technological advancements, energy efficiency requirements, safety considerations, and the pursuit of enhanced user experience.

This chapter aims to provide a comprehensive overview of elevator systems as a foundation for understanding the development of smart elevators, by reviewing their history and evolution, various types, main components, and the latest innovations in the field. Thus, this chapter sets the stage for subsequent chapters that will explore the concept of the smart elevator and its role in shaping the future of vertical transportation.

I.2 Background

One hundred fifty years ago, cities appeared significantly different than they do today. Often, the cityscape was flat and uniformly patterned. The heights of residential and commercial structures were rarely as tall as flagpoles. However, today, cities are growing vertically. Population increases, rapid urban regeneration, rising land prices, active agglomeration, ego, and globalization drive building upward. Indeed, the race to build the world’s highest skyscraper seems to go on forever, reaching ever-impressive heights. Around the beginning of the new Millennium, in 1998, Kuala Lumpur, Malaysia, built the 452 m (1483 ft) Petronas Towers, snatching the title of the world’s tallest building from the 442 m(1450ft) Sears Tower (renamed Willis Tower) constructed in 1973 in Chicago. In 2004, Taipei, Taiwan, erected the 508 m (1667 ft) Taipei 101. In 2010, Dubai, UAE, built the 828 m (2717 ft) Burj Khalifa, the world’s tallest. As such, in just 12 years, the height of the tallest building almost doubled [1,2].

Besides globalization and land prices, the rapid increase in urban population forces cities to build upward. The United Nations predicts that 70% of the world population in 2050, about 9.7 billion, will live in urban areas, up from 51% in 2010. Such an increase entails adding almost a quarter million urban dwellers globally every week. To expand cities horizontally to accommodate urban population increase, we will face sprawl problems. Sprawl has caused numerous economic, social, and environmental crises and is an unsustainable way to grow. After learning the hard lessons of urban sprawl ills, planners have reverted to the vertical and compact model [3]. As such, since the turn of the century, many cities have been erecting high-rises worldwide.

High-rise buildings consume more energy than low-rise buildings for many reasons, including the employment of vertical transportation. Elevators use between 5 and 15% of a high-rise building's power, so efforts to reduce their energy consumption are worthwhile. Further, elevators use significant valuable space in a skyscraper. Sometimes, they may occupy 25–40% of the floor plans. Of course, this figure includes all elevators (e.g., passenger, freight, emergency, and shuttle). Therefore, reducing the required space and number of shafts is a sought-after goal in elevator design [1].

I.3 New Elevator Systems

Like automobiles and rail transport, elevators are becoming increasingly high-tech, pushing manufacturers to improve elevator speed and safety. The development of elevator speed has been astounding. If we compare the speed of the first passenger elevators (12 m per minute) to that of the world's fastest elevators (1200 m per minute) located at the CTF Finance Center in Guangzhou, China, the speed has increased one hundredfold. For improving passenger flow, destination dispatching systems are most efficient. When passengers click buttons corresponding to their desired floors, the system directs them to the elevators with the shortest travel times. Enhanced routing will result in more efficient passenger transfer, especially during peak traffic in hotels, residences, and offices. Further, new systems allow building managers to program elevators to correspond most efficiently to passengers' demands throughout the week, day, night, and holidays [4].

As time passes, elevators are becoming more intelligent and safer. Modern elevators provide smooth, comfortable journeys for passengers while covering greater distances, reducing the need to use transfer or sky lobbies. They are also energy-efficient; some produce energy, such as the regenerative drive. New design promises to make elevators move not only up and down but also sideways and diagonally. Such innovative design will revolutionize the architecture and layout of high-rise developments. It will allow buildings to achieve more excellent connectivity and improve people flow [4].

However, building elevators are not an exception to the harsh reality that everything eventually wears out and must be replaced. Even with routine maintenance, old machinery always requires updates. Modernizing elevators is a feasible way to increase the value and appeal of a tall building. Intelligent elevator systems provide enhanced travel comfort and the flexibility to adapt to changing building requirements, thereby enhancing performance [5,6]. Internet-connected elevators represent the cutting edge of elevator maintenance. This technology notifies building managers in real-time when a problem is beginning to develop. This is intended to reduce maintenance expenses and save time. Sensors gather data on variables, such as usage, that can impact the deterioration of components. The data are sent to a cloud-based platform for processing and analysis, enabling building managers to apply proactive measures, preventing problems from occurring [4].

I.4 Definition of an elevator

An elevator is a platform or enclosed compartment used for transporting people or goods vertically between floors in a building. Elevators are typically powered by electric motors and operate with the help of cables, pulleys, and counterweights [4].

Elevator, car that moves in a vertical shaft to carry passengers or freight between the levels of a multistory building. Most modern elevators are propelled by electric motors, with the aid of a counterweight, through a system of cables and pulleys [7].

I.5 Elevator Types

In tall buildings, different basic types of elevators are often employed [5,8]

I.5.1 Passenger elevator

A passenger elevator’s primary purpose is to transport people or lightweight goods. Conventionally, passenger elevators are calculated for weight loads of between 907 kg and 2268 kg ; however, some models are available with higher load ratings. These weight measures correspond to car areas that range between 2.3 and 5.1 m2 (25 and 55 ft2). Therefore, these elevators usually take lighter loads and are smaller than freight elevators [5,8].

Figure I.1. Passenger elevator [9]

I.5.2 Freight elevator

These are designed to transport heavy goods and equipment. They are characterized by doors that open vertically (such as cage doors), and they are robust but have unsightly finishes. Individual buttons are necessary for freight elevators to call the car and open and close the doors. Yet, a freight elevator is less automated than a standard elevator, so the user has less control over how the elevator works [5,8].

Figure I.2. Freight elevator [9]

I.5.3 Service elevator

These elevators carry both people and light equipment simultaneously. Not to be confused with freight elevators, the shape of service elevator cars is deep and narrow, making it easier to load long cleaning carts, supply carts, and similar lightweight equipment. In contrast, passenger-shaped elevator cars are often shallow and wide, making it easier for passengers to enter and exit the front of the elevator without becoming trapped in the back. In addition to the front door, rear doors are available on both passenger and service car designs [5,8].

Figure.I.3. Service elevator [9]

I.5.4 Shuttle Elevator

The shuttle elevator travels rapidly between lobby floors. To reach their desired floor, travelers switch to a local elevator on the lobby level. Connecting high-capacity/high-speed shuttle elevators with local elevators makes traveling efficiently throughout a tall structure possible. Not only do the elevator/shuttle systems save space, but they also save time [5,8].

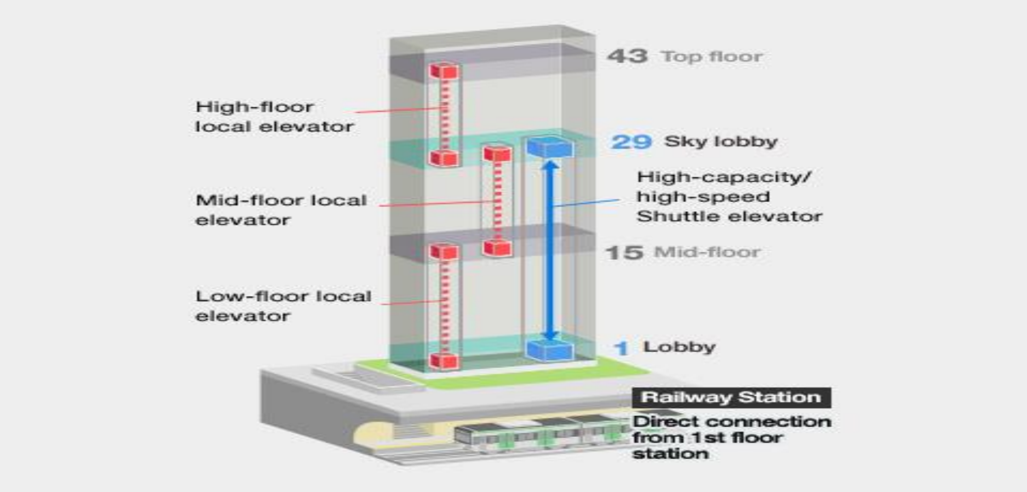


Figure I.4. Shuttle elevator [10]

These elevators are installed so that fire crews can reach the upper floors to conduct necessary rescue procedures and evacuate trapped tenants. Since other elevators (including passenger elevators) are shut during a fire incident, emergency elevators are paramount. They are also crucial for disabled people. During fire incidents, tenants with mobility impairments are evacuated via emergency elevators with the assistance of firefighters [5,8].

I.6 Main Elevator Systems

There are two main types of elevator systems: hydraulic and traction. Hydraulic Elevators obtain power from hydraulic jacks, fluid-driven pistons inside a cylinder. In contrast, steel ropes or belts are wound around pulleys and used to operate traction elevators [3].

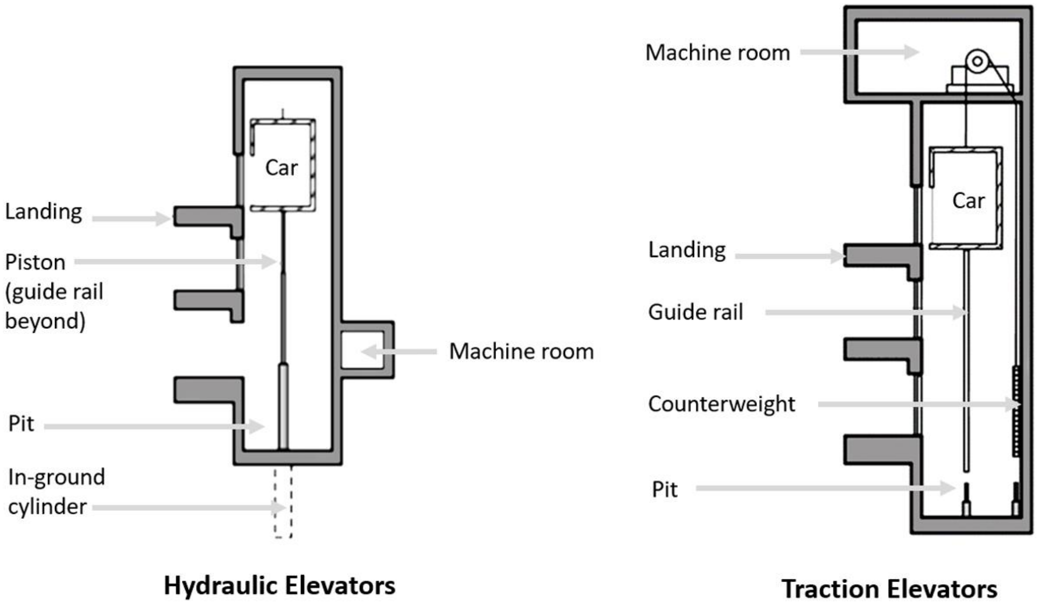


Figure I.5. A schematic illustration of the differences between hydraulic and traction elevators [3]

I.6.1 Hydraulic Elevators

Hydraulic elevators are the systems that provide the ability to drive through the hydraulic pump unit. In hydraulic elevators, the weight of the elevator car is used in downward movements. The engine room of the hydraulic lift is usually designed to be on the ground floor. In the engine room, there is an oil boiler and a hydraulic system, a control panel, and hoses through which the hydraulic fluid passes. In this system, within the elevator shaft, elevator car, carrier carcass, cylinder piston system, suspension device, if there are bumpers counterweight assembly [11].

