Design of Visualization System for Horizontal Transportation Operation of Container Terminal

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Abstract. Aiming at the problem of resource allocation and planning of container trucks in container terminals, the visualization system for horizontal transportation operation of container terminals is designed based on virtual reality technology. The system mainly includes task allocation module, statistical analysis module and visualization module. Based on the real-time communication interface, the synchronous operation of physical scene and virtual scene is realized, which is convenient for remote and real-time control of field operation; based on the principle of the shortest total operation time, the vehicle transfer task is allocated to maximize the resource utilization; with the FCFS (first come first service), priority level and other scheduling strategies, the vehicle path planning is realized to avoid accidents such as collision; through statistics and analysis of data, workers can get real-time information such as vehicle status and total working hours. The scale-down experiment is designed to simulate the container transfer operation of the terminal, which verifies the function of the system. The overall solution of horizontal transportation operation for the container terminal is provided, which can promote the intelligent construction of the terminal.

1 Foreword

Container transportation is one of the main modes of sea transportation. Many scholars have done a lot of research$^{[1-4]}$, committed to solving equipment decoupling, intelligent control and other problems in container terminal. The horizontal transport operation of container terminal, that is, the transport operation of containers between the shore and the yard, is the key link to affect the operation of centralized transport. The allocation strategy and the information degree of transfer task will seriously affect the loading and unloading efficiency and accident rate of the terminal. The visualization system for horizontal transportation operation of container terminal is designed to realize the management and control of AGV and the operation transportation. The scale-down experiment is carried out to simulate the container transfer operation and verify the function of the system.
2 Detailed design

2.1 Design of system architecture

The system adopts the framework of front and back separation with strong expansion ability and flexible deployment. It adopts restful interface, and integrates swagger UI online interface document and JWT token security verification to facilitate client docking. The system architecture is shown in Figure 1. The horizontal transportation system of container terminal is divided into equipment layer, communication layer, data layer, application layer and display layer. The equipment layer mainly includes the communication equipment related to the centralized transportation and sparse operation, which needs to collect the environmental information of the operation site, container status information and so on. The communication layer is mainly based on TCP/IP to complete the interaction between the host computer and the vehicle. The data layer mainly stores and processes the received information. The application layer mainly connects the designed and developed subsystems into a whole according to the operation process and the functional modules of the horizontal transportation system. The display layer mainly displays and manages AGV transportation operations in the form of control center and remote monitoring, which is suitable for terminal control room, operators, container logistics center, etc.

![Figure 1. Structure of horizontal transportation system of container terminal.](image-url)
2.2 Process design of system module

Based on TCP/IP and middleware, the system can obtain the information of the apron of terminal, AGV status etc. Then the task allocation module calculates the time and task sequence based on scheduling algorithm and program logic algorithm, and the visualization module generates the initialization interface. According to the idle and good condition of vehicles on site, the task allocation module completes vehicle task allocation. The system updates the visual interface and data statistics in real time based on feedback information. If there is a risk of vehicle collision, the system will give the order of avoidance or wait based on the scheduling strategy. Until there is no task sequence in the system, the program will be terminated. The specific process is shown in Figure 2.

2.3 Module design

The visualization system of container terminal horizontal transportation mainly includes task assignment module, module of statistic and analysis and visualization module.

(1) Task assignment module

1) Basic data

The basic data mainly includes container handling task sequence, number of berth, idle status of berth, loading and unloading position coordinates of the apron of terminal, number of yard, status of yard parking position, coordinates of yard parking position, number of container, container size, container type, initial location, destination, etc.

2) Objective function

When all container transportation tasks are completed according to the requirements of terminal management and control operation, the tasks in the current cycle are finished. The objective function that minimize the completion time of the final task is designed. The mathematical model were shown in Formula 1.

\[ f = \max \left( \sum_{n} \left( \min \left( \sum_{i} t_{gi} + d_{gi} + l_{i} + t_{si} + d_{si} \right) \right) \right) \]  

(1)
where, $M$ is the total number of task, $N$ is the total number of AGV, $m$ is the ID of container transportation tasks, $m = 1, 2 \bigcup M$, $n$ is the ID of AGV, $n = 1, 2 \bigcup N$, $t_q$ is the time required of $m$ task be transferred to $q$ QC (quay crane), $d_q$ is the waiting time of $m$ task be transferred to $q$ QC, $l_m$ is the transportation time of available AGV for $m$ task , $t_a$ is the time of $m$ task be transferred to a ARMG (Automated Rail-Mounted Container Gantry Crane), $d_a$ is the waiting time of $m$ task be transferred to a ARMG.

3 Scheduling strategy
During the running of multiple AGV in the terminal, the main forms of conflict are node conflict, opposite conflict, and chase conflict, which is shown in Figure 3.

![Conflict type of AGV operation](image)

**Figure 3.** Conflict type of AGV operation.

The following scheduling strategies are used to arrange vehicle scheduling.

a. Priority for long-time operation
   In the vicinity of the location where there is a risk of collision, the task with the longest running time from the corresponding vehicle operation task queue is selected to pass first and the rest of vehicles must wait. Then the vehicles takes less time pass again, and so on until all vehicles pass.

b. First come first serve scheduling strategy
   The system schedules tasks according to their order. For scheduling tasks with similar time-consuming and priority to reach the turning point, the first come first run strategy is adopted.

4) Scheduling algorithm

a. A-star algorithm
   For global path search, A-star algorithm is a classical heuristic search algorithm. Due to the influence of vehicle status and task status on the field, the scheduling path is dynamically adjusted based on the optimization of time window .

$$f(i) = g(i) + h(i)$$  \hspace{1cm} (2)

where, $f(i)$ is the function of estimated cost , $g(i)$ is the actual cost from the starting point to the $i$ node, $h(i)$ is the function of estimated cost reach target point for the $i$ node. $g(i)$ is the product of mobile cost and cost factor. There are many ways to estimate the value of $h(i)$ , such as Manhattan distance, European distance, diagonal valuation.

b. Optimization of AGV scheduling algorithm based on time window
   Task sequence is updated and detected at a certain time interval based on dynamic time window. The algorithm can solve the conflicts and task changes caused by unpredictable factors, and carry out task re-planning requests. Tasks that fail to be assigned or have
problems are deleted firstly from the queue of tasks to be executed. Then when there are
idle vehicles, the system plans again based on A-star and adds the optimization results to
the queue of tasks to be executed.
2 Module of statistic and analysis
Based on the process and progress of container transportation, the system can realize
data statistics and data display.

\[ f_a = \frac{\sum_{i=1}^{B} d_i}{t_B} \]  \hspace{2cm} (3)

\[ f_{wn} = \frac{\sum_{i=1}^{d} t_d}{d} \]  \hspace{2cm} (4)

\[ f_y = \frac{\sum_{i=1}^{n} t_{ad}}{T_n} \]  \hspace{2cm} (5)

where, \( f_{wn} \) is average consumption time of AGV, \( f_y \) is the available utilization of AGV,
\( f_a \) is Average operation cycle. \( B, B = 1,2 \cap N \) Is the total number of vehicles involved in
the transportation, \( t \) is consumption time (in hours), \( d \) is the number of \( n \) vehicle transfer
cycles, \( t_d \) is consumption time of \( n \) vehicle during each transfer cycle, \( t_{ad} \) is the available
utilization of \( n \) vehicle, \( T_n \) is the total time of current loading or unloading operations of
\( n \) vehicle.
3 Visualization module
Based on 3D Max, WebGL and 3D engine of browser, the system can realize the
coordination of virtual scene and real container transportation scene, and achieve the
purpose of remote monitoring. JSON format is used to exchange data between host
computer and AGV based on websocket protocol. The interactive data mainly includes IP
of AGV, coordinate, electric quantity, load condition, speed, corner, etc. The system
realizes data visualization based on echart and assists the dispatcher to make decision.

3 Design and verification of scale-down experiment
The scale-down equipment and scenario was built to simulate the operations of container
terminal. The layout of the scale-down scenario are shown in Figure 4 and figure 5
respectively. Three AGV, several containers, four yard positions, one apron position,
visualization system of horizontal transportation, screen and other software or hardware
were used for scale-down experiment.

**Figure 4.** Layout of the scale-down experiment. **Figure 5.** The on-the-spot scene.
The visualization system of horizontal transportation is located in the central control room, including visualization software, server, screen, etc. The system needs to assign tasks for AGV and command AGV to transport empty or heavy containers between the shore and the yard. During this period, the system commands AGV to complete the straight, parking, waiting, turning, overtaking, reversing, waiting, charging and other driving operations in the straight area, T-junction, etc. The statistical analysis and virtual visualization interface are shown in Figure 6 and Figure 7.

![System statistical analysis interface.](image1)

**Figure 6.** System statistical analysis interface.

![System virtual visualization interface.](image2)

**Figure 7.** System virtual visualization interface.

### 4 Conclusion

Based on A-star algorithm, blending control and linkage by mapping from virtual to real and so on, visualization system for horizontal transportation operation of container terminal is designed. The system mainly consists of task allocation module, statistical analysis module and visualization module, which can realize the management and control of AGV state, the analysis and display of operation data, etc. Through the scale-down experiment, the effectiveness of the system is verified. In the future research, we will combine different ports actual operations, big data and blockchain etc to explore its intelligent application.

### References

1. X. Yang, etc. *Design and Simulation of Automatic Container Terminal*. Shanghai Science and Technology Press, 1(2016).

