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DESIGN AND IMPLEMENTATION OF MODERN ELEVATOR GROUP CONTROL SYSTEM

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Abstract:

The design and implementation of a modern elevator group control system (EGCS) is introduced in this paper. The basic considerations of designing an EGCS are discussed, including related system parameters, evaluation criterions and traffic patterns. Least squares support vector machine algorithm is employed for traffic prediction. Using multi-support vector machine, the traffic pattern recognition is accomplished, then based on that recognition, the control strategies are generated. In the hall call assignment, the re-scheduling ability is achieved by the elevator suitability re-evaluation mechanism. A comparison with an older model demonstrates the effectiveness of the proposed EGCS.

Keywords:

Elevator group control system; Traffic prediction; Traffic pattern recognition; Support vector machine; Hall call assignment

1. Introduction

This paper describes the design of a modern elevator group control system (EGCS) and its implementation commercially.

Nowadays, for spatial or commercial reasons, more and more high-rise buildings are constructed requiring multiple elevators in order to transport the people between floors rapidly. This EGCS is proposed and developed to enable such elevators to work synergistically and efficiently.

An EGCS is a system that manages multiple, usually three or more, elevators inside a building in order to reduce wait time, increase comfort, reduce power consumption and to improve other desired performance indices. It is a complex, discrete, dynamic system in that the conditions of the environment where it serves are always in change. The arrival time and the initial floors of the passengers are stochastic; their destination floors are unknown; the capacity of each elevator is limited, and so forth.

Many studies have been done on developing an EGCS. ChangBum Kim et al employed fuzzy theory to construct their EGCS [1]-[3]. In their work, the membership functions of the hall call assignment method were generated with the classified traffic modes and the importance degrees of the evaluation criteria in the control strategy generation part, and the suitability of each elevator for a hall call was determined by fuzzy inference. A fuzzy expert system was employed by Ishikawa, et al [4]-[5]. But designing proper membership functions and inference rules, which greatly affects the system performance, is a difficult task. The acquisition of expert knowledge is a difficulty when an expert system is employed. ZiLiang Zong proposed a reinforcement learning algorithm by combing Q-learning and residual gradient [6]. This method combined dynamic programming and supervised learning to yield a powerful machine learning system, but it is time-consuming. T. P. Albert and J. R. Beebe employed the artificial neural network (ANN) [7] while N. Imasaki [8]-[9] and DeWen Zhu [10] used the fuzzy neural network in designing an EGCS. But neural network has its limitations. It is time-consuming during the network-training period and has an uncertain network structure and a local minimization problem. Other researchers are doing related studies using genetic network, Petri net, and so forth [11]-[13].

Based on our previous work [14]-[16], the elevator traffic prediction and traffic pattern recognition are here accomplished using the support vector machine (SVM). SVM has greater generalization ability than the neural network and guarantees global minima for any given training data. Based on the traffic prediction and the system model, the hall call assignment, which is the core of an EGCS, is implemented. Re-scheduling ability, crucial in a complex dynamic system, is achieved by a suitability re-evaluation mechanism.

The remainder of this paper is organized as follows. In Section 2 the major considerations of designing an EGCS are discussed. The design and implementation method is given in Section 3. The results and analysis of the system performance are in Section 4. Finally, we have a conclusion in Section 5.

2. Major Considerations of designing an EGCS

Consider the following example on the service routing of an EGCS [3]:

1) A passenger who wants to go to the 15th floor arrives at the elevator door on the second floor, where a hall call panel (usually with an up and a down-direction button) is installed, and he presses the up button.
2) The hall call signal is transmitted to the EGCS.
3) Based on calculation, the EGCS selects the most suitable elevator to serve the passenger.
4) The EGCS sends a message to the selected elevator.
5) The selected elevator moves to the second floor and the passenger boards.
6) The passenger presses the car call button for the 15th floor.
7) The elevator sends a message to the EGCS and leaves for the 15th floor.
8) The elevator arrives at the 15th floor and the passenger leaves.

among these eight steps of the routing, the third one is the core of the EGCS. Because the EGCS is a complex, discrete, dynamic system, the suitability of an elevator may be changed before the hall call is actually accomplished, due to changes in the traffic conditions. Therefore re-scheduling ability is needed.

From this routing example, we can draw up some major considerations for designing an EGCS.

2.1. Basic system parameters

The basic system parameters include all parameters related to the EGCS: the function of the building, the floor specifications, the rated speed, acceleration and deceleration of the elevator, the drive control mode of the elevator, and so on.

The function of a building determines the characteristics of the traffic flow inside the building, and has a great influence on the traffic prediction and traffic pattern recognition.

The acceleration and deceleration of the elevator, the floor information such as the height of each floor, are employed in the calculation of the wait time, the ride time, and so forth. In addition, the acceleration and deceleration also have a direct relation to the sense of comfort felt by the passengers.

2.2. Design objectives

The primary objective of primal EGCSs was to reduce the average wait time of the passengers. But the demand for service quality is now becoming more critical. Besides wait time reduction, other control objectives have been proposed and the performance of an EGCS can be evaluated by such criterions as the average ride time of the passengers, the percentage of passengers waiting more than 60 seconds (long wait percent), the overcrowding rate, the power consumption, and so forth.

Average wait time (AWT) is the average of the time intervals between the moment the hall calls are pressed down and the moment the serving elevators arrive over a given unit of time.

Average ride time (ART) is the average time the passengers spend in the elevator car over the same unit time.

Long wait percent (LWP) is the percentage of passengers who wait for the elevator more than 60 seconds in the unit time.

The power consumption is measured by the number of times the elevator moves in the unit time (RNC).

The crowding rate (CR) is calculated as the actual load above the rated load capacity.

It is very difficult to satisfy all these criterions at the same time.

Let S_i be the total suitability of the ith elevator, and $V_{i,AWT}$, $V_{i,ART}$, $V_{i,LWP}$, $V_{i,RNC}$, $V_{i,CR}$ be the value of AWT, ART, LWP, RNC and CR, respectively. Then the suitability of the ith elevator for a certain hall call can be calculated by:

$$\begin{aligned} S_i = {} & w_{AWT} \times V_{i,AWT} + w_{ART} \times V_{i,ART} + \\ & w_{LWP} \times V_{i,LWP} + w_{RNC} \times V_{i,RNC} + w_{CR} \times V_{i,CR} \end{aligned} \tag{1}$$

where w_{AWT}, w_{ART}, w_{LWP}, w_{RNC}, $w_{CR} \in [0,1]$ are the weighting factors of each evaluation criterion. The elevator with the maximum suitability value will become the selected elevator in Step 3 of the service routing.

2.3. Passenger traffic patterns

For buildings of different functions, the state of the traffic flow varies by time of day. For example, in a typical office building, at the office-opening time, around 9:00 a.m., there may be the most passengers, so the traffic pattern can be defined as up peak mode (UP). During business hours, from 9:30 a.m. to 11:30 a.m., the traffic will be medial between floors and can be defined as stochastic inter-floor mode (SIF).

Some researchers [3] classify traffic into eight patterns: business time, up peak, down peak, lunch time A, lunch time B, inactive time, heavy traffic in business time and heavy traffic at any time modes. Considering the actual situation of most buildings, a five-pattern classification method shown in Table 1 is employed in our EGCS.

Table 1. Passenger Traffic Patterns

up peak (UP)	a lot of passengers go upwards
down peak (DN)	a lot of passengers go downwards
Stochastic inter-floor (SIF)	the traffic is normal between floors
2-way inter floor (TIF)	heavy traffic between two floors
idle mode (IM)	the traffic is rather light

3. Design and implementation

In this section, the design and implementation method of the EGCS is introduced.

3.1. System overview

The overview of the proposed system is illustrated in Figure 1.

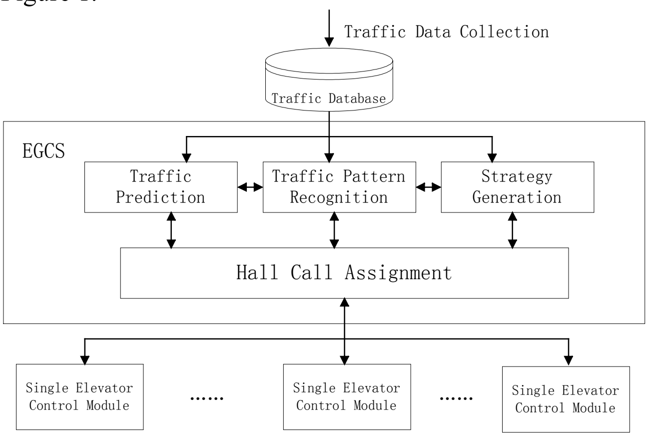

Figure 1. System overview

In this system, the EGCS consists of five modules: the traffic database, the traffic prediction, the traffic pattern recognition, the strategy generation and the hall call assignment modules. Among them the hall call assignment module is the core component, as it has the greatest influence on the performance of the whole system.

The traffic data is collected from the hall call panels, cars and elevator wells, stored in the traffic database along with other traffic information, and then sent to the prediction, pattern recognition and strategy generation modules. Based on the processing results gained from these modules, the hall call assignment component selects a suitable elevator to serve the hall call.

Different from other EGCSs, here there are separate elevator control modules that are employed to control each elevator. Each control module has its own car movement control module and communication module. This makes it easy to isolate a single car when any irregularity occurs or re-connect to the EGCS after the irregularity is handled. This makes the overall control of the elevators more flexible and the expansion of the EGCS easier.

3.2. Traffic prediction

Accurate passenger traffic prediction is helpful in improving the performance of an EGCS. Traffic information consists of the number of passengers, typical passenger appearances and the passenger distributing status. Practically, the traffic data in this module is divided into three parts [17]:

1) passenger numbers in the whole building
2) passenger numbers entering the lobby
3) passenger numbers leaving the lobby

Least squares SVM (LS-SVM), which compared to ANN has better generalization ability and guarantees global minima for a given training data, is employed to construct the predictor (Figure 2).

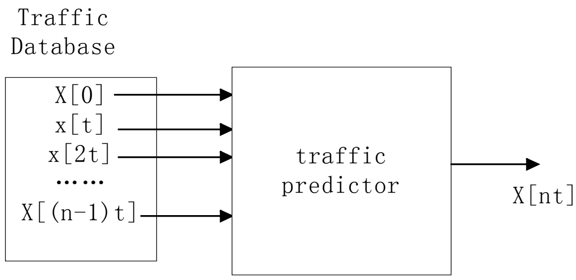

Figure 2. Diagram of the traffic predictor

here x[0], x[t], x[2t], ⋯, x[(n-1)t] are the traffic data sampled every five minutes, and t is the data sampling interval. So the predictor can be described by [14]:

$$x(n) = f(n, x(n-1), x(n-2), \cdots, x(n-m)) \quad (2)$$

The LS-SVM model for the function f is:

$$y(x) = \sum_{k=1}^{N} \alpha_k K(x, x_k) + b \quad (3)$$

where $K(x, x_k)$ is the kernel function, α and b are the solutions of equation (3). Choosing the error parameter, the kernel function and its parameters properly, the predictor for each of the three parts of the traffic data can be constructed.

3.3. Traffic pattern recognition

A multi-support vector machine (M-SVM) is employed to construct the traffic pattern classifier. The procedure is shown in Figure 3.

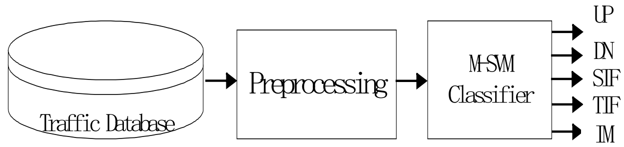

Figure 3. Diagram of traffic pattern classifier

The purpose of the preprocessing is to extract the number of total passengers, the number of passengers entering the lobby, the number of passengers leaving the lobby, the number of passengers on the floor with the heaviest traffic, the number of passengers on the floor with the second heaviest traffic, and so forth.

For the M-SVM classifier, a sub-classifier for two traffic modes is first established. The mathematical description for the sub-classifier is [15]:

$$y(x) = \operatorname{sgn}\left|\sum_{x_i \in SV} \alpha_i y_i K(x_i, x) + b\right| \tag{4}$$

where SV is the support vector, $K(x_i, x)$ is the kernel function.

Then the pattern recognition classifier for all the traffic patterns is established using a one-against-one M-SVM algorithm. There are $k(k-1)$ sub-classifiers for a k-class problem so we get 20 sub-classifiers for the five traffic modes here. After the 20 sub-classifiers are established, the traffic data is estimated from each of these classifiers and the data is classified using the voting strategy. Then the traffic is assumed to be in the pattern that has the largest vote.

3.4. Control strategy generation and hall call assignment

Based on the traffic information and the traffic modes classified by the traffic pattern recognition module, different control strategies of the EGCS can be generated. For example, if the traffic is in the up peak mode around 9:00 a.m., it will be more suitable to set the w_{AWT}, w_{LWP} in Equation (1) larger in order to reduce the wait time and long-time waiting percentage of the passengers. However, one can set w_{RNC} to a larger value when the traffic is in the idle mode to reduce the power consumption.