I.6.1.1 Types of Hydraulic Elevators

- **In-Ground or Holed Hydraulic Elevator**

It shares similarities with conventional hydraulic elevators, but differs in that they are installed below the elevator shaft, in a designated pit. This particular installation method makes them a favored choice for retrofitting older buildings that lack the space for an overhead machine room [12].

- **Hole-Less Hydraulic Elevator**

  Utilize a telescoping piston system that eliminates the need for a separate cylinder and pit, resulting in a more space-efficient option that does not require excavation below the elevator shaft [12].

- **Roped Hydraulic Elevator**

  Combine hydraulic and mechanical systems to vertically transport the elevator cab. They feature a piston and cylinder system, similar to conventional hydraulic elevators, but also utilize ropes and a sheave system to provide added support and stability [12].

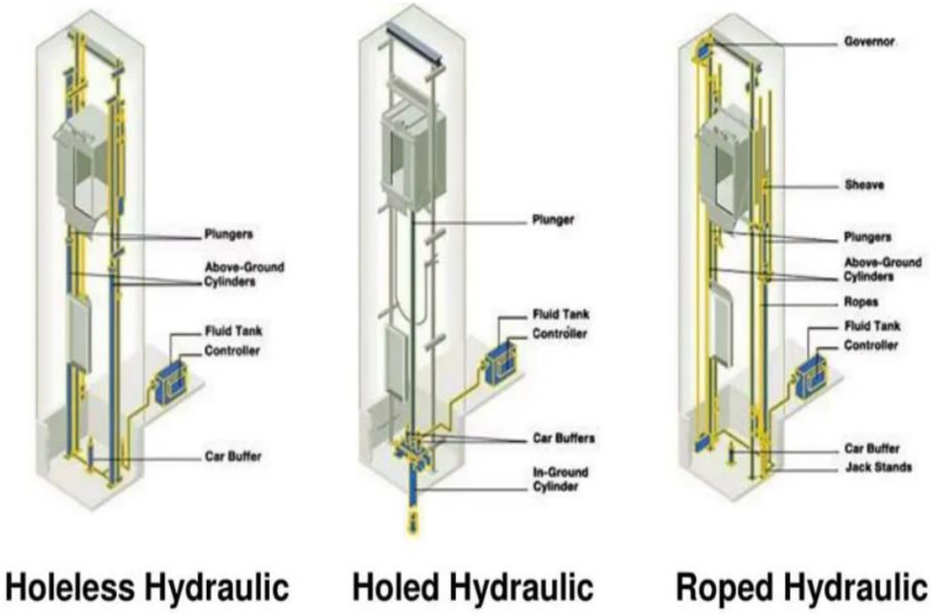


Figure I.6. Types of Hydraulic Elevators [12]

I.6.2 Traction Elevators:

A traction elevator, also referred to as an electric elevator or cable-driven elevator, is a type of elevator that utilizes ropes or cables along with a motor-driven pulley system for vertical transportation of people or goods between floors in a building. This type of elevator is suitable for use in various building types and is recognized for its efficiency, speed, and versatility [12].

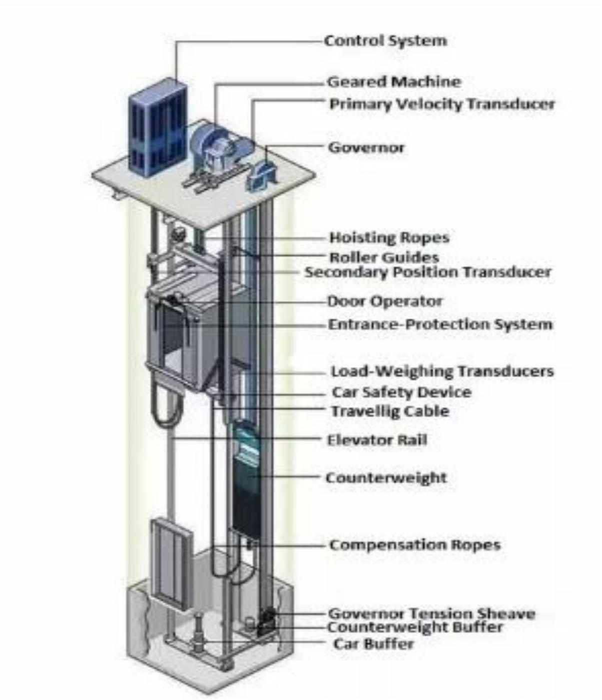


Figure I.7. Traction elevator [12]

I.6.2.1 Types of Traction Elevators

- **Geared Traction Elevator:**
  Utilize a gearbox and a motor to drive the elevator car through a hoist rope. They are commonly installed in medium to high-rise buildings and have a maximum weight capacity of 10,000 pounds. Geared traction elevators are praised for their smooth and quiet ride, and are often found in office buildings, hotels, and residential buildings [13].
- **Gearless Traction Elevator:**
  Utilize a motor that is directly connected to the hoist rope, eliminating the need for a gearbox. This design enables higher speeds and weight capacities compared to geared traction elevators, with maximum weight capacities of up to 25,000 pounds. Gearless traction elevators are commonly used in tall buildings such as skyscrapers and offer a smooth and quiet ride [13].
- **MRL Traction Elevator:**
  Integrate the elevator equipment into the shaftway, eliminating the need for a separate machine room. This design saves space and reduces installation costs, making it a

popular choice for modern buildings. MRL traction elevators are available in both geared and gearless versions [13].

I .7 Recent Developments and Advances in Elevator Systems

I.7.1 Regenerative Drive

The regenerative motor, which enables "heat" energy to be recycled rather than squandered, is a critical advancement in energy-efficient elevator technology. It works by gathering and transforming the energy lost during braking, which is necessary to maintain the elevator's speed. In other words, it converts the mechanical "heat" energy generated by braking into electrical energy ("regenerated"), which is then transferred to the building power system. An elevator applies a brake in three cases: (1) when it goes up with a load of passengers lighter than the counterweight, (2) when it goes down with a load of passengers heavier than the counterweight, and (3) when it goes down with a load of passengers lighter than the counterweight. In these cases, the motor functions as an energy generator, converting mechanical energy into electrical energy and channeling it back into the facility's electrical system. Another elevator or other electrical devices can use the generated power. Importantly, these little quantities of energy generated during the brakes build up to significant savings over time. Regenerative drives can lower the energy consumption of a building transportation system by up to 70% [14,15]. The energy needed to run the HVAC system is also reduced because the structure and machinery exposed to the excessive heat produced by conventional motors no longer need to be cooled in the new system [16]. Despite the higher costs of the generative drive model, more buildings are embracing it due to its energy efficiency.

I.7 .2 Elevator Rope

Because it links the elevator engine with the cab, sheaves, and counterweight, the elevator rope is a crucial part of traction elevators. Steel ropes hold cabins. However, in very tall buildings, the rope gets too long and too heavy to the point that it cannot support its own weight. As height increases, starting currents and energy usage rise, increasing energy consumption. In other words, the combined weight of the steel ropes required to operate elevators to supertall heights is the largest obstacle. Each elevator requires six to eight ropes, and at a certain height, it becomes impractical to utilize them for single runs on supertall structures, forcing builders to incorporate one or more transfer levels, or "sky lobbies". In response to this challenge, elevator manufacturers have been strengthening cables. The Schindler aramid fiber rope is more robust and lighter than steel. Otis' tiny Gen2 elevators use ultra-thin wires encased in polyurethane instead of steel ropes. Mitsubishi produced a more potent, denser string with concentric steel wire (Figure I.8). These more robust, lighter cords move elevator cabs more efficiently, conserving energy [17,18,19]. The KONE "UltraRope" is the most significant breakthrough. It has a carbon-fiber core and a unique high-friction coating, allowing cars to travel up to 1,000 m (3,280 ft). This is twice the current 500 m (1,640 ft) limit. A 1000-m UltraRope weighs 10% of steel ropes. The 90% reduction in rope mass saves considerable energy. The 1-kilometer, 3,281-foot-tall Jeddah Tower in Saudi Arabia (construction on hold) plans to install the super-light KONE Ultra Rope elevators, reducing the number of required sky lobbies. Using UltraRope, an elevator can travel the breathtaking 653 meters from the Jeddah Tower's base to its observation deck in just one trip. In South Quay Plaza, one of the highest residential buildings in Europe and the first to be outfitted with KONE UltraRope, eight of these elevators were built [18]. In the future, technology such as UltraRope will enable elevators to ascend higher and reduce the need for sky lobbies. During the next iteration, KONE plans to devise methods for moving people that high and quickly while ensuring their safety and well-being particularly related to variations in pressure and temperature at high altitudes [2].

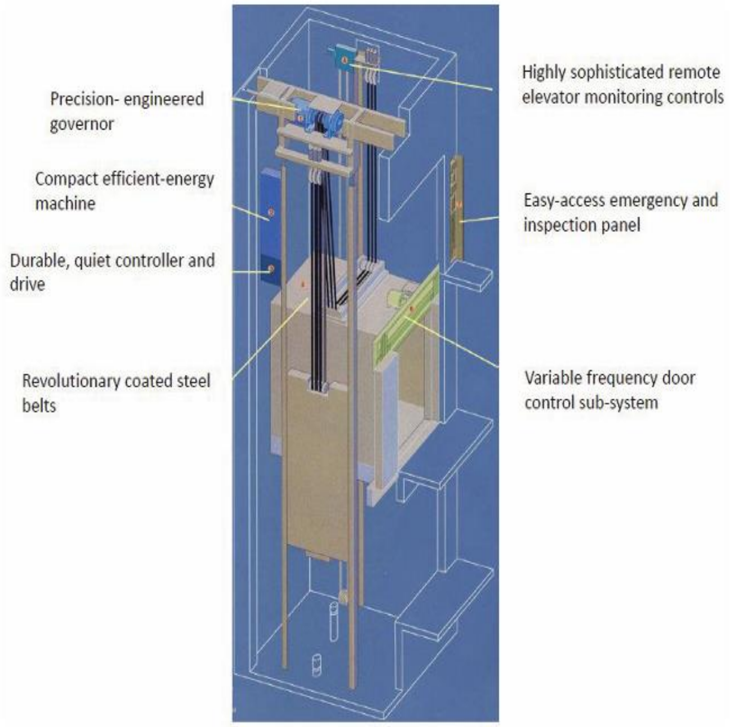


Figure I.8. Diagram of OTIS GeN2 lift [2]

I.7.3 Double-deck elevators

A double-deck elevator consists of two stacked cabs where one serves floors with even numbers, and the other serves floors with odd numbers. As skyscrapers get higher, reducing the number of elevators needed becomes more important because they eat up valuable interior space on every floor (Figure I.9). Double-deck elevators are most useful for applications in very tall buildings, particularly for shuttle services [17,18]. How ever, the double-deck elevators suffer from some operational challenges. Equal floor rise could present a limitation; i.e., for local service, double-deck elevators must load and unload two decks simultaneously. Even though traffic is reduced during off-peak hours, both decks will be operating [20,21].

