Design of Smart and Secure Elevator System in High-Rise Building

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Abstract—Due to the increasing complexity of modern buildings, the effective operations of transportation systems like elevators are vital. Elevators are potentially invaluable in certain emergencies. Further, quick evacuation of the passengers in case of fire or earthquake needs to be possible. The introduced research work proposes an astute lift with the setting of a keen structure. A decision engine is designed and implemented that can control the elevator's action if there should arise an occurrence of debacles accordingly guaranteeing client safety. The system works in two modes, i.e., the normal mode and the emergency mode. In normal mode, the system utilizes the information provided by the fuzzy rules and cameras with image recognition software to reduce the waiting time thus improving user satisfaction. In the emergency mode, the algorithm imposes certain conditions on the usage of the elevator in times of fire, building collapse, or earthquakes. Moreover, the movement of the elevator is faster in the emergency mode as compared to the normal mode.

Index Terms— **Decision making, Disaster, Fuzzy logic, Safety, Smart elevator**

I. INTRODUCTION

In the era of the digital revolution, the growth of real estate is vertical instead of horizontal, giving rise to high-rise buildings. Further, the demand for the smart cities is giving birth to the requirement of secure and power-efficient algorithms to control various electromagnetic devices like elevators, sensors, and many more [1]. With the rapid development of IoT, plenty of devices inside buildings have become accessible through a wireless network. It facilitates the building to integrate the heterogeneous devices and further utilize artificial intelligence to acquire deep knowledge of the monitored environment [2], at long last to convey the independence and insight to end-clients, that could expand clients' time effectiveness, efficiency and facilitate their everyday life.

[3] One of the most intricate issues in high-rise buildings is to make transportation between floors better. In high-rise buildings, the main transportation apparatuses are lifts and the goal of the elevator control system should be maximizing the capability of transportation and improving the service quality. [4] The decision-making in such elevator systems is a complicated procedure, which includes a lot of uncertainty. To tackle this uncertainty an intelligent automated expert system, that works cost-viably with minimal interruption of customer loads, should be invented.

In this paper, a smart building is to be assumed which is equipped with surveillance cameras on each floor, which constantly captures and records everything [5]. These cameras should be installed in front of the elevator on each floor and use modern image recognition software to report the number of people waiting for the elevator. The weight sensors in the lift will give the absolute load of travellers inside the lift. Using these data, an intelligent decision-making system based on fuzzy rules is developed that exhibits a very convenient and efficient decision-making mechanism.

In high-rise buildings, elevators are the main means for reaching higher floors as they are simpler to utilize and extensively quicker than stairs. Unfortunately, during an emergency, their usage is not considered safe. Sometimes passengers get stuck between the floors during an imminent hazard such as fire or earthquake. So the elevator needs to make an intelligent decision during an imminent hazard. In our proposed system the elevator works on a priority basis at the time of emergency. If there are passengers inside the elevator, it drops them to the nearest floor otherwise it stops executing. [6] [7] Yet if there is an occurrence of fire, the lift consequently goes relentlessly to an assigned floor. This is generally a leave-floor, where travelers may securely leave the building. However, if the fire alarm is triggered from the designated floor, the elevator would move towards a predetermined secondary landing. The movement of the lift will be faster compared to the normal mode.

The aim of this research paper is twofold:

- An effective way is proposed to improve elevator systems and to provide transportation efficiency for mid-rise and high-rise buildings, increasing the flexibility of elevators. A new scheduling method is developed that can effectively utilize advanced traffic information.

- A decision engine is designed that can control the elevator's action in case of disasters by providing necessary checks periodically and following the optimum approach so that the passengers stuck inside the elevator can be evacuated in the least possible time.

II. Related Work

A summary of recent developments in smart elevator systems in high-rise buildings which are supported by decision making are described as follows:

The research on elevators has mainly focused on scheduling problems and alleviating the waiting time problem. An intelligent elevator that works according to the information that is provided by fuzzy rules and by cameras with image recognition software to reduce waiting time was proposed in [4] [5]. On the other side, [8] looked at a similar challenge of decreasing passenger waiting time in multi-car elevators for high-rise structures. A complex group control system (EGCS) based on dynamic fuzzy logic was proposed in this paper. An elevator group control system based on the delay optimal dispatching algorithm using PLC combined with frequency conversion speed regulation and microcomputer control technology is proposed to minimize the average waiting time of passengers in [9]. The system designed in [30] uses a generic algorithm that automatically sends an elevator with a short waiting time to floors where busy business divisions exist.

Some researchers explored the usage of heuristic algorithms and dynamic programming in elevator systems. A multiple-approach system has been determined in which Analytic Hierarchy Process (AHP) method chooses the suitable intelligent elevator control system according to the weighted criterion [3]. In [10] [11], deep learning is used to predict the passenger's destination floor. For this task, passenger profiles are used which are established through deep learning. The destination floor is predicted by elaborating on the passenger's trip history. In [12], wireless ad-hoc sensor nodes connected in a multi-hop fashion are utilized to develop a smart elevator system to sense passenger traffic in real-time. The movement of the elevator system is optimized by establishing communication between the floors for sharing traffic information. The author demonstrated a way to apply reinforcement learning (RL) to elevator systems [13] in contrast to traditional dynamic programming algorithms since RL techniques learn based on their own experience and are suited for the systems having large state space.

One efficient elevator system is proposed [14] that uses the concept of *zoning*, which is assigning a designated set of floors to each elevator. They proposed the zoning configuration, elevators can only pick up and drop off customers at the designated floors. Multiple elevators that are not completely capacitated may make numerous stops at shared floors, resulting in extended service times and inefficiencies of the system.

A smart elevator system was proposed in 2017 [15] to reduce uncertainty and improve efficiency. This system has keypads to enter the passenger's destination floor so that destination is known in advance. The floors are identified through IR sensing so that the lift on the nearest floor will move to the destination. In case of emergency, the lift will move to the floor where the smoke is sensed and the movement of the lift in the emergency will be faster. Various methods to estimate and improve the up-peak handling capacity of the Destination Control System (DCS) were studied [16].

Jiwen Chan *et al.* [17] addressed an important issue of transverse movement of passengers and designed a vertical and transverse elevator model for double shafts structures based on TRIZ theory by using functional models, causal analysis, conflict analysis, and Su-Field model to innovate on traditional elevators and improve transverse mobility efficiency.

Another crucial factor is the analysis of elevator traffic in high-rise buildings. C Ciflikli and E O Tartan developed a parking algorithm for EGCS [18] which is based on passengers' arrival probability. In their other work, they designed a model for visualization and analysis of traffic for EGCS [19]. In the first approach, called 'route visualization', the elevator traffic was decomposed into its components, investigated separately, and then superimposed to get a reconstructed model of the traffic. In the second approach, a comparative analysis of various algorithms such as Park or Dispatch algorithms was done for different combinations of traffic components.

Other research works applied the concept of the Internet of Things (IoT) to optimize already-established elevator systems. Intellevator–an intelligent elevator system capable of proactively providing passengers helpful information (e.g., real-time waiting time) based on real-time context sensing and awareness –was developed by converting a traditional elevator system into an IoT-based elevator system [1]. Passengers perceived the Intellevator as useful. In parallel, another smart elevator system was presented [20] the PrecaElevator, a pre-call-enabled elevator system in a smart building in which an elevator could be pre-called using a specific user interface within an office area, thus reducing passenger waiting times by a significant factor on a conventional office elevator and improve system performance.

While several researchers address controlling the elevator for optimized usage, others have focused on developing various energy-efficient techniques. A new elevator scheduling algorithm for a smart building that takes the dynamic changes in electricity price and passenger traffic into consideration was presented in [21]. In [22], an energy-saving elevator scheduling system comprised of six methods that can achieve fewer Internet of Things (IoT) message exchanges is presented (i.e. communication transmissions) between the Scheduler subsystem and the Car subsystem to achieve motor energy-saving and green wireless communications was suggested.

As the technology is getting advanced and everything is automated, regular inspection and maintenance become important and issues such as power failure need to be addressed effectively. A warning system was suggested [23] that extracts and analyses elevator operation data and determines whether there is a power outage or a levelling fault, which may reduce latency to rectify the issue.

Apart from time and energy efficiency, an intelligent elevator system should be able to take decisions during an emergency to ensure user safety. Chang-Su Ryu [6] proposed an IoT-based intelligent fire emergency response system that can regulate directional guidance intelligently according to the time and location of a disaster. This system reduces casualties and the time required for evacuation by guiding evacuees into dispersed detours that bypass the location of the fire. A smart digital signage system based on the Internet of Things (IoT) was designed and implemented [24] for the safety of elevator passengers. This is accomplished by providing intuitive content for the radical movements of the elevator due to an emergency such as an earthquake or fire. An experimental study was carried out [25] to analyze the behavior of evacuees around the combined use of elevators and stairs during high-rise building evacuation. A decision-support system based on a technology called the Active Dynamic Signage System (ADSS) was proposed [26] suggesting various evacuation strategies for fire scenarios. This was accomplished by simulating distinct test cases. During actual hazard, the nearest approximated test case is considered, and an optimal evacuation strategy is communicated for pathfinding and crowd handling. An elevator safety monitoring system based on the Internet of Things was designed in [29]. The design scheme of this system gives early warnings, saves manpower, and provides elevator safety handling to reduce and avoid elevator accidents.

The presented solution compared with the works mentioned earlier has a crucial difference. The research so far has focused on the possible consequences of the aftermath of imminent hazards. Some researchers worked on developing systems that can take precautionary measures to reduce the damage during catastrophic events. However, it is highly probable for people to panic during the actual event. The main motive of the presented work is to tackle this situation in an optimized way. The proposed system utilizes fuzzy rules to develop a decision model that can work in two modes. Normal mode focuses primarily on user satisfaction and improving the quality of service. The emergency mode emphasizes the safety of passengers by modifying the working of the elevator as per the occurrence of hazardous events. The model can be used for any number of floors and the parameters can be varied accordingly. On account of the aforementioned attributes, the behavior of the system is stable, flexible, and secure.

III. Proposed Methodology

As demonstrated in the flowchart in fig. 1, a decision model is developed that can work in two modes *viz-a-viz* Normal Mode and Emergency Mode. The algorithm can be implemented for any number of floors and in any direction, *i.e.*, upward or downward.

In this model, the information provided by monitoring cameras in buildings is utilized. Cameras will monitor the entrance of elevators on each floor. An image recognition software will utilize that information and provide an estimate of the number of people waiting outside the elevator.

In the proposed algorithm, a boolean variable ‘M’ is initialized which will get ‘SET’ or ‘HIGH’ (logic ‘1’) in case of an emergency and remain ‘LOW’ (logic ‘0’) in regular mode.

In regular mode, the model checks whether the lift has adequate room for individuals waiting outside. For this purpose, we initialize the following variables:

Y = Weight measured inside the elevator;
A = Permissible weight inside the elevator;
a = People waiting outside the elevator on a particular floor at a given instant of time.
Assume ‘x’ to be the average weight of people.
The weight inside the elevator is continuously checked by the sensors. If the difference between the permissible weight inside the elevator (A) and weight measured by the sensors (Y) is greater than the approximated weight of the people standing outside, in simpler words, if the lift has enough space to accommodate the people standing outside the elevator, the elevator will stop at that floor. If the lift doesn’t have enough space, it is checked whether the elevator has space to accommodate at least two people (say), the lift will stop at that floor, otherwise, that particular floor is skipped.

In emergency mode, the model works accordingly in case of fire or an earthquake. If no one is present inside the elevator, the execution of the elevator stops. But if people are stuck inside the elevator, the model acts accordingly so that user safety is ensured. This is done by checking the weight inside the elevator. Moreover, the elevator speed increases by some factor so that it reaches safety as soon as possible. A boolean variable ‘E’ is declared which gets ‘HIGH’ in case of fire and gets ‘LOW’ in case of an earthquake. In case of fire, a floor ‘P’ is designated (primary landing) which has an emergency exit. But if the fire alarm is triggered on floor ‘P’, an alternative floor ‘S’ (secondary landing) can be used. To determine whether the fire is at the primary landing or some other floor, a boolean variable ‘F_P’ is initialized which gets ‘HIGH’ if the fire alarm is initiated at the floor ‘P’ and remains ‘LOW’ if the alarm is triggered at some other floor.

After making suitable assumptions and declarations, the cases can be enumerated as follows:

- M = 0 (elevator operates in normal mode)
    1. If A-Y > a*x at a particular floor, the elevator has enough space to accommodate people waiting outside, and hence, the elevator will stop at that floor.
    2. Else the model will check if the elevator has space to accommodate at least two people. Following cases arise:
        a. If A-Y > 2*x, the elevator will stop on that floor.
        b. Else, skip that floor and continue.
- M = 1 (elevator operates in emergency mode)
    1. If Y < x/3, the execution of the elevator is stopped until necessary safety measures have been taken.
    2. Else
        a. E = 0 (earthquake), drop the passengers at the nearest floor.
        b. E = 1 (fire);
            i. F_P = 0, stop at the floor ‘P’.
            ii. F_P = 1, stop at the floor ‘S’.

The value of ‘M’ is checked periodically.

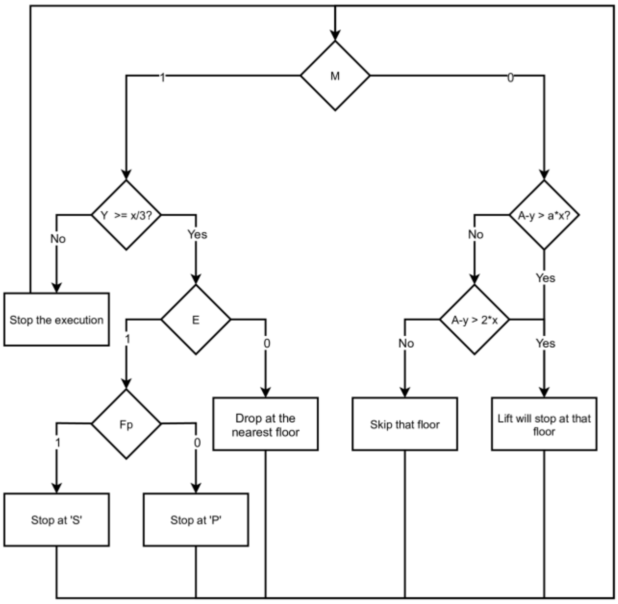

Fig. 1. Flow design of operation of our proposed elevator

IV. Conclusion

This paper presented an algorithm to design and implement an intelligent elevator. The working of the system is optimized to decrease the overall reaching time, i.e., the time required by the elevator to reach a particular floor. Additionally, the framework can make choices appropriately during a calamity.

The system's working depends on a decision parameter that is checked periodically to determine whether the elevator needs to perform the regular operation or needs to adjust as per the imminent hazard, for example, fire, earthquakes, or building collapse. The decision-making time should be as minimum as possible. This is taken care of by the sensors provided in the elevator system.

During the regular flow of operation, traffic at each floor is determined by using surveillance cameras installed on each floor. The image recognition is then utilized to get an estimate of the number of users waiting for the elevator. Based on this information, the system decides whether to stop the elevator on that particular floor or to continue moving in its direction.

During a catastrophic situation such as a fire breakout or an earthquake, the behavior of the elevator is shifted in such a way that the evacuation of the passengers can be done in the minimum time possible. If no one is present inside the elevator, the execution is stopped till safety is ensured to prevent people from using the elevators as there are high chances of system failure. But there may be times when someone might get stuck inside the elevator during the occurrence of the disaster. If that happens, then the passenger is dropped to the nearest floor. If a fire alarm is triggered, then the elevator moves toward a predetermined floor having necessary arrangements for quick evacuation. Additionally, the speed of the lift increases with the goal that the travelers stuck inside the lift can be evacuated in the least time possible along these lines guaranteeing client wellbeing.

The proposed approach is simple yet effective for buildings having a single elevator. It would be useful to develop the system for buildings with more than one elevator as a future extension. The approach can also be integrated with Artificial Intelligence (AI) and the Internet of Things (IoT) to improve user satisfaction. Various heuristic algorithms and techniques can be employed to adjust as per the changing behavior of the system. An important extension would be to utilize energy-efficient techniques. A software can be developed which allows the user to pre-call the elevator which further reduces waiting time thus making the overall system more interactive and user-friendly. Further, more preliminaries and tests will be made for model approval.

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