The hall call assignment calculates the suitability of each elevator using equation (1) when new hall calls occur and then assigns calls to suitable elevators. As the core component of the EGCS, the hall call assignment is supported by the traffic database, the traffic prediction, the traffic pattern recognition and strategy generation components.

The following equations show how $V_{i,AWT}$ and $V_{i,CR}$ in Equation (1) are calculated:

$$V_{i,AWT} = T_{i,r-s} + T_{i,acc} + T_{i,dece} + T_{i,op} + T_{i,cl} + T_{i,in-out} \tag{5}$$

where $T_{i,r-s}$ is the total time of the ith elevator running at the rated speed, $T_{i,acc}$ is the acceleration time, $T_{i,dece}$ is the deceleration time, $T_{i,op}$ is the door-opening time, $T_{i,cl}$ is the door-closing time and $T_{i,in-out}$ is the time passengers spend on entering or leaving the elevator car.

$$V_{i,CR} = 1 - L_{actual} / L_{rated} \tag{6}$$

where L_{actual} is the actual load of the ith elevator, and L_{rated} is the rated load.

During the calculation, the basic traffic information, including the rated speed of the elevator, the height of each floor, the opening and closing time for the door motor, the hall calls and car calls and their distribution, and the traffic prediction are employed.

After a certain hall call is assigned to a specific elevator and before that elevator arrives at the hall call's floor, the traffic conditions may change, for example, new hall calls may occur, or an irregularity may remove the elevator from the EGCS. Therefore, in every execution routing of the group control program, all the elevators will be re-evaluated for each hall call, including those calls having been assigned but not served, and the hall calls will be re-assigned to adapt to the changes. In this way the re-scheduling mechanism is realized.

3.5. Hardware structure

The hardware structure of the proposed EGCS is illustrated in Figure 4, where Block A is the EGCS system board, B is the single elevator control board, C is the inverter, D is the car system, E is the hall call panel, F is the car call panel and G is the remote monitor module. Block 1, 2 and 3 are the communication interfaces for the CAN bus. Block 4 is the input interface for the signals from the elevator well and the car system. The CAN field bus is employed as the communication bus.

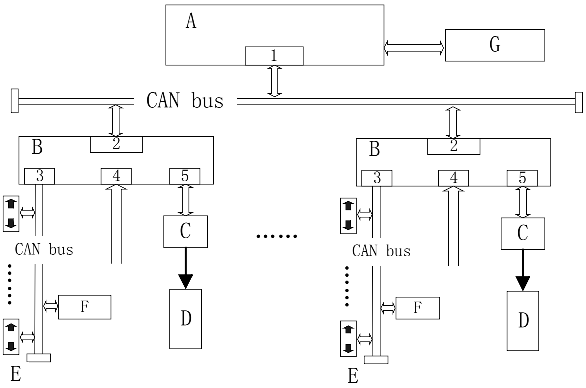

Figure 4. Hardware structure

4. Results and analysis

In this section, a performance comparison between the proposed EGCS and a previous control strategy is analyzed. This four-elevator EGCS was installed inside a building with 26 floors and the data was sampled from its working traffic data. In its previous control strategy the four elevators were divided into 2 groups, each group operating in parallel. The data was sampled over a period of one week under three traffic modes: up peak (UP), down peak (DN) and stochastic inter-floor (SIF) mode. The average results are shown in Table 2. The value at the right upper corner of each element is the data from the EGCS. The value in the lower corner is from the original system.

As seen in Table 2, every evaluation index in every traffic mode has been improved. The average AWT is reduced over 70%. The long wait percent is also reduced remarkably.

The result demonstrates that the proposed EGCS can accurately recognize the traffic pattern and that satisfying performance indices have been achieved.

Table 2. Performance comparison

criterion mode	AWT/s	ART/s	LWP/%
UP	27.5 47.6	41.3 53.4	13.5 32.3
DN	25.4 45.3	35.7 46.3	11.8 27.5
SIF	15.2 25.3	30.3 37.1	7.6 15.4

5. Conclusion

In this paper, the design and implementation of a modern EGCS is introduced. Several considerations for designing an EGCS are discussed first. Then the traffic prediction, the traffic pattern recognition modules based on a new SVM algorithm, and the control generation module are developed. The hall call assignment with re-scheduling ability is constructed and the whole system is implemented. Finally, a comparison of the actual environment traffic data confirms the effectiveness of our proposed system.

Further measures can be taken to improve the EGCS's performance. For example, hall call panels with destination register function or cameras for traffic prediction can be installed to make the traffic prediction more accurate.

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