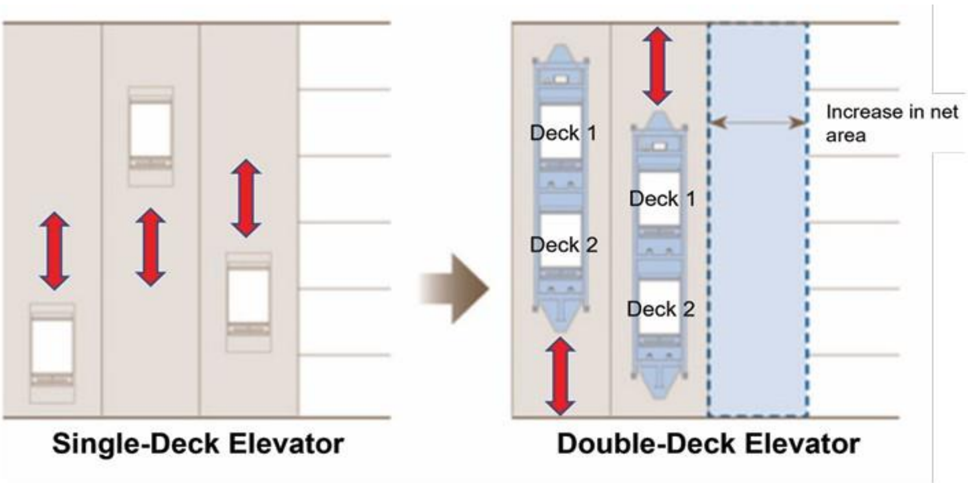


Figure I.9. Double-deck elevators save on the number of shafts [2]

I.7.3 The TWIN systems

Sharing similar characteristics with double deck systems, TWIN is an elevator system in which two standard cabs are installed within the same shaft but operate independently. A device that monitors the distance between two elevators prevents them from collisions (Figure 1.9). A computerized system optimizes travel for both cabins by assigning passengers to the most efficient locations, reducing wait time and empty journeys, and saving energy [21-22]. Simply, the system enables more elevators with fewer shafts – it is estimated to require one-third fewer shafts than conventional elevators, saving core space. In addition to freeing up valuable space, the TWIN system reduces the required building materials for shafts, decreasing embodied energy. Because there is just one control machine for both elevators in the same shaft, significant space and energy are saved as a result of this design decision [23,24].

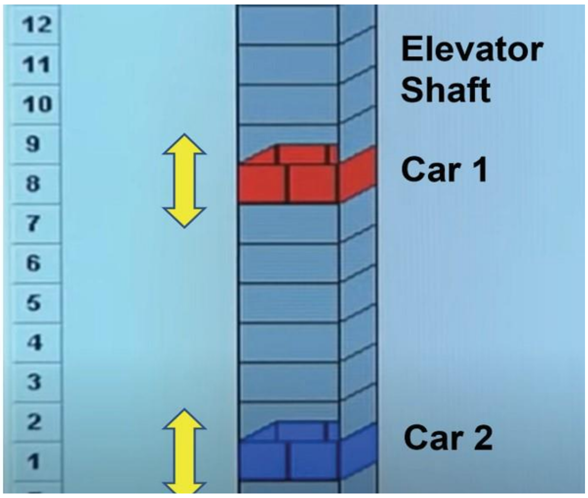


Figure I.10. the TWIN system [2]

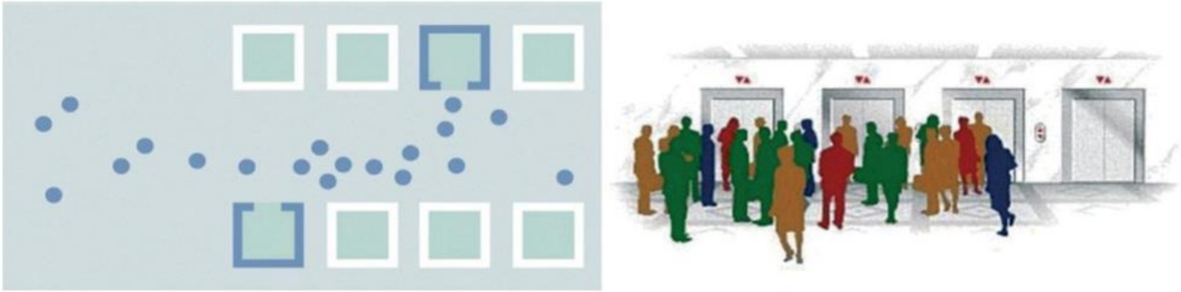
Figure I.10. In the TWIN system, each shaft holds two cars that operate independently. A computerized system along sensors coordinates their movements and ensure no collisions [2].

I.7.4 Energy-efficient software

Research on elevator traffic shows that an elevator's operation cycle greatly affects its energy use. Factors such as the number of floors served, peak and low usage periods, and empty trips are key in building energy consumption models. These models support efficient management and control strategies, increasingly aided by modern software tools [18,25].

I.7 .4.1 Destination dispatching systems

Traditional elevators respond to up and down button calls, which works well in low-traffic buildings. However, in high-traffic situations, multiple calls lead to frequent stops and longer travel times—each stop in a high-speed elevator (6 m/s) can add 10–13 seconds. To address this, the **Destination Dispatching System (DDS)** was developed in the 1990s, following advances in microprocessor technology. DDS optimizes multi-elevator use by grouping passengers with similar destinations into the same elevator. Passengers input their destinations via keypads or touchscreens on a **Destination Operation Panel (DOP)**, typically located in the lobby. The system then assigns them to the most efficient elevator, reducing stops and improving travel efficiency. [19,26] (Figure I.11).



Conventional dispatching system

Destination dispatching system

Figure I.11. Conventional (top) versus destination dispatching system (bottom) [2]

I.7 .4.2 People flow solutions

People Flow Solutions, much like the DDS, are intended to regulate demand on elevators and improve the flow of foot traffic, but primarily in more extreme circumstances. For example, KONE’s Advanced People Flow Systems provide enhanced safety, convenience, and comfort. They integrate access and destination control, communication, and equipment monitoring to provide a seamless experience for users moving between facilities [18,27]. A solution that is both modular and linked, enabling tailored user experiences and touchless access that can be adapted to meet the specific requirements of a building [2].

I.7.4 .3 Standby mode

Standby mode allows elevators to enter a low-power "sleep" state during periods of low usage, typically when demand is minimal throughout the day. Although elevators are idle most of the time, they still consume power to remain ready for service. The standby system reduces energy consumption by shutting down non-essential functions—such as lights, fans, music, and screens—when the elevator is not in use. This energy-saving feature can cut total elevator power usage by 25% to 80%, depending on the specific equipment and control systems in place [24,28].

I.7 .4.4 Predictive maintenance Apps

The development of AI and machine learning algorithms has enabled real-time monitoring of elevator systems. Modern apps now support predictive maintenance by analyzing elevator data to detect issues early, notify building owners, and sometimes resolve problems automatically. Through IoT devices connected to the elevator controller, detailed information can be collected to identify faults before failure and assist technicians with repairs. These apps provide building owners with instant insights via mobile devices, improving building management [28,29].

I.8 Conclusion

In this chapter, we provided a brief overview of what an elevator is, along with its most common uses, components, and the recent developments that have shaped modern elevator systems. These insights highlight how elevator technology has evolved to become more efficient, safer, and smarter.

In the next chapter, we will explore the essential hardware and software components that form the foundation of the smart elevator system.

CHAPTER 2

SOFTWARE AND HARDWARE PRESENTATION

II.1 Introduction

In this chapter, the hardware and software components of the proposed intelligent elevator system are presented. The aim is to describe, from a theoretical perspective, the different parts of the system, highlighting their main characteristics, functions, and the reasons for their selection.

The integration of artificial intelligence (AI) into an elevator system serves two main purposes:

1. **Enhancing security** by implementing face recognition technology to ensure that only authorized individuals can access specific floors or use the elevator.
2. **Improving maintenance efficiency** through predictive maintenance algorithms that analyze sensor data to detect abnormal patterns, allowing potential faults to be identified and resolved before they cause service interruptions.

By achieving these objectives, the intelligent elevator can reduce downtime, extend the lifespan of mechanical components, optimize maintenance schedules, and provide a safer, more reliable service to users.

The hardware section of this chapter focuses on the physical components responsible for data acquisition and processing, such as the central control unit, sensors, and peripheral devices. The software section introduces the operating systems and development environments that enable the implementation of the desired functionalities.

The following table summarizes the main components of the system, divided into **hardware** and **software** categories:

Category	Component	Function
Hardware	Raspberry Pi 5	Central processing and control unit
	USB Webcam	Image acquisition for face recognition
	MPU6050 Gyroscope & Accelerometer	Vibration and motion detection
	Infrared Speed Sensor	Measurement of elevator speed

Category	Component	Function
	AM2301A Temperature & Humidity Sensor	Monitoring environmental conditions
Software	Power Supply & Wiring Accessories	Providing stable power and physical connections
	Raspberry Pi OS	Operating system for Raspberry Pi
	Python Programming Environment	Development platform for algorithms
	EcoStruxure Machine Expert and Vijeo Designer	Industrial control programming platform (PLC) HMI design software for system monitoring and data visualization

Tab II.1. The main components of the system

This combination of hardware and software ensures that the intelligent elevator system can operate efficiently, securely, and with the ability to predict potential issues, thus improving both **user safety** and **system reliability**.

II.2 Hardware Presentation

II.2.1 Raspberry Pi 5

Figure. II.1. The Raspberry Pi 5 [30].

The **Raspberry Pi 5** serves as the **central processing and control unit** of the intelligent elevator system. It is a compact, low-cost single-board computer developed by the Raspberry

Pi Foundation, designed to provide high performance in a small form factor while supporting a variety of peripherals and sensors [30].

In the proposed system, the Raspberry Pi 5 performs two primary roles:

1. **Processing visual data** from the USB camera to perform face recognition using AI-based algorithms.
2. **Collecting and analyzing sensor data** from the MPU6050 gyroscope, infrared speed sensor, and AM2301A temperature/humidity sensor to implement predictive maintenance capabilities [30].

Equipped with a **quad-core ARM Cortex-A76 CPU** and high-speed I/O interfaces, the Raspberry Pi 5 can manage concurrent tasks efficiently, which is essential for real-time applications such as image processing and sensor monitoring [30]. Its built-in **Wi-Fi** and **Bluetooth** modules enable wireless communication with mobile devices and remote monitoring platforms, facilitating data exchange and system control [31].

Specification	Value
Processor	2.4 GHz quad-core ARM Cortex-A76
RAM	4 GB or 8 GB LPDDR4X
Storage	microSD card (supports up to 512 GB)
Connectivity	Wi-Fi 802.11ac, Bluetooth 5.0, Gigabit Ethernet
USB Ports	2 × USB 3.0, 2 × USB 2.0
Video Output	2 × micro-HDMI (up to 4Kp60)
GPIO	40-pin header (backward compatible)
Power Supply	USB-C (5V, 5A)
Dimensions	85.6 mm × 56.5 mm

Tab II.2. Technical Specifications of Raspberry Pi 5

The decision to use the Raspberry Pi 5 is based on its combination of **computational power, connectivity, and flexibility**. Unlike microcontrollers, it runs a complete operating system, allowing the integration of advanced AI frameworks, multi-threaded programs, and real-time monitoring systems [31. This makes it a suitable choice for a project requiring both **intelligent image processing** and **multi-sensor data acquisition** in an embedded environment [32].

II.2.2 USB Webcam

Figure. II.2. The USB webcam [33].

The **USB webcam** is responsible for capturing real-time images and video streams, which are then processed by the Raspberry Pi 5 to perform **face recognition**. In this project, the camera is connected directly via a USB 2.0 or USB 3.0 port, ensuring a stable and fast transfer of image data to the processing unit [33].

The choice of a USB webcam, as opposed to the official Raspberry Pi Camera Module, is motivated by factors such as **cost-effectiveness**, **plug-and-play compatibility**, and **broad driver support** across multiple operating systems [31]. Most USB webcams can be used without additional hardware modifications, making them ideal for prototyping and experimental setups [31].

