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WIRELESS INTER-CRANE COMMUNICATION METHOD FOR MULTI-CRANE SCHEDULING IN MARITIME CONTAINER TERMINALS

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One of the main problems in the maritime container terminals is inefficient use of technical (quay cranes, yard cranes, mobile cranes) and human resources. All this affects negatively the scheduling of transportation and storage processes in the terminals. A new method proposed for the multi-crane scheduling in maritime container terminals is based on the wireless inter-crane communication networks and dynamical localization of the mobile cranes using the Differential Global Positioning System (DGPS) technologies. It is shown that this method outperforms significantly the currently used owing to better time dependence of the crane traveling distance which allows for saving time resources.

Keywords: *DGPS technologies, container terminal, scheduling algorithms.*

1. INTRODUCTION

In the recent years the issues related to the container terminal operations have received much attention from industrial and scientific circles due to the increased importance of marine transportation systems. One of the issues – namely, incorporation of artificial intelligence (AI) in these systems – relates to the optimal scheduling of container terminal cranes where it is becoming of particular value, bringing various benefits in terms of efficiency.

In this work, a new method is proposed for the multi-crane scheduling in maritime container terminals based on the wireless inter-crane communication networks. The method relates to the use of container reach stackers (RSs), mobile harbor cranes (MHCs), and to dynamic localization of the cranes using differential global positioning system (DGPS).

Systems of the type can be divided into three main classes: self-, remote and indirect positioning ones. For the stationary operations a good solution is to use a global positioning system (GPS), while mobile RSs need more precise and local positioning for the container localization and storage. For fast moving sensors the higher positioning precision can be provided by a DGPS which consists of the reference and rover stations. The reference station should be set on a known and motionless place or crane (such as the main harbor crane) or in a stationary place near the complex for sending and receiving signals, while the rover station is placed on each RS. As the positioning must be very accurate, the sensor is to be more precise than the meter. For this purpose the carrier phase real-time differential positioning of centimeter accuracy is suitable. In this system, the reference station transfers the accumulated row carrier-phase and pseudorange measurement results to the rover station, where the coordinate is calculated using a differencing algorithm.

2. RELATED WORKS

Most of the recent research works review the problems of quay crane (QC) operation – such as cargo ships' positioning in the areas where cranes can be operated separately but where also overlapping areas exist which can make the crane operation inefficient [1]; another problem could be berth allocation, e.g. the not allowed quay space occupation simultaneously by another quay and the allowed berthing time for each vessel [2]. Such problems can be solved by optimal crane distribution; therefore, schedule planning as well as integrated operation planning and optimization in the seaport are required [1, 2].

Dividing a container storing terminal into separate parts causes another problem – the crane's moving among containers. Each container section is operated by a different crane, which slows down the work – especially when the crane has to move among such sections in parallel rows: in this case 90^{o} turns are required, leading to traffic jam, delays or even collisions [3]. Also, this section-to-section movement causes loss in the crane productivity [4]. In general, solution to this problem is defined as the off-line planning and knowledge-based system development. Also, researchers offer to use heuristic methods for allocation of a vacant yard crane that could be displaced to another unit; or, in the case of NP-complete problem (NP stands for Non-Deterministic Polynomial) a parallel genetic algorithm (PGA) can be used [3, 4].

In practice, not the most appropriate choice of resources enforces the seaport operators and drivers to choose between two operational strategies: of single-cycling and of dual-cycling; however, they mostly do not choose the latter strategy although it reduces unnecessary movements and increases the effectiveness of carrying cargos. In such cases it is offered to improve the single-cycling strategies for drivers by using heuristic and genetic algorithms [5].

A compatibility difficulty arises when the crane operation depends not only on the strategy chosen by operator: it is necessary to find out how to assign the crane to serve tasks of reducing the makespan, because a ship can only leave the port after the cranes finish their operation. It was found that the genetic algorithm can be applied to the quay crane schedule problem, which would allow reaching better results in the cases of small- and medium-sized events. Also, with PGA application less computational time is needed than with available methods [6].

3. ALGORITHM OF RS SELECTION FOR CONTAINER TRANSPORTATION

This paper does not focus on the QC work but proposes and describes a new effective method of RS exploitation in the dynamic wireless localization of the cranes in terminal.

First, the reference station mounted on the main MHC or near it scans *n* RSs for their states: available/unavailable, with *m* being the number of available RSs. If an RS is available, the main MHC asks for its coordinates to connect, otherwise the MHC scans for another RS. When the MHC receives the coordinates of available RS it performs scanning to find out whether there are left any unchecked RSs. At n=0 the MHC stops scanning and checks if there is any available RS. If all RSs at the moment are busy (m = 0), MHC waits 10 s and repeats scanning.

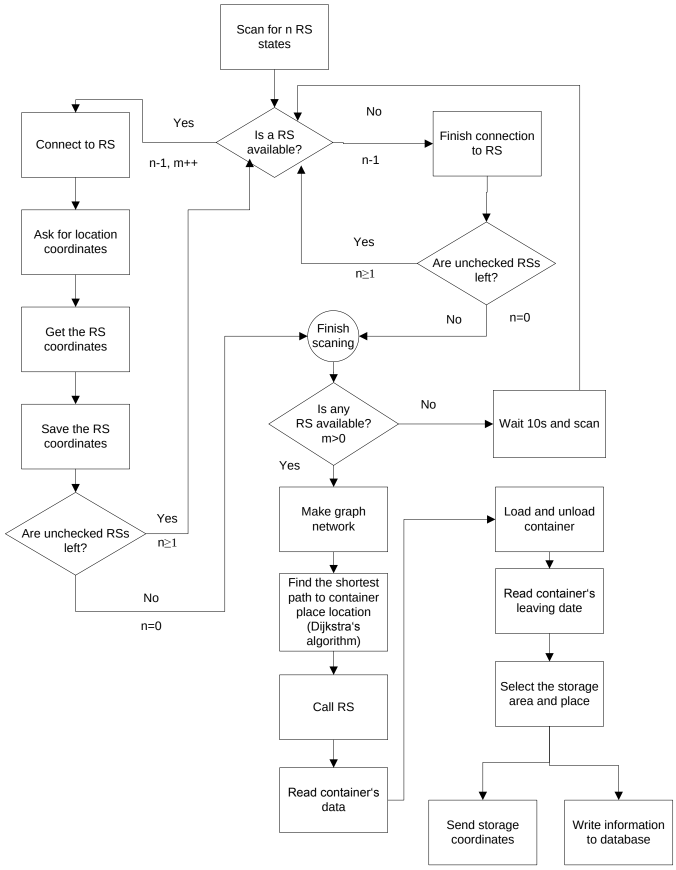

Fig. 1. Algorithm of RS selection for storing containers.

To make a graph network of the RSs available for taking a container at $m \geq 1$, the system installed on MHC computes the paths of each available RS, and, using Dijkstra's algorithm detects the nearest RS, which is called up by sending the destination (MHC) coordinate to it. While the RS is going to the specified location, MHC unloads the container form the cargo ship, reads its main information and fixes the date when the container leaves terminal. The storage area and place are selected by the leaving date. The MHC unloads a container from the ship and sends its storage coordinate to RS, after which this RS loads the container. Then the

MHC writes the storage information in the database. This process is not interrupted until all the containers from ship are unloaded by MCH.

4. STORAGE MODEL AND GRAPH NETWORK OF CONTAINER TERMINAL

The time for transportation of a container from the cargo ship to the storage place includes: the time for MHC unloading the container from the cargo ship, for providing storage coordinates to RS, for RS getting at the given coordinates, and for unloading the container from RS. The MHC operation is almost invariable and cannot be accelerated, while for the RS traveling/route this can be done. One of the methods to do this is to reduce the time for the crane to reach the storage place. The route time decreases when RS uses the shortest path from MHC to the container storage place. This means that the path is not chosen randomly by the driver or operator but given by the program automatically (using Dijksta's algorithm). Therefore, a graphic network of RS movement has been created for the whole container terminal (Fig. 2).

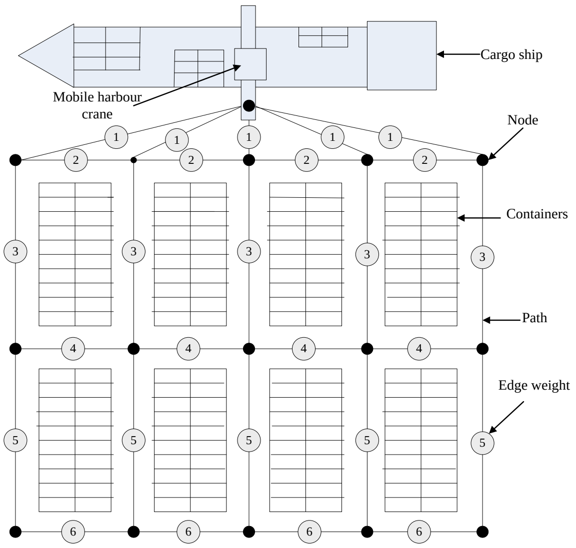

Fig. 2. Graph network of RS movement in container terminal.

Another method for increasing the productivity of a terminal is to create its plan. Dividing the whole multilevel terminal area into different level sub-areas (four in our model) is mainly determined by the distance of container coordinate from the MHC and by the container storage time. The first level area is chosen for short-term storage. The coordinates of second- and third-level areas are assigned to the containers to be stored in the terminal for a longer time and waiting for the dispatch or a future process (the longest time till container's departure and the farthest area are selected). It should be noted that the short-term storage of a container requires greater fuel and time expenditures (except the first-level area). Also, a container cannot be stored there if its leaving time does not match the time span assigned to this area, since otherwise additional traveling of the container to another place can occur. Areas of other levels also have the assigned time intervals which should not be exceeded. Some of them may be overlapped in order to avoid storage errors and lack of space in the terminal.

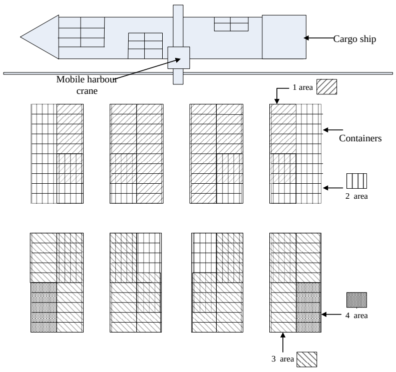

Fig. 3. Container storage areas.

5. SIMULATION RESULTS AND DISCUSSION

To reveal the difference between the currently used method and the proposed method a simulation with *ARENA* software has been performed (Fig. 4). *ARENA* is a powerful modeling and simulation software tool, which allows constructing a simulation model and running experiments in compliance with the appropriate algorithm. Taking the handling models from [7] for the MHC, gantry crane (GC), and RS, the performance of the two methods was modeled and simulated for two hundred standard 20-foot general purpose containers.

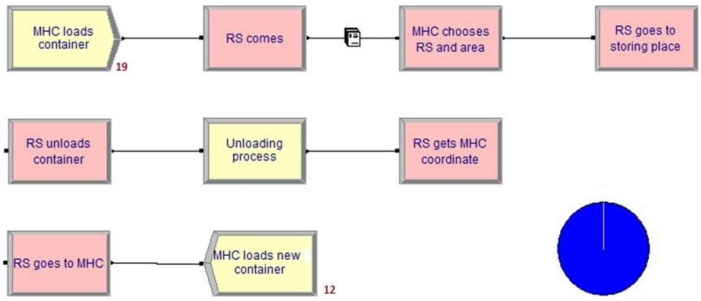

Fig. 4. Algorithm of the proposed method (*ARENA* software).

The parameters simulated for the first (currently used) method are: MHC full container unloading from the cargo ship (mt) – 0.856 min, standard deviation (sd) – 0.221 min; gantry crane (GC) mean speed - 12.916 m/min, sd – 5.515 m/min; GC container loading from stack row in the terminal mt – 0.758 min, sd – 0.283 min; GC unloading to truck mt – 1.303 min, sd – 0.460 min. For the proposed method (based on the wireless inter-crane communication network and dynamic localization of the cranes for multi-crane scheduling in container terminals) the simulation parameters are: MHC loading container mt – 1.257, sd – 0.444; unloading mt – 0.586, sd – 0.221; RS speed with container and without it – 830 m/min, sd – 240 m/min, the maximum and minimum distances – 330 m and 50 m, respectively.

In the simulation four operating resources were taken. According to the distribution of terminal areas shown in Fig. 5, Resource 1 means that almost all RSs have containers to be placed in the first area, unlike Resource 4 with only 37 containers but in the farthest terminal areas.

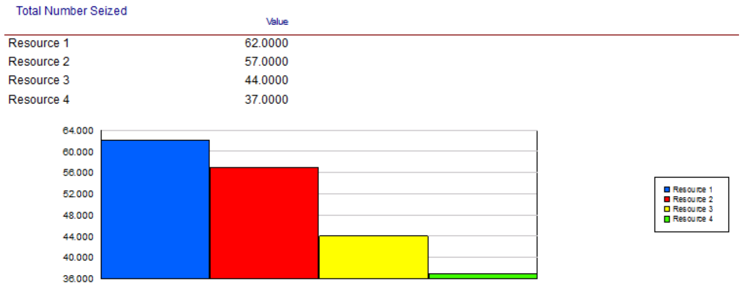

Fig. 5. Distribution of terminal areas.

The experimental results in Fig. 6 show the distance dependence on time for both methods.

It can be seen that our method (the 2nd in Fig. 6) outperforms significantly the currently used (the 1st in Fig. 6). In the first method more time is needed for GC to transport a container to the storage place. The main disadvantages are a low mobility and lack of dynamism of the crane. This way of transporting can be used only for short distances and heavy containers. At the same time, our method provides much faster moving of RS without load and quicker turning in the case when it is needed to reach faster a farther distance from the main MHC.

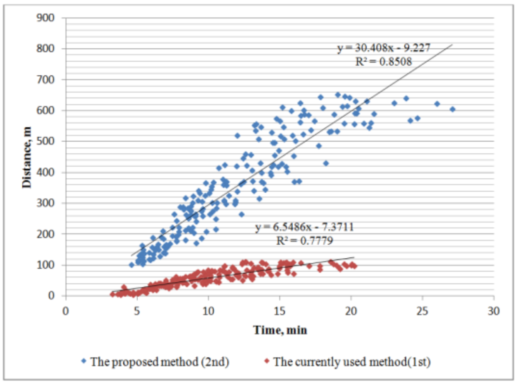

Fig. 6. Results of comparative simulation.

6. CONCLUSIONS

Conclusions that could be drawn from the results obtained are as follows.

The proposed method for the multi-crane scheduling in container terminals provides better choice of paths for transportation and storage of the containers. For example, while in the currently used method the time required for transportation and storing of a container that is at a distance of a hundred m from MCH is 12-15 min, in the proposed method it is only ~ 5 min. The time for the same storage distances depends not only on the type of container but also on the number of crane turns while reaching the required location, which could give more than a 10-min difference. Therefore, making a network graph plan and sheