A COMPUTER VISION BASED GROUP SUPERVISORY CONTROL SYSTEM

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ABSTRACT

It is generally believed that the efficiency and handling capacity of a lift system heavily relies on its group supervisory control system. At present, the microprocessor based supervisory control system coordinates a group of lifts by means of logical rules which have information input from landing call and car call registrations. Such information cannot give a total picture regarding the real-time status and demand. This paper highlights the idea of introducing computer vision to the conventional group supervisory control system. The real time distribution of passengers within the building is determined so that a set of intelligent car allocation algorithms can be formulated. A computer simulation is conducted to show the distinctive improvement by the new scheme.

1. INTRODUCTION

Most conventional lift design packages are based on certain standard modes of traffic, say up-peak traffic etc. The pattern of utilisation and population of each floor in the building has been assumed during the design stage. However, during real-time operation, a lot of factors will deviate from the standards employed during the design stage and the performance relies on the automatic correction by the group supervisory control system. One of the primary considerations in designing a lift configuration is to maximise the traffic flow with the minimum installation. The system must be capable of handling the required passenger traffic densities and attempt to keep passenger waiting times within certain limits. The group supervisory control system plays a very important role in lift system performance[1]. This is something to do with both the quantity and quality of service of the lift system. At the same time, it has been shown that[2] the power consumption during rated speed operation does not differ too much for different drive systems while the major consumption comes from the acceleration and deceleration stages. Hence, it is expected that energy saving will be significant by reducing the number of start/stop per hour of lift operation and this can be accomplished with the aid of a computerized supervisory control system. This is something to do with the efficiency of the lift system from an energy point of view. This paper introduces the idea of incorporating computer vision in modern computerized supervisory control systems to improve service and reduce energy consumption. It must be emphasised that this is not a new system but an existing system with an additional feature.

2. MODERN GROUP SUPERVISORY CONTROL

The latest in modern group supervisory control has a range of operating modes and features tat provide very efficient service. The following description is based on a Japanese model on the market[3]. Special features are highlighted below:

2.1 Waiting Time Distribution: The system is designed to distribute waiting time equally throughout the system, so that no landing call is kept waiting for any more than the ideal waiting time duration of 10 to 20 seconds. High-performance micro-processor intelligence constantly monitors in real-time, every detail of the lifts' movements and operations. When a landing call is received, the computer calculates the expected service distribution time with split-second speed and then immediately dispatches the most suitable car for service. The appropriate hall lantern is lit to keep callers informed.

2.2 Self-Learning Capacity: The system assumes fixed patterns to the seeming chaos of traffic that uses the lifts everyday. The computer observes and analyzes the changes in the traffic flow and develops suitable real-time operation patterns. Second by second, it absorbs a constant flow of real-time operation data, including such patterns and details as call frequency, traffic volume and traffic direction etc. for any given span of time. The information is used to forecast further events to achieve condition-responsive operation patterns.

2.3 Up-Peak Operations: The system efficiently increases handling capacity to meet up-direction peak traffic demand by assigning express return to main terminal after each lift car has completed its job queue.

2.4 Automatic Bypass: The system eliminates redundant landing stops for fully loaded cars.

2.5 Car Spacing for Intermittent Time: Idle cars are dispersed over several floors, instead of basing them at, say the main terminal. The parking policy ensures the cars are evenly distributed within the building. With the introduction of the Self-Learning Capacity, the resultant parking pattern will be even more favourable to new car allocations.

2.6 Advanced Arrival Indication: Hall lanterns and chimes inform the waiting passengers of approaching cars, usually four to five seconds before arrival.

2.7 Delayed Car Cut Out: The system automatically cuts out a delayed car from the group and provides back-up with the remaining cars.

2.8 Up-Peak Split-Zone Operations: The lift bank is divided into specific operation zones during up-direction peak traffic hours for maximum service efficiency. This mode can be slightly modified to suit down-peak traffic conditions.

2.9 Lunchtime Operations: The system increases services to and from restaurant floors during lunchtime, in accordance with expected demands.

2.10 VIP Services: A car is cut off from the group for exclusive service.

2.11 Specific Floor Priority Service: The system provides preferential service for a specified floor.

2.12 Anti-Nuisance Devices: This can avoid unnecessary car trips and stops due to practical jokers who register car calls and then leave the car.

3. USEFUL INFORMATION RETRIEVED BY COMPUTER VISION

It is reasonable to believe that perfect control can be achieved if the supervisory control system actually knows every detail of the traffic flow. The information includes the number of passengers waiting at the lobby, preferably their destinations as well as the number of passengers inside each lift car. An optimal computer group control[1] using ACA is deemed favourable but lots of difficulties have to be overcome before such a system can be actually implemented, particularly anything related to the usual practice or behaviour of passengers. Thus, it is quite satisfactory if we are able to discriminate an up- or down- direction landing call and let the destinations be recorded during the car call registration stage. By employing computer vision, it is possible to estimate the exact number of passengers inside a lift car as well as the number of passengers waiting at the lobby under a real-time basis. Certain additional advantages can be incorporated and will be discussed later. Computer vision[4] applies to both the low-level (e.g. geometric and grey value processing etc.) and high-level (e.g. image understanding) aspects. Often the people who do not appreciate the complexity of this task are those who have never tried to solve even a very simple or reduced version of it. The major difficultly lies with the fact that the processing capability of human visual systems is often taken for granted. This is not a negative remark as it merely reflects the fact that much of the cognitive processes are buried in the subconscious. The subtlety and difficulty of describing the exact operation of subconscious functions presents significant difficulty in developing algorithms to emulate human visual behaviour.

4. IMPROVEMENTS IN GROUP CONTROL WITH THE INTRODUCTION OF COMPUTER VISION

This section deals with the improvements expected when an ordinary lift system with a conventional car allocation algorithm is equipped with computer vision.

4.1 Conventional Car Allocation Algorithm

Conventionally, a cost function based on waiting time for allocating a specified lift car to serve a specified landing call is used. There are various ways, say Duplex/Triplex System, Fixed Sectoring Priority Timed System, Fixed Sectoring System and Dynamic Sectoring System etc. The algorithm used in our simulation program is described below:

Consider the ith car which is at the jth floor for the time being. This car has been assigned a job list previously, which includes both car calls and landing calls.

It has to serve c number of car calls, i.e. releasing passengers at c number of floors $f_{car}(i, k=1..c)$. The car allocation procedure always ensures a smooth traffic flow, i.e. there are only two conditions, either

$f_{car}(i, x) < f_{car}(i, x+1) < f_{car}(i, x+2)$ or
$f_{car}(i, x) > f_{car}(i, x+1) > f_{car}(i, x+2)$
where $1 \leq x \leq c$.

At the same time, it has been assigned l number of landing calls, i.e. stopping at l number of floors $f_{land}(i,k=1..L)$ to receive passengers. The car allocation procedure always ensure a smooth traffic flow, i.e. there are only four conditions, either

$f_{land}(i, x) < f_{land}(i, x+1) < f_{land}(i, x+2)$ or
$f_{land}(i, x) > f_{land}(i, x+1) > f_{land}(i, x+2)$ or
if $f_{land}(i, x) > f_{land}(i, x+1)$ and $f_{land}(i, x+1) < f_{land}(i, x+2)$ then
$f_{land}(i, x+1) < f_{land}(i, k \neq x+1)$ for $k \in \{1,\ldots,L\}$ or
if $f_{land}(i, x) < f_{land}(i, x+1)$ and $f_{land}(i, x+1) > f_{land}(i, x+2)$ then
$f_{land}(i, x+1) > f_{land}(i, k \neq x+1)$ for $k \in \{1,\ldots,L\}$

A new landing call at the nth floor is registered. If it is an up-direction call, its code is +1 and -1 for down-direction call. In order to calculate the cost function based on waiting time for the ith lift car to attend this landing call at the nth floor, the job list is searched through to find out where should this call be placed. A +1 landing call means searching in the ascending order list of f_{car} and f_{land} and vice versa for -1 landing call. Once it is placed, say between $f_{car}(i, x)$ and $f_{car}(i, x+1)$; $f_{land}(i, x')$ and

$f_{land}(i, x'+1)$, the cost function is evaluated by the following steps:

a) Check $\min(\| f_{car}(i, x)-n \| , \| f_{land}(i, x')-n \|)$.

b) Arrange $f_{car}(i, k=1..x)$ and $f_{land}(i, k=1..x')$ in order.
Find out the floor nearest to jth floor, i.e. $\min (\| f_{car}(i, 1)-j \| , \| f_{land}(i, 1)-j \|)$.
Assume $f_{car}(i, 1)$ is nearest. Check $s_L = \mathrm{sgn}(f_{land}(i, 2)-f_{land}(i, 1))$.
Check $s_c = \mathrm{sgn}(f_{car}(i, 2)-f_{car}(i, 1))$. If $s_L = s_c$, find x s.t.
$s_c(f_{car}(i, x+1)) \geq s_L(f_{land}(i, 1)) \geq s_c(f_{car}(i, x))$.
Insert $f_{land}(i, 1)$ between $f_{car}(i, x+1)$ and $f_{car}(i, x)$.
The process is repeated until $f_{land}(i, L)$.

c) Calculate the total travelling time for jth floor to the nth floor going through subsequent floors $f_{car}(i, k=1..x)$ and $f_{land}(i, k=1..x')$.

d) Calculate the total expected stopping time at $f_{car}(i, k=1..x)$ and $f_{land}(i, k=1..x)$.

e) Add the value at (c) and (d) together, arriving at the cost function.

The lift car (i) with the minimum cost function is assigned to the call at the nth floor. The stopping time at each floor is assumed in accordance with past experience. Cars loaded 90% of its capacity are not considered for allocation.

4.2 Computer Vision Aided Car Allocation Algorithm

The algorithm mentioned in 4.1 has a lot of imperfections. It only considers two aspects, namely the distance between the current position of a lift car and the landing call demand floor and the number of foreseeable stoppages when the lift car travels from the current floor to the landing call demand floor. Certain factors have not been considered:

a) The number of passengers initiating such a landing call.

b) The ratio of up-direction and down-direction passengers if both the up-direction and down-direction buttons are pressed.

c) The spare capacity in terms of number of passengers left inside the lift car for further entry.

d) The space/weight ratio of passengers inside the lift car.

The above factors seriously affect the efficiency of car allocation procedures in various ways. Consideration of the above factors facilitate the following improvements:

a) Landing calls initiated by a large group of passengers shall be given priority over landing calls initiated by one or two passengers if they are registered simultaneously.

b) Any floor being occupied by a large number of passengers during heavy interfloor traffic situation shall be assigned a preferential floor or heavy demand floor automatically. More than one lift car shall be assigned to serve such preferential floor. The occurrence of heavy interfloor traffic is random and is difficult to predict. Most lift systems behave unsatisfactorily upon such conditions even if they have good performance with up-peak and down-peak traffic flow.

c) A lift car with over 90% load shall be given the chance to serve a landing call initiated by one or two passengers to reduce average waiting time.

d) Once a lift car is allocated to a landing call with number of passengers exceeding its spare capacity, another lift car shall be immediately allocated to serve that landing call without waiting for the abandoned passengers to initiate a new a landing call afterwards.

e) It is possible to discriminate the number of up-direction passengers and down-direction passengers at the landing by tracing the passenger movement after the advanced arrival indicators have been lit up. The direction with heavy demand shall be treated with priority.

f) A lift car with number of passengers inside exceeding the contract capacity shall not be considered for allocation even if the weight has not yet exceeded 90% of full load value. This is based on the assumption that the cross-sectional area of a human being, and hence his/her occupied space, might not be directly proportional to the weight.

g) Any landing with landing button on but without any passenger shall be considered as a nuisance floor. Hereafter, any car assigned to this floor shall have its job queue cancelled accordingly.

h) At present, there is usually a holding time for the car doors to open once the lift car stops at a landing. Such holding time is a waste if there is only one to two passengers entering the lift car. In real practice, the car doors shall be closed instantly if there is no passenger left at the landing for a landing call.

i) When the car doors start to close, an additional passenger is rushing towards the lift car. He or she will be missed if the "landing" button cannot be pressed on time or the passengers inside the lift car do not hold the car doors by pressing "door-open" button. This extra passenger shall be served as well by leaving the car door open.

The features or problems mentioned above can only be accomplished or solved with the aid of computer vision. They are transformed into cost functions or logical rules which are used to modify the conventional cost functions described in 4.1 for more intelligent allocation schemes or for real time car control for improved service. The most valuable feature for effective car allocation is that it is quite impossible to know the number of passengers that initiate a particular car call but it is quite possible to know the number of passengers that initiate a particular landing call.