In the proposed intelligent elevator system, the webcam performs the following tasks:

1. **Image Acquisition** – capturing the face of the user in the elevator cabin or at the entrance.
2. **Data Transfer** – sending raw image frames to the Raspberry Pi 5 for preprocessing.
3. **Integration with AI Models** – allowing real-time execution of face detection and recognition algorithms to verify user identity.

For effective face recognition, the webcam should have:

- **Resolution**: at least 720p HD for accurate detection.
- **Frame Rate**: minimum 30 FPS for real-time operation.
- **Low-Light Performance**: to maintain accuracy in poorly lit elevator environments.

Specification	Value
Resolution	1280 × 720 (HD) or 1920 × 1080 (Full HD)
Frame Rate	30 FPS (minimum)
Focus Type	Fixed or Auto-focus
Interface	USB 2.0 / USB 3.0
Field of View	60–90 degrees
Compatibility	Linux, Windows, macOS

Tab II.3. Example Specifications of a Suitable USB Webcam

The integration of the USB webcam in the elevator system ensures **secure access control** by authenticating users before granting them permission to operate the elevator or reach restricted floors. When combined with AI algorithms, it allows **contactless identification**, which improves hygiene and convenience, especially in public spaces [34].

II.2.3 MPU6050 Gyroscope and Accelerometer

Figure. II.3. The MPU6050 [35].

II.2.3.1 Description of MPU6050

The **MPU6050** is a compact and cost-effective motion-tracking device that integrates a **3-axis gyroscope** and a **3-axis accelerometer** on the same silicon chip. It is widely used in embedded systems for detecting **orientation, acceleration, and rotational motion**, making it suitable for vibration analysis and movement monitoring in mechanical systems such as elevators [35].

In the proposed intelligent elevator system, the MPU6050 is installed inside the elevator cabin or on a structural component to:

1. **Detect Abnormal Vibrations** – monitoring irregular motion patterns that may indicate mechanical wear or imbalance.
2. **Measure Tilt and Acceleration** – ensuring smooth operation and detecting abrupt starts or stops.
3. **Provide Data for Predictive Maintenance** – feeding vibration and motion data into AI algorithms to predict possible faults before they occur.

The MPU6050 communicates with the **Raspberry Pi 5** using the **I²C (Inter-Integrated Circuit)** protocol, allowing efficient data transfer with minimal wiring [35].

Specification	Value
Gyroscope Range	±250, ±500, ±1000, ±2000 °/s
Accelerometer Range	±2, ±4, ±8, ±16 g
Communication Interface	I²C (400 kHz)
Operating Voltage	2.3–3.4 V
Power Consumption	3.9 mA (active mode)
Package Dimensions	4 × 4 × 0.9 mm

Tab II.4. Technical Specifications of MPU6050

II.2.3.2 Advantages of Using MPU6050 in the Elevator System

- **Compact Size**: can be easily integrated without modifying the elevator's structure.
- **High Sensitivity**: capable of detecting small variations in movement.
- **Real-Time Data**: provides continuous readings for instant analysis by the AI model.

The inclusion of the MPU6050 enables the intelligent elevator to perform **real-time vibration analysis**, which is a critical component of predictive maintenance. By identifying unusual motion patterns, the system can schedule maintenance before a failure occurs, reducing downtime and improving passenger safety [36][37].

II.2.4 Infrared Speed Sensor

II.2.4.1 Description of the infrared (IR) speed sensor

The **infrared (IR) speed sensor** is an optical sensing device designed to detect the rotational or linear speed of moving components without direct physical contact. It operates by emitting infrared light toward a reflective surface or an object passing in front of the sensor. The reflected signal is then detected by a photodiode or phototransistor, allowing the system to measure speed based on the time intervals between reflections [38].

Figure. II.4. The infrared (IR) speed sensor [38].

In the intelligent elevator system, the IR speed sensor plays a critical role in:

1. **Monitoring Elevator Motion** – measuring the speed of the cabin to ensure compliance with safety limits.
2. **Detecting Abnormal Speed Changes** – identifying sudden acceleration or deceleration that may indicate mechanical or control system faults.
3. **Supporting Predictive Maintenance** – providing data for AI algorithms to detect patterns related to potential failures in the motor or braking system.

This sensor is typically mounted near the moving parts of the elevator (e.g., pulley, motor shaft, or guide rails) where it can detect rotational or linear motion without being exposed to physical wear [38].

Specification	Value
Detection Method	Infrared reflection
Detection Distance	2–30 mm (adjustable)
Output Signal	Digital (High/Low)
Supply Voltage	3.3–5 V
Response Time	< 1 ms
Operating Temperature	−10°C to 50°C
Interface	GPIO / Interrupt pin

Tab II.5. Technical Specifications of a Typical IR Speed Sensor

II.2.4.2 Advantages of Using IR Speed Sensor in the Elevator System

- **Non-contact measurement**: avoids wear and tear.
- **High response speed**: suitable for real-time monitoring.
- **Low power consumption**: ideal for embedded systems.
- **Reliability in various lighting conditions**: infrared operation is less affected by ambient light changes.

By integrating the IR speed sensor with the **Raspberry Pi 5**, the elevator system can continuously track cabin speed, log motion data, and detect anomalies in real-time. This enhances both **passenger safety** and **system reliability** [39][40].

II.2.5 DHT11 Temperature and Humidity Sensor

II.2.5.1. Description of the DHT11 Temperature and Humidity Sensor

The DHT11 is a low-cost digital sensor that measures both ambient temperature and relative humidity with reasonable accuracy for general environmental monitoring applications. It is widely used in embedded systems because of its simple communication protocol, low power consumption, and compact design [41].

Figure. II.5. The DHT11 Temperature and Humidity Sensor [41].

In the intelligent elevator system, the DHT11 is employed to:

1. **Monitor Cabin Comfort Levels** – ensuring that temperature and humidity remain within acceptable limits for passenger comfort.
2. **Assist Predictive Maintenance** – detecting environmental conditions that may accelerate wear or cause faults in sensitive electronic components.
3. **Trigger Automated Actions** – such as activating ventilation fans or climate control systems if temperature or humidity exceed preset thresholds [41].

The DHT11 communicates with the **Raspberry Pi 5** via a **single-wire digital interface**, which minimizes the number of connections required and simplifies integration [41].

Specification	Value
Temperature Range	0°C to 50°C ±2°C accuracy
Humidity Range	20% to 90% RH ±5% accuracy
Output Signal	Digital (single-wire protocol)
Operating Voltage	3.3–5 V
Sampling Period	1 Hz (1 reading per second)
Power Consumption	< 2.5 mA during measurement
Dimensions	15.5 mm × 12 mm × 5.5 mm

Tab II.6. Technical Specifications of DHT11

II.2.5.2 Advantages of Using DHT11 in the Elevator System

- **Compact and lightweight**: suitable for integration inside the elevator cabin.
- **Low cost**: economical choice for environmental monitoring.
- **Sufficient accuracy** for non-critical temperature/humidity control.
- **Easy to interface** with Raspberry Pi via a single GPIO pin.

By including the DHT11, the elevator system gains the ability to monitor **environmental quality** inside the cabin. Data collected can also be logged for trend analysis, enabling detection of unusual patterns—such as excessive humidity that might indicate water ingress—before they lead to system degradation [42][43].

II.2.6. Schneider M221 controller 16 IO transistor PNP Ethernet

The Schneider Electric Modicon M221 programmable logic controller (PLC) is a compact and cost-effective solution for controlling, automating small to medium-sized machines and processes like our process of the smart elevator. The PLC provides reliable performance and flexibility in a compact form factor. The M221 PLC is designed to be energy-efficient, helping to reduce power consumption and operational costs in processes and industrial automation applications and that’s one of our objectives. Concerning programming it can be easy to configure it using Schneider Electric's use EcoStuxure MACHINE EXPERT software, which offers a user-friendly interface for creating and editing logic control. Figure II.1 shows M221 PLC [44].

Figure II.6. Schneider M221 Controller [44].

II.2.7. Human Machine Interface GTO2310 HMI:

II.2.7.1. Description of The GTO2310 HMI

The GTO2310 Human-Machine Interface (HMI) is a highly versatile and user-friendly interface designed for industrial control systems. It allows operators to interact with machines, monitor system parameters, and manage processes in real-time. The GTO2310 model stands out for its high-resolution display, compact design, and easy integration with a wide range of controllers. Its touchscreen capability makes it intuitive, providing operators with a seamless experience when controlling or configuring systems. This HMI is designed with a focus on both durability and clarity, ensuring that it can handle demanding industrial environments while offering a clear, responsive interface for users [44].

Whether used for simple control tasks or more complex process management, the GTO2310 is reliable and adaptable to various needs.

Figure II.7. GTO2310 HMI [44]

II.2.7.2 Applications of the GTO2310 HMI

The GTO2310 HMI finds use in a variety of industrial applications, from manufacturing processes to automation in different sectors. Its ability to connect seamlessly with controllers like PLCs (Programmable Logic Controllers) makes it an essential tool in monitoring and controlling automated systems [44].

In manufacturing, it can be used to monitor machine performance, set parameters, and quickly respond to system alerts. In energy management systems, it helps visualize power flows and control energy distribution. The GTO2310 is also commonly used in transportation systems, building automation, and industrial safety systems, offering an intuitive and centralized control interface [44].

II.2.7.3 Cabling for the GTO2310 HMI

1. **Power Supply:** The HMI operates on 24V DC, requiring properly rated 2-wire shielded cables (typically 1.5mm² or 16 AWG) for reliable power.
2. **Communication:**
   - Ethernet: Use CAT5e/CAT6 Ethernet cables for high-speed communication with the M221 controller or network.
   - RS232/RS422/485: Use shielded serial communication cables for direct serial communication, ensuring the proper pin configuration (TX, RX, GND).
   - USB: For programming or peripherals, use standard USB 2.0 cables.
3. **Grounding and Shielding:** Proper grounding and shielding of cables are necessary to prevent electrical noise and ensure reliable data transmission [44].

II.2.7.4 Role of the GTO2310 in Our Smart Elevator Process

In our smart elevator system, the GTO2310 HMI plays a pivotal role in providing both simulation and real-time control. It serves as the primary interface for operators to monitor the system's status, visualize the elevator's movements, and manage security features such as facial recognition. The HMI enables easy access to system parameters, floor selection, and fault detection, ensuring that the elevator operates smoothly and safely [44].

The touchscreen interface allows for quick configuration of system settings, making it simple to adjust operational parameters or respond to issues. By integrating the HMI with the M221 Schneider controller, the GTO2310 ensures that the elevator's movements are coordinated effectively, offering a clear and responsive interface for both simulation and live control. This integration greatly enhances the elevator’s user-friendliness and security management, making it an indispensable part of the overall system [44].

II.3 Software presentation

II.3.1 Raspberry Pi OS

II.3.1.1 Description

Raspberry Pi OS (formerly known as Raspbian) is the official operating system for Raspberry Pi devices, developed and maintained by the Raspberry Pi Foundation. It is based on the Debian Linux distribution and optimized for the ARM architecture, providing a stable, lightweight, and fully functional environment for running applications, managing hardware, and interfacing with various sensors and peripherals [45].

In the intelligent elevator system, **Raspberry Pi OS** serves as the main software platform for:

1. **Hardware Control**: managing communication between the Raspberry Pi 5 and connected devices such as the webcam, MPU6050, IR speed sensor, and DHT11.
2. **AI Processing**: hosting face recognition algorithms and predictive maintenance models.
3. **Data Logging and Management**: storing operational data, environmental readings, and motion statistics for analysis.
4. **Networking and Remote Access**: enabling remote monitoring, software updates, and system diagnostics through secure network connections [45].

II.3.1.2 Advantages of Raspberry Pi OS for this project

- **Compatibility**: supports a wide range of hardware drivers and software libraries required for AI and sensor integration.
- **Stability**: reliable performance for long-term operation in embedded applications.
- **Flexibility**: ability to install and configure multiple AI frameworks (e.g., scikit-learn , OpenCV).
- **Community Support**: large online community providing tutorials, troubleshooting, and software packages.

Feature	Description
Base System	Debian GNU/Linux
Architecture	ARMv8 (optimized for Raspberry Pi)
User Interface	LXDE-based desktop environment
Package Management	APT (Advanced Package Tool)
AI/ML Framework Support	scikit-learn, PyTorch, OpenCV
Networking	Ethernet, Wi-Fi, Bluetooth
Security Features	SSH, user permissions, firewall tools

Tab II.7. Key Features of Raspberry Pi OS

In this project, **Raspberry Pi OS (64-bit)** will be installed on a high-speed microSD card (at least 32 GB, Class 10), ensuring sufficient storage for AI models and operational logs. It provides the foundation upon which all other software layers—such as AI algorithms, sensor drivers, and monitoring interfaces—will be built [31][46].

II.3.2 Python Programming Language

II.3.2.1 Description of python

Python is a high-level, interpreted programming language known for its readability, simplicity, and extensive library support. It has become one of the most widely used languages in artificial intelligence, machine learning, and embedded systems due to its versatility and strong community support [47].

In the context of the intelligent elevator system, Python is chosen as the main programming language for several reasons:

1. **Ease of Integration with Hardware** – Python libraries such as RPi.GPIO, smbus, and Adafruit_DHT allow seamless communication with sensors like MPU6050, IR speed sensor, and DHT11.
2. **AI and Computer Vision Capabilities** – Python supports frameworks such as **OpenCV** for face recognition and **scikit-learn** for predictive maintenance models.
3. **Cross-Platform Compatibility** – Python code can be easily deployed on Raspberry Pi OS without complex compilation steps.

4. **Rapid Prototyping** – Python’s concise syntax enables faster development and testing compared to low-level languages [47].

Feature	Benefit in Elevator System
Extensive Libraries	Direct access to AI, image processing, and hardware control packages.
Easy Learning Curve	Facilitates quick adaptation for engineers and technicians.
Strong Community Support	Access to tutorials, forums, and troubleshooting resources.
Compatibility with Raspberry Pi	Direct execution without recompilation.
Open Source	No licensing costs for development or deployment.

Tab II.8. Advantages of Python for the Project

II.3.2.2 Application in the Intelligent Elevator System

- **Face Recognition Module**: Using Python’s **OpenCV** and **face_recognition** libraries to detect and identify passengers.
- **Predictive Maintenance**: Using Python’s **scikit-learn** or **TensorFlow Lite** to process sensor data and predict failures.
- **System Monitoring**: Logging real-time operational data and environmental conditions for analysis.
- **Control Logic**: Implementing elevator movement algorithms, safety checks, and emergency stop functions.

Python’s ability to bridge **low-level hardware control** and **high-level AI processing** makes it an ideal choice for the dual objectives of this project: **enhancing passenger security through face recognition** and **improving system reliability through predictive maintenance** [48][49].

II.3.3 Thonny IDE

II.3.3.1 Description of the program

Thonny IDE is an integrated development environment (IDE) for Python that comes pre-installed with Raspbian. Designed especially for beginners, Thonny offers a clean interface and powerful debugging tools that make it ideal for developing, testing, and troubleshooting Python scripts on the Raspberry Pi [50].

II.3.3.2 Role of Thonny in the Project

- Writing and testing Python code for sensor data acquisition.
- Implementing AI-based face recognition and maintenance prediction modules.
- Debugging system logic in real-time.
- Managing project files and scripts in an organized environment [50].

II.3.3.3 Advantages of Using Thonny

- Built-in Python interpreter and package manager.
- Step-by-step debugging for precise error tracking.
- Lightweight and fast performance on Raspberry Pi hardware.
- Simple interface suitable for both prototyping and final deployment [31].

Component	**Key Features**	**Benefit to Project**
Raspbian OS	Debian-based, optimized for Raspberry Pi, built-in drivers	Ensures stable operation and hardware compatibility
Thonny IDE	Python-focused, integrated debugger, package management	Simplifies coding, testing, and debugging AI and control logic

Tab II.9. Summary of Raspbian and Thonny Features

II.3.4 EcoStruxure Machine Expert Software

II.3.4.1 Software description

(Formerly known as SoMachine) is an advanced software platform developed by Schneider Electric for the programming, configuration, commissioning, and maintenance of industrial automation systems, particularly those using Modicon PLCs, HMI, drives, and servo systems. It is designed to support all phases of a machine’s lifecycle, from design and engineering to operation and maintenance, within a single integrated environment [51].

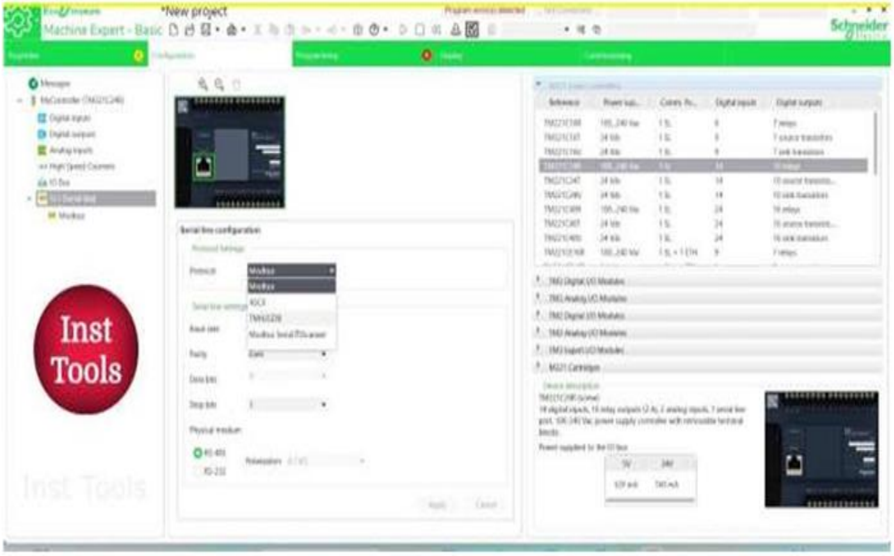


Figure II.8. EcoStruxure MACHINE EXPERT software Interface

II.3.4.2 Key Features [51]

1. **Integrated Development Environment (IDE)**

- Provides a unified platform for programming, debugging, and configuration, supporting various Schneider Electric devices like Modicon PLCs, HMIs, and servo drives.

2. **Multi-Programming Language Support Conforms to IEC 61131-3 standards, allowing programming in multiple languages:**

- Ladder Diagram (LD)
- Structured Text (ST)
- Function Block Diagram (FBD)
- Instruction List (IL)
- Sequential Function Chart (SFC)

3. **Device Configuration:**

- Simplifies the configuration of different components (PLCs, HMIs, drives) using predefined libraries and templates.

4. **Automation Libraries:**

- Offers a wide range of pre-built function blocks and libraries to speed up development, including safety libraries and motion control modules.

5. **Graphical User Interface:**

- Intuitive and user-friendly, allowing for easier project navigation, component selection, and system visualization.

6. **Simulation & Diagnostics:**

- Provides simulation tools for offline testing of the program before deployment and offers powerful diagnostic tools for troubleshooting and monitoring system performance.

7. **Fieldbus& Communication Protocols:**

- Supports multiple industrial communication protocols, such as Modbus TCP/IP, Ethernet/IP, CANopen, and PROFIBUS, ensuring interoperability with a wide variety of devices.

8. **Version Control & Project Management:**

- Integrates version control systems to track changes and manage project revisions efficiently, offering collaboration capabilities across teams.

9. **Scalability:**

- Suitable for a range of applications, from simple standalone machines to more complex, interconnected systems with multiple devices.

10. **EcoStruxure Integration:**

- As part of Schneider Electric’s EcoStruxure architecture, it allows seamless integration with the larger EcoStruxure platform for IIoT (Industrial Internet of Things), offering cloud connectivity, data analytics, and remote monitoring [51].

II.3.4.3 Applications

- Used in machine automation projects for sectors like packaging, material handling, robotics, and general manufacturing.
- Optimized for creating highly efficient, flexible, and connected machines with enhanced diagnostics and remote access [51].

II.3.5. Vijeo Designer 6.2 SP13 Software

II.3.5.1 Software description

Vijeo Designer 6.2 SP13 is a powerful software tool used for developing Human-Machine Interface (HMI) applications, commonly in industrial automation. It provides a user-friendly environment for designing, configuring, and simulating operator interfaces that control machines or processes. The software is part of Schneider Electric's EcoStruxure suite, designed to integrate with various hardware like the M221 controller that we are using in our smart elevator project [52].

II.3.5.2 Key Features of Vijeo Designer 6.2 SP13 [52].

1. **User Interface Design:** Vijeo Designer allows the creation of custom HMI screens with interactive components such as buttons, indicators, gauges, and alarms. These can be used to monitor the real-time state of the elevator system, such as its current floor, door status, and error alerts.

2. **Controller Communication:** Vijeo Designer seamlessly integrates with the M221 Schneider PLC, facilitating smooth data exchange between the controller and HMI. In our smart elevator, this means that the PLC can send sensor and actuator data to the HMI, and operators can input commands via the HMI, such as floor selection or maintenance mode activation.

3. **Alarm Management:** The software supports advanced alarm monitoring, which can be useful for your smart elevator system. Alarms can be configured for various system states like door malfunctions, overload, or power failures. These alerts can be displayed on the HMI, allowing operators to respond quickly.

4.Data Logging and Trending: It offers tools for logging operational data and displaying trends over time. In the context of your smart elevator system, this feature can be used to track usage patterns, monitor performance, and troubleshoot issues based on historical data.

5.Simulation and Debugging: Vijeo Designer provides simulation capabilities, allowing you to test and debug the elevator HMI without deploying it on the actual hardware. This is particularly helpful in refining the user interface and ensuring that all controls and indicators behave as expected before integrating with the M221controller.

6.Remote Access: With the Vijeo Web Server feature, operators can monitor and control the elevator system remotely through a web browser. This can be useful for maintenance personnel who may need to check the system's status without being physically present [52].