4.3 Additional Features with the aid of Computer Vision

Computer vision can lead to significant improvements in a conventional lift system and to a lesser extent, it can improve some features of a modern group supervisory control system like the one outlined in section 2. Self-Learning Capacity can be enhanced since the pattern can be verified daily for more accurate forecasting of events. Up-peak mode can be automatically switched on when the arrival rate of passengers at the main terminal exceeds a threshold value. Similarly, down-peak mode can be automatically switched on when the number of down-direction passengers at every floor exceeds a threshold value. The advantage is that such modes can be immediately switched on and off automatically when necessary and it is quite impossible for any other system that depends on a time schedule to achieve the objective. The function of "Delayed Car Cut Out" can be further enhanced if it is possible to judge whether the delay is due to high passenger flow rate or machine fault. For anti-nuisance devices, the lift system ignores a single child with light weight inside the lift, which is extremely dangerous. The detector for such a feature shall be replaced by computer vision which is more secure. The computer vision system actually performs like a 24-hour watchman at each landing as well as in the lift car.

5. THE COMPUTER VISION SYSTEM

It is a combination of hardware setup for image grabbing and low-level image processing and software algorithms for image understanding. Fig. 1 shows a typical image processing system. A standard CCTV camera, mode WV-BL200/G is connected to a Matrox MVP-AT series frame grabber with maximum resolution of 1024 x 1024 pixels. The grabber is responsible for the sampling and quantization of the image into digital pixels. A common PC/386, together with the frame grabber, is the hardware foundation for the various tasks of the Computer Vision System, namely image enhancement, image restoration, image reconstruction and the most important aspect, image understanding. The PC/386 is linked up to the Lift Supervisory Control System for continuous intercommunication and data sharing. The data manipulated is the number of passengers inside the lift car and at each landing. In most modern commercial buildings, CCTV cameras have been installed on the ceiling of each lift car and at each landing for security purpose. The captioned system only requires a high speed time-multiplexer to sequentially connect the frame grabber to each camera. This justifies the cost effectiveness of this system.

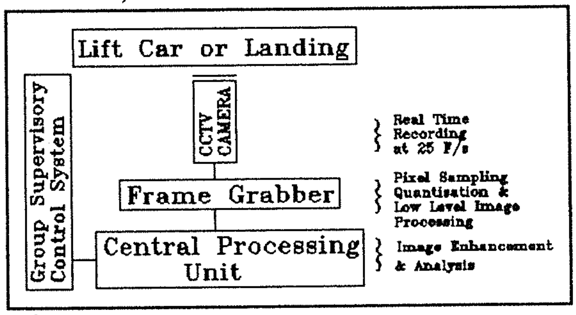

Figure 1

6. FUZZY-SET BASED PASSENGER RECOGNITION

6.1 AUTOMATIC GAIN CONTROL

In order to reduce installation cost, the CCTV cameras used are normally not equipped with auto-iris lens. It is therefore necessary to keep the average brightness level of the images constant, from time to time, by adjusting the gain and offset of the video amplifier of the frame grabber continuously. If the required gain is out of the control range, offset is adjusted automatically by the following algorithm.

$$e = set\_point - \frac{\sum\sum image[i,j]}{N^2}$$

where image[i,j] is the grey level of pixel at ith row, jth column and N = total number of pixels on the image (i.e. 512x512)

$$gain = K_P\, e + K_I \int e\, dt + K_D \frac{de}{dt}$$

6.2 IMAGE SUBTRACTION

In order to determine the existence of passengers on any image, a comparison is made between the current image $image_t[i,j]$ and an image with no passenger $image_o[i,j]$ which has been prepared during the initialisation stage and stored in the hard disk. A resultant image is generated by the absolute subtraction of the two images:

result[i,j] = abs($image_t[i,j]$ - $image_o[i,j]$) for i= 0..511 and j= 0..511

This resultant image reviews any change in the original $image_o[i,j]$ and the changes correspond to the existence of passengers if cargo and animals are neglected.

6.3 IMAGE THRESHOLDING

Since there is a PID control on the gain and offset of the frame grabber, the pixel which does not fall on a passenger shall result in a very small value after the subtraction. A threshold value T_d is chosen during the initialisation stage. It is unavoidable for this value to change from site to site and hence, the choice should be based on human experience. Each pixel on the resultant image is transformed into either 1 or 0 by:

$$result[i,j] = \begin{cases} 1 & \text{if } result[i,j] > T_d \\ 0 & \text{if } result[i,j] \leq T_d \end{cases}$$

Fig. 2 shows an image after thresholding and it consists of four passengers.

6.4 PATCH SEARCHING[5]

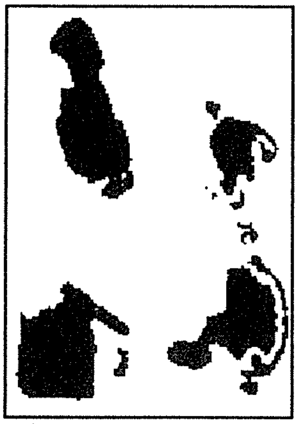

Figure 2

Up to this stage, the resultant image shall consist of patches of brightness (i.e. 1) on a black background. The following job is to find out the total number of patches, their positions and their dimensions on the image for analysis. A patch searching algorithm is employed and once the coordinates of one patch is identified and recorded, the patch is removed from the image (i.e. change '1' for this patch to '0'). Let's assume a patch, which is partially identified and needs further searching, consists of N number of pixels and the coordinates of each pixel is represented by [x(i), y(i)] where i = 1..N and a counter C is used to indicate the last C number of points within the N number of points that require further processing. A point searching procedure scans through the eight neighbouring points of the first priority point within the C number of points i.e. [x(N+1-C]+m, y(N+1-C)+n] for m = -1..1 and n = -1..1 s.t. (m and n) ≠ 0
At the point [x(N+1-C]+m, y(N+1-C)+n], a point-try procedure is executed:

BEGIN

If intensity of [x(N+1-C]+m, y(N+1-C)+n] = 1, assume this point has not yet been recorded within the N previously registered points, i.e.
[x(N+1-C)+m, y(N+1-C)+n] ∉ { [x(i), y(i)] | i=1..N }
Search through the N points and if confirmed,
N:=N+1, C:=C+1, x(N+1):=x(N+1-C)+m, y:=y(N+1-C)+n
else increment m and n accordingly

END

The procedure is executed eight times for each point and the point [x(N+1-C), y(N+1-C)] needs no further processing and C:=C-1. The point searching procedure is executed until C = 0 and after that, the whole patch is isolated, which has coordinates: { [x(i), y(i)] | i=1..N }.

6.5 PASSENGER NUMBER RECOGNITION

Each patch may correspond to part of a passenger, one, two or more passengers standing together. The area (i.e. number of pixels) of the ith patch is calculated by the result in 6.4, designated by A_i. The average area, estimated during the initialisation stage by human experience and site surveying, corresponding to one passenger is denoted by A_1, A_2 for two passengers, and A_k for k passengers standing together. Then, k number of fuzzy sets are formed as follows:

$$\tilde{A}_j = \{ (A_i, \mu_{\tilde{A}_j}(A_i)) \} \quad \text{for } j \in \{1,2,..k\}$$

$$\text{where } \mu_{\tilde{A}_j}(A_i) = \begin{cases} e^{\lambda(A_i - A_j)} & \text{for } A_i \le A_j \\ e^{-\lambda(A_i - A_j)} & \text{for } A_i > A_j \end{cases}$$

and λ is modified for different camera locations

To consider the appropriate description of A_i, the best way is to substitute A_i into the k fuzzy sets and evaluate the corresponding membership functions. The one $\tilde{A}_j$ with maximum membership function implies the probability that such patch corresponds to j number of passengers is the highest. During the course of experiments, it is found that there is a possibility that one passenger is broken into several patches. That may be due to the fact that colour of the clothing is quite similar to the background floor. The area of these patches are found similarly as in 6.4 and their corresponding centres of gravity are evaluated:

$$\bar{x} = \sum_{p=1}^{N} \frac{x(p)}{N} \qquad \bar{y} = \sum_{p=1}^{N} \frac{y(p)}{N}$$

It is certain that such patches shall have area much smaller than A_1 and if the distances of the centres of gravity between two such patches are smaller than a threshold value, the two patches can be considered as belonging to one passenger.

7. COMPUTER SIMULATION

7.1 The Simulation Program

A sample building with 25 floors above the main terminal with average floor height equal to 4 m is used for simulation. The building is served by a group of 4 lift cars under quadruplex control, contract capacity being 20 passengers and 1200 kg each. Each lift car serves all the 26 landings. The contract speed is 5 m/s and an interfloor flight time table is prepared to account for the acceleration/deceleration profile. Door opening time is set at 0.8 s; closing time is 1.5 s; door holding time is 5 s. Since the real operation is extremely dynamic, the computer program makes use of dynamic memory allocation i.e. *link-list* to handle all events. The modularity approach of the program makes it highly flexible and efficient and hence, it is adaptable to any building and any lift system by minor modifications to the database only. The difficulty in preparing the program lies in the fact that although the real situation is very complicated and dynamic, the program has to consider every tiny detail, including the weight of each passenger and any ad hoc event etc. The program, basically, consists of three modules. The first module, the Simulator, continuously updates the car and passenger status by following a job list and generates car call and extra landing call in the event file in case the car assigned to serve that landing call is full. The second module, the Supervisor, handles all events including car and landing calls from an event file. It then generates the appropriate job list for the Simulator to execute. The third module, the Car Allocator, is the most important module within the program. It is responsible for assigning the optimal car to serve a landing call. It is where two sub-modules are prepared, one based on the conventional car allocation algorithm as detailed in 4.1 and the other based on the computer vision aided car allocation algorithm as detailed in 4.2. All the three modules are executed under a real-time mode with information being exchanged freely between them to simulate a real lift system.

7.2 Simulation Results

An event file with duration 30 minutes is prepared. The event file provides information with respect to the time, the starting floor, the destination floor, the number of passengers and the weight of each passenger with respect to the landing call. Car calls and ad hoc landing calls due to car full are internally generated during program execution. A 0.1 s time step is used for each time increment during the program execution and the accuracy is far beyond that required. Three types of traffic flow have been examined, namely the up-peak, the down-peak and the heavy interfloor traffic situations. It is found that for up-peak and down-peak modes, the improvement is not so significant. Only the modes are being called in earlier with the use of computer vision. The major improvement comes from heavy interfloor traffic situation. The average handling capacity is about 35% higher and the number of start/stop within the 30 minute period has been reduced by 6%, distance travelled by 2%, i.e. more than 6% energy saving, for the same event file under the two car allocation algorithms. The major improvement comes from the average waiting time per passenger, from 31.14 s without computer vision to 24.43 with computer vision. Another discovery during the course of simulation is that the chance of car bunching is high during heavy passenger demand situation by using conventional car allocation algorithms. This phenomenon nearly vanishes when the computer vision algorithms are called in. The reason is that we can foresee problems occurring at heavy demand floors by using computer vision while that is quite impossible for conventional supervisory control. In general, it is quite difficult to have a theoretical estimation to summarise all the improvements due to the new technique since it varies case by case. The figures shown above are based on a study on three cases per type of traffic flow simulation.

8. CONCLUSION

The paper describes a new approach to enhancing the existing features of a modern lift supervisory control system. Three points should be emphasised for this system. The cameras have originally been installed at appropriate locations for other purpose such as security control etc., even without this computer vision approach. In this way, the extra hardware cost incurred is the time multiplexer, the frame grabber, the central processing unit PC/386 and the necessary communication linkage with the lift supervisory control system. The cost is negligible compared with the total capital cost of the lift system. The second point is that this computer vision based system only serves as a consultant to the Group Supervisory Control and it is not a necessity for the normal operation of the lift system. In other words, the information generated will certainly upgrade the efficiency and handling capacity but its degree of accuracy will, in no way, downgrade a conventional modern supervisory control system. Thirdly, the number of passengers can be estimated by just using one grabbed image instead of using image sequence analysis, which guarantees a fast response rate by minimum hardware setup. The design of this system is in line with the worldwide interest in robotics development and artificial intelligence.

9. AREA REQUIRING FURTHER INVESTIGATIONS

For the time being, the location of the camera is very restricted. It should always be placed right up in the ceiling of the lift car or the landing and the top view is registered. Only by this arrangement can the passengers appear as individual patches on the image where, most importantly, the area of the patch has a direct relationship with the number of passengers corresponding to the patch. Further research is deemed necessary on the real pattern recognition of human beings where the camera can be placed at any corner with one passenger overlapping another passenger on the image. Algorithms are to be established to emulate the visual cognitive ability of the high-level biological visual system of human beings.

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