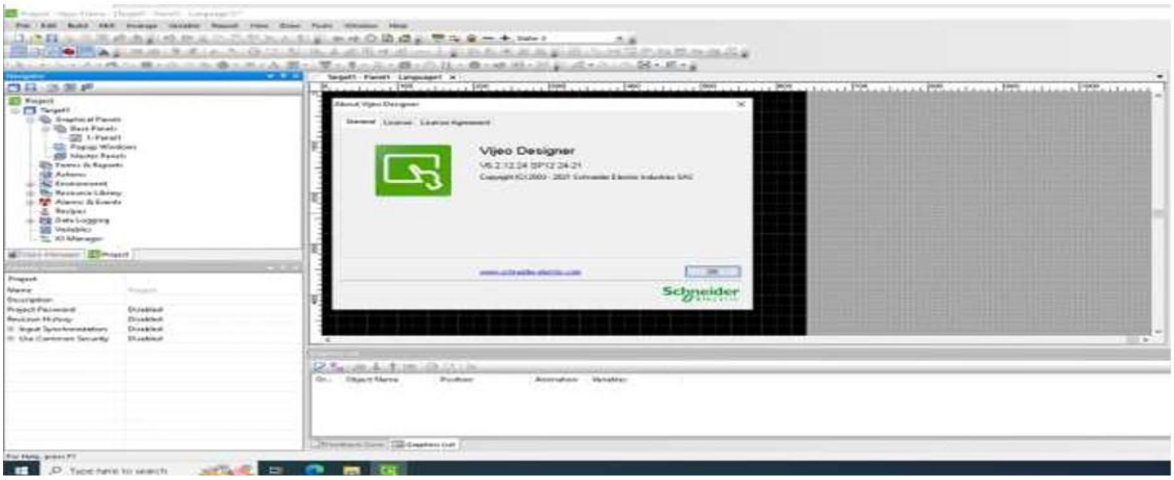


Figure II.9. Vijeo Designer 6.2 SP13 Interface

II.4 Conclusion

This chapter presented the **hardware and software components** required for the implementation of the intelligent elevator system integrating artificial intelligence. The hardware section detailed the choice of **Raspberry Pi 5** as the central processing unit, supported by peripheral devices such as the **USB webcam** for face recognition, the **MPU6050 gyroscope and accelerometer** for motion monitoring, the **IR speed sensor** for velocity measurement, and the **DHT11 humidity and temperature sensor** for environmental monitoring. Each component was selected based on **compatibility, cost-efficiency, and functional requirements** of the system.

On the software side, the chapter highlighted the importance of **Raspbian (Raspberry Pi OS)** as the base operating system, **Python** as the main programming language, and development tools such as **Thonny IDE** for code creation and debugging. Additionally, it introduced the use of **AI and computer vision frameworks** like **OpenCV** and **scikit-learn** which will be key to implementing the **face recognition module** and **predictive maintenance algorithms**.

The combination of these hardware and software elements ensures that the system will be **scalable, maintainable, and capable of real-time performance**. The modular architecture allows for easy upgrades, whether by replacing sensors, improving AI models, or expanding monitoring capabilities.

By carefully integrating these components, the intelligent elevator system will be able to:

- **Enhance passenger safety** through accurate and fast face recognition.
- **Reduce downtime** via predictive maintenance based on sensor data.
- **Provide flexible control and monitoring** through network connectivity.

In the next chapter, we will present a general description of the elevator prototype and discuss the practical tests performed.

CHAPTER 3

REALIZATION, SIMULATION AND PRACTICAL TESTS

III.1 Introduction

This chapter presents the developed prototype of the smart elevator and highlights several operational tests conducted to evaluate its performance. Key control parameters are analyzed to assess the system's efficiency, safety, and responsiveness under various operating conditions. The design and implementation of the intelligent elevator control system are introduced, which integrates advanced features such as a face recognition module for secure and automated access and a predictive maintenance system for real-time monitoring of operational conditions**.** The system is built on a Raspberry Pi 5 running the Raspbian operating system, with software development carried out using Thonny IDE for Python programming and Vijeo Designer 6.2 SP13 for the Human–Machine Interface (HMI). This configuration allows seamless coordination between embedded control, AI-based decision-making, and user interaction, demonstrating the practical feasibility of combining industrial automation with artificial intelligence in modern elevator systems.

III.2 General description of the elevator prototype

Initially all doors of the elevator are securely closed. Once this condition is ensured, passengers can request the elevator by pressing the corresponding button for their desired floor. The cabin can move either up or down, depending on the request, and continues until it reaches the selected floor. As the elevator approaches its target, the motor gradually slows down, and precise floor position sensors (CP-ET1, CP-ET2) are activated to bring the cabin to a smooth stop. To open the doors, a face recognition module was interfaced with the smart elevator's door control system to enable secure and automated access management. Upon successful identification of a registered user through the OpenCV-based facial recognition process running on the Raspberry Pi 5, a digital output signal is transmitted to the elevator's microcontroller or relay driver circuit to activate the door mechanism. The system also includes an access control feature that allows limiting the number of entries per user (e.g., one or two accesses), ensuring controlled usage and enhanced security. This integration provides seamless coordination between the vision-based recognition module and the electromechanical door control system, improving both reliability and access management efficiency. These doors will remain open for a set period of 5 seconds, allowing passengers to safely enter or exit the cabin. Once this time has elapsed, the doors close automatically. After the doors have closed, an additional sensor checks for any new requests. If no new request is detected within a 5-second window, the system switches into a standby mode, ready to promptly respond to any subsequent passenger inputs, Inside the elevator cabin, A user-friendly control interface was designed using **Schneider Magelis HMI** to allow the operator to monitor and control the elevator system in real time. The interface displays the current floor position and cabin location, as well as the date and time.

As shown in **Figure III.3** the interface includes two main buttons to select the desired floor (1 and 2), and dynamically updates the display to indicate the current position of the elevator between **FLOOR1** and **FLOOR2**. The HMI was programmed using **Vijeo Designer**, and communicates directly with the **PLC Schneider TM221CE16T**, which executes the movement commands. This enables full integration between the graphical interface, the control unit, and the intelligent system implemented on the **Raspberry Pi 5**.

This integration provides an intuitive and efficient human–machine interaction, representing an important step toward developing intelligent elevator control systems that combine industrial automation with artificial intelligence.

The predictive maintenance system was implemented using a Raspberry Pi 5 as the central processing unit. The system integrates multiple sensors, including the AM2301A for temperature and humidity monitoring, and the MPU6050 for vibration and acceleration measurement. These sensors continuously collect operational data from the elevator cabin and motor. The acquired data are processed in real time and transmitted to the predictive model, which analyzes patterns to detect early signs of mechanical anomalies or abnormal operating conditions. A representative output of the experiment is illustrated in **Figure III.5**, showing an automated maintenance notification received via email. The alert contains the timestamp, measured sensor values, and the anomaly score, allowing maintenance staff to remotely identify and verify the elevator's operational status.

III.3 Practical tests

III.3.1 Face Recognition and Access Control Results

The **face recognition module** was successfully implemented and tested using the Raspberry Pi 5. The system activates the webcam through the OpenCV library (cv2.VideoCapture(0)) and performs real-time facial recognition using the pre-registered images stored in the /home/pi5/door/img directory.

Each authorized individual is identified based on the encoding of their facial features, and a **confidence score** is computed. When the recognition confidence is higher than the defined threshold (FACE_THRESHOLD = 0.45), the system confirms identity and executes the door-opening function by sending a signal through the **GPIO pin 17** to the PLC input channel.

The access control mechanism is managed through specific naming conventions embedded in the image filenames, allowing automatic recognition of the access rights:

- **PP** → Permanent access (e.g., AhmedPP.jpg)
- **AA + number** → Limited entry count (e.g., AliAA3.jpg)
- **UU + number + D** → Temporary access (e.g., SaraUU5D.jpg)

This naming logic simplifies database management and reduces computational complexity, as access rights are directly inferred from the filename.

The figure below **Figure III.1** shows the **real-time recognition result** where the system successfully identifies the authorized user "MOHAMED" and displays the name within a green bounding box, indicating a valid recognition event. Once identified, the Raspberry Pi sends a high logic signal to the PLC to open the elevator door.

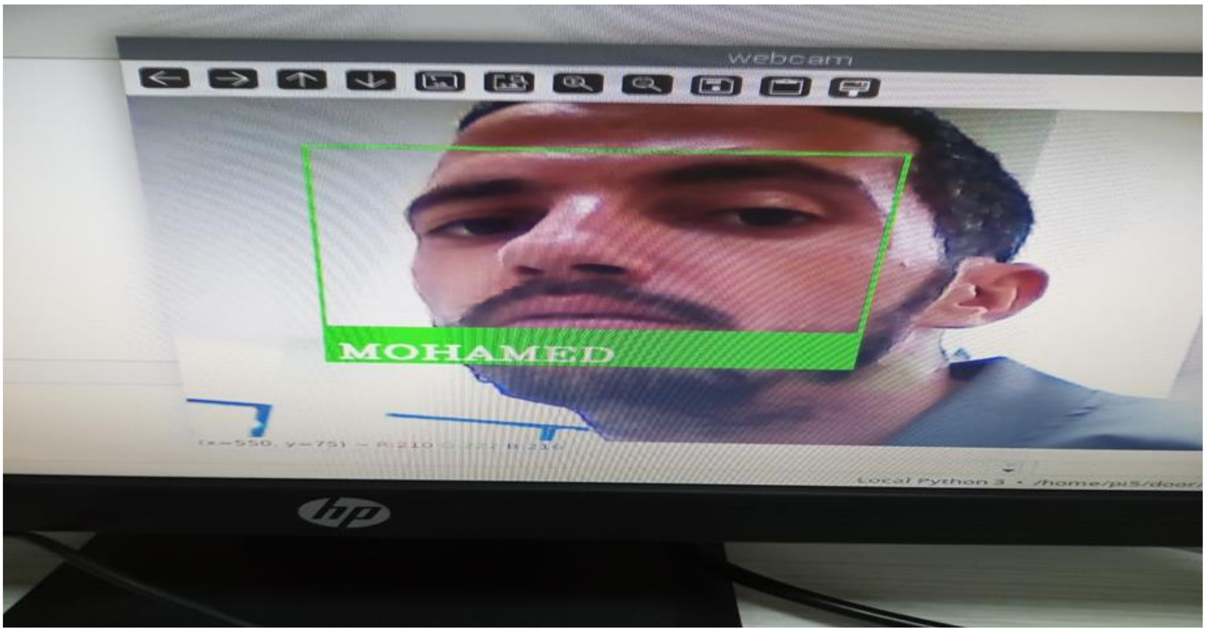
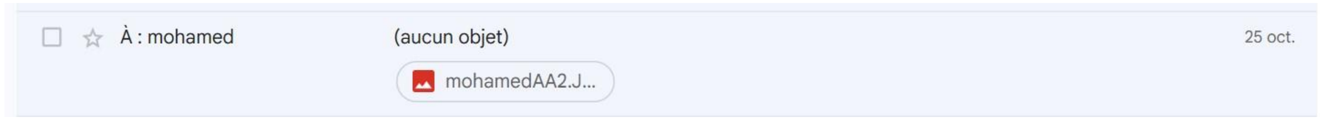


Figure III.1. Real-time facial recognition and access validation result

(Captured during experimental testing on Raspberry Pi 5)

During the experimental testing phase, the access control logic was validated using several user profiles with different permission levels. One of these test cases involved the user **“MohamedAA2”**, whose filename indicates that he is allowed to enter **only twice**. When the facial recognition module identifies “MohamedAA2”, the system automatically decrements his remaining access count by one.Once both authorized entries are used, any further recognition attempt will result in **access denial**, and the door will remain closed.

This feature demonstrates the system’s ability to manage user-specific access limits directly through the image filename encoding, ensuring flexibility and eliminating the need for an external database.



☐ ☆ À : mohamed (aucun objet) 25 oct.

mohamedAA2.J...

Figure III.2. Access control result for user “MohamedAA2”, showing limited two-entry permission *(Captured during experimental testing on Raspberry Pi 5)*

III.3.2 Human Machine Interface (HMI)

As shown in **Figure III.3** the interface includes two main buttons to select the desired floor (1 and 2), and dynamically updates the display to indicate the current position of the elevator between **FLOOR1** and **FLOOR2**.

The HMI was programmed using **Vijeo Designer**, and communicates directly with the **PLC Schneider TM221CE16T**, which executes the movement commands. This enables full integration between the graphical interface, the control unit, and the intelligent system implemented on the **Raspberry Pi 5**.

Figure III.3.HMI control interface of the elevator system (Schneider Magelis screen)

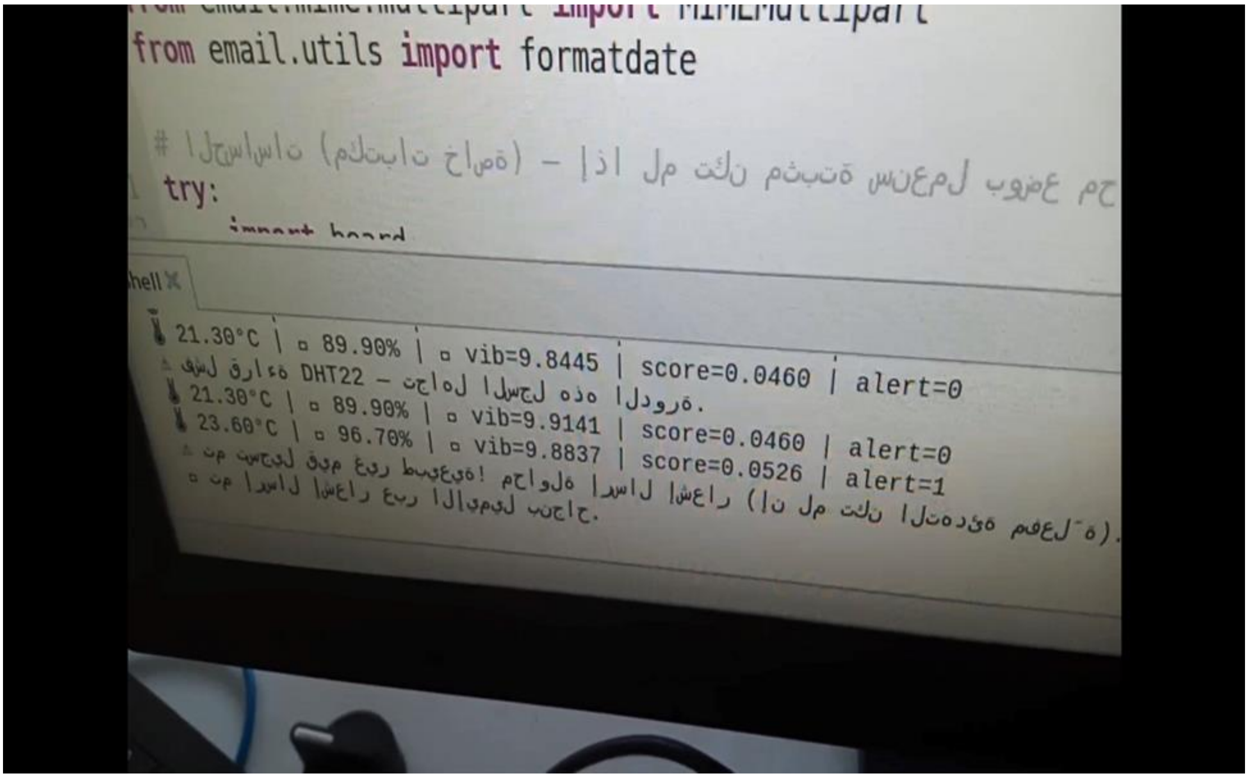
III.3.3 The predictive maintenance and intelligent monitoring modules

III.3.3.1. Experimental Setup and Results Observation

The predictive maintenance system was successfully implemented on the Raspberry Pi 5 platform and tested using two primary sensors: the AM2301A (for temperature and humidity monitoring) and the MPU6050 (for vibration measurement).

During the experimental phase, the system continuously monitored the real-time data from both sensors. When the temperature, humidity, or vibration values exceeded the pre-trained model's threshold limits, the system triggered a predictive alert.

Figure III.4 below shows the real-time output displayed on the **Serial Monitor** when an anomaly was detected. The message "⚠ Predictive Maintenance Alert Triggered" confirms that the AI model recognized an early fault signature in the elevator's operation, which would require preventive action from the maintenance staff.



```
from email.utils import formatdate

try:
```

```
21.30°C | ▫ 89.90% | ▫ vib=9.8445 | score=0.0460 | alert=0
21.30°C | ▫ 89.90% | ▫ vib=9.9141 | score=0.0460 | alert=0
23.60°C | ▫ 96.70% | ▫ vib=9.8837 | score=0.0526 | alert=1
```

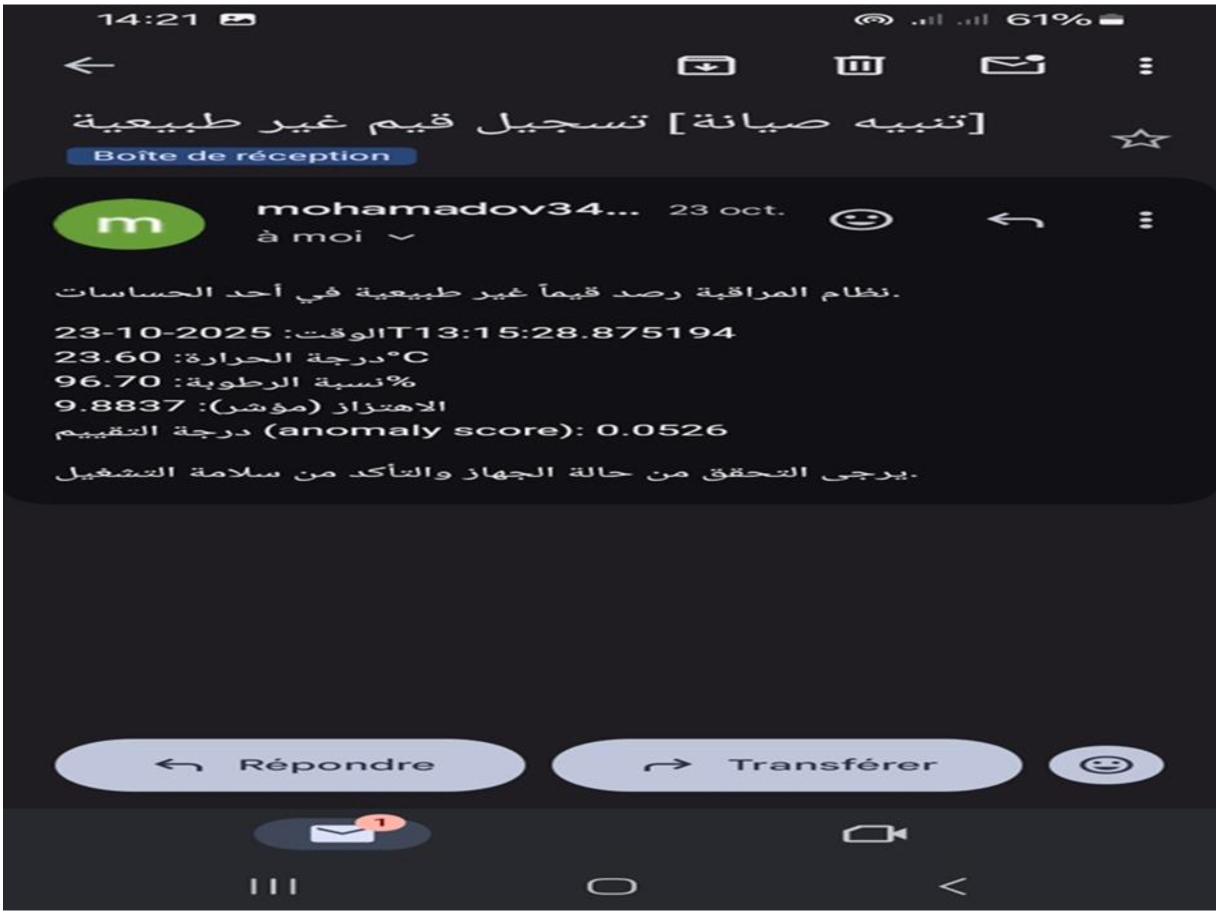
Figure III.4. Serial Monitor

Pi 5 automatically transmitted a **maintenance alert email** to the technician. This email contained all critical information, including:

- Elevator ID and location (GPS coordinates)
- Type of detected anomaly (Temperature / Vibration / Humidity)
- Severity level and timestamp

Figure III.5 presents the email notification received on the technician's device. The inclusion of these details allows for immediate and accurate response, reducing downtime and preventing system failure.

Through these results, it was demonstrated that the proposed predictive maintenance system effectively integrates sensor data acquisition, machine learning-based fault detection, and real-time alert communication. This confirms the system's reliability and readiness for real-world elevator maintenance applications.



[تنبيه صيانة] تسجيل قيم غير طبيعية

mohamadov34... 23 oct.
à moi

نظام المراقبة رصد قيماً غير طبيعية في أحد الحساسات.

الوقت: 23-10-2025T13:15:28.875194
درجة الحرارة: 23.60°C
نسبة الرطوبة: 96.70%
الاهتزاز (مؤشر): 9.8837
درجة التقييم (anomaly score): 0.0526

يرجى التحقق من حالة الجهاز والتأكد من سلامة التشغيل.

Figure III.5. Maintenance Alert Email Generated by the Predictive System

III.3.3.2. Discussion of Results

The obtained experimental results clearly demonstrate the system's ability to detect early signs of malfunction through real-time monitoring of environmental and mechanical parameters inside the elevator shaft.

When a temperature increase was observed by the AM2301A sensor, the system interpreted it as a potential issue related to motor overheating or poor ventilation. Such a condition could accelerate component wear or trigger safety shutdowns if left unattended.

Similarly, abnormal vibration patterns captured by the MPU6050 indicated possible mechanical imbalance, bearing degradation, or misalignment in the elevator's moving parts. These subtle vibration anomalies were identified by the trained AI model before the mechanical failure became critical, thus validating the effectiveness of the predictive maintenance approach.

The humidity variation, although less critical, also provided valuable information. A sudden increase in humidity inside the elevator shaft could indicate moisture ingress or seal degradation, which might later affect electrical contacts or metal corrosion.

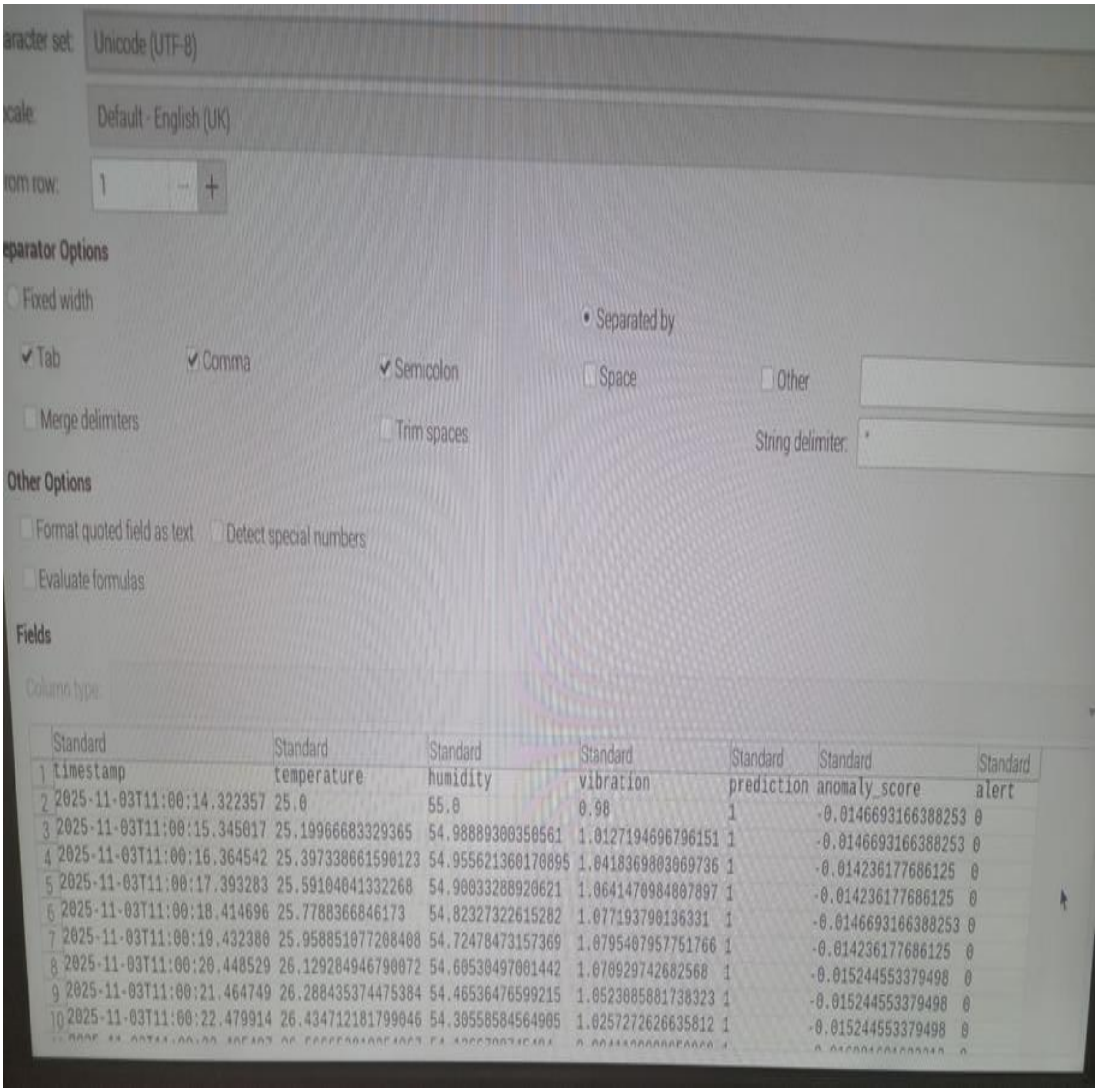
Overall, these results confirm that integrating AI-driven predictive maintenance with IoT-based sensing and alerting mechanisms offers a significant improvement in operational safety and maintenance efficiency. The system allows the technician to act proactively rather than reactively, minimizing unplanned downtime and maintenance costs**.**

III.3.3.3 Example of anomaly log records stored in the Raspberry Pi system

After implementing the predictive maintenance system on the Raspberry Pi 5, several experiments were carried out to validate the system's ability to detect and record abnormal sensor behavior in real time. The collected measurements were automatically stored in a dedicated file named "anomaly_log.csv", which contains all sensor readings, including temperature, humidity, vibration, anomaly prediction, anomaly score, and alert status.

Figure III.6 shows a sample of the log recorded during normal operation. Each row corresponds to a real-time measurement captured from the AM2301A sensor (temperature and humidity) and the MPU6050 sensor (vibration). During normal conditions, the temperature ranged between 25°C and 27°C, the humidity between 54% and 56%, and the vibration values around 0.9–1.0.

In this state, the anomaly score remained very low (approximately 0.0146), and both prediction and alert columns were equal to 0, confirming that the system correctly identified stable operating conditions with no detected anomalies.



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● Separated by

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☐ Merge delimiters ☐ Trim spaces String delimiter: "

Other Options

☐ Format quoted field as text ☐ Detect special numbers

☐ Evaluate formulas

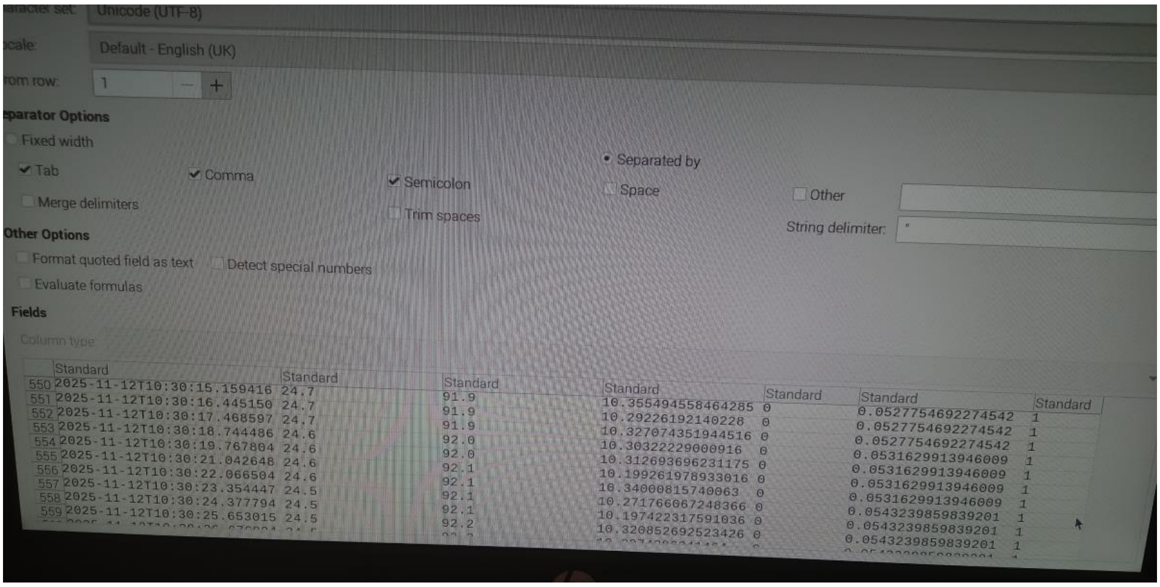
Fields

Column type

	Standard	Standard	Standard	Standard	Standard	Standard	Standard
1	timestamp	temperature	humidity	vibration	prediction	anomaly_score	alert
2	2025-11-03T11:00:14.322357	25.0	55.0	0.98	1	-0.0146693166388253	0
3	2025-11-03T11:00:15.345017	25.19966683329365	54.98889300350561	1.0127194696796151	1	-0.0146693166388253	0
4	2025-11-03T11:00:16.364542	25.397338661590123	54.955621360170895	1.0418369803069736	1	-0.014236177686125	0
5	2025-11-03T11:00:17.393283	25.59104041332268	54.90033288920621	1.0641470984807897	1	-0.014236177686125	0
6	2025-11-03T11:00:18.414696	25.7788366846173	54.82327322615282	1.077193790136331	1	-0.0146693166388253	0
7	2025-11-03T11:00:19.432380	25.958851077208408	54.72478473157369	1.0795407957751766	1	-0.014236177686125	0
8	2025-11-03T11:00:20.448529	26.129284946790072	54.60530497001442	1.070929742682568	1	-0.015244553379498	0
9	2025-11-03T11:00:21.464749	26.288435374475384	54.46536476599215	1.0523085881738323	1	-0.015244553379498	0
10	2025-11-03T11:00:22.479914	26.434712181799046	54.30558584564905	1.0257272626635812	1	-0.015244553379498	0

Figure III.6. A sample of the log recorded during normal operation

In contrast, **Figure III.7.** presents a log segment collected during an abnormal event. Here, the humidity level increased significantly to around 91–92%, while the vibration values rose to approximately 10.3. As a result, the trained model classified these readings as abnormal, setting the anomaly and alert columns to 1. The anomaly scores also increased to around 0.052, reflecting a clear deviation from the learned normal behavior pattern.



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● Separated by
☑ Tab ☑ Comma ☑ Semicolon ☐ Space ☐ Other
☐ Merge delimiters ☐ Trim spaces
String delimiter: "

Other Options

☐ Format quoted field as text ☐ Detect special numbers
☐ Evaluate formulas

Fields

Column type

	Standard	Standard	Standard	Standard	Standard	Standard	Standard
550	2025-11-12T10:30:15.159416	24.7	91.9	10.355494558464285	0	0.0527754692274542	1
551	2025-11-12T10:30:16.445150	24.7	91.9	10.29226192140228	0	0.0527754692274542	1
552	2025-11-12T10:30:17.468597	24.7	91.9	10.327074351944516	0	0.0527754692274542	1
553	2025-11-12T10:30:18.744486	24.6	92.0	10.30322229000916	0	0.0531629913946009	1
554	2025-11-12T10:30:19.767804	24.6	92.0	10.312693696231175	0	0.0531629913946009	1
555	2025-11-12T10:30:21.042648	24.6	92.1	10.199261978933016	0	0.0531629913946009	1
556	2025-11-12T10:30:22.066504	24.6	92.1	10.34000815740063	0	0.0531629913946009	1
557	2025-11-12T10:30:23.354447	24.5	92.1	10.271766067248366	0	0.0543239859839201	1
558	2025-11-12T10:30:24.377794	24.5	92.1	10.197422317591036	0	0.0543239859839201	1
559	2025-11-12T10:30:25.653015	24.5	92.2	10.320852692523426	0	0.0543239859839201	1

Figure III.7. A log segment collected during an abnormal event

These results demonstrate the effectiveness of the implemented predictive maintenance model in distinguishing between normal and abnormal system states with high sensitivity. The automatic detection and recording process ensure that every anomaly is timestamped for traceability and future analysis. Moreover, the continuous accumulation of these records in the anomaly_log.csv file provides a valuable dataset for retraining and improving the model's accuracy over time.

III.4 CONCLUSION

In conclusion, the developed smart elevator prototype successfully demonstrates the integration of modern control technologies, including face recognition for secure passenger access and a predictive maintenance system for real-time monitoring of operational conditions. The experimental results confirm the system's reliability, safety, and efficiency under various operating scenarios. The seamless coordination between the Raspberry Pi 5, sensors, HMI interface, and embedded AI algorithms highlights the practical feasibility of combining industrial automation with intelligent decision-making. Overall, this prototype represents a significant step toward the development of advanced elevator systems that enhance both user experience and maintenance effectiveness.

General Conclusion

IV. General Conclusion

The objective of this work was to design and implement a smart elevator system that combines artificial intelligence and industrial automation using Schneider Electric technology.

The project integrates a Raspberry Pi 5 for intelligent decision-making and facial recognition, a Schneider TM221CE16T PLC for process control, and a Magelis HMI programmed with Vijeo Designer for visualization and manual control.

This system represents an advanced step toward the development of intelligent elevators capable of interacting autonomously with users. The Raspberry Pi sends control signals to the PLC, which manages motor operation and door opening based on real-time data and recognition results. The HMI interface displays floor positions, movement status, and time information in a clear and interactive way.

The predictive maintenance module is supported by sensors such as the AM2301A (DHT) for temperature and humidity measurement and the MPU6050 for vibration monitoring. These sensors continuously provide real-time data to the Raspberry Pi, allowing early detection of abnormal conditions.

This project has enabled us to acquire valuable experience in both embedded systems and industrial control. It strengthened our understanding of AI integration with PLCs, as well as communication between multiple automation devices.

We also learned to synchronize hardware components and software platforms, ensuring reliability and safety in operation.

Developing the control logic required a complete understanding of the elevator’s functioning, its structure, and its security mechanisms. Through this study, we were able to merge theoretical knowledge and practical implementation effectively.

The results obtained from both the simulation and the real-time testing validated the proper functioning of our system.

The smart elevator responded correctly to facial recognition commands, and the communication between Raspberry Pi, PLC, and HMI was stable and accurate.

In conclusion, the objective set at the beginning of this project was fully achieved.Our work successfully demonstrated how artificial intelligence can be integrated into industrial automation systems to enhance safety, comfort, and efficiency.

This experience has deepened our technical knowledge and confirmed the importance of intelligent control in the future of modern elevators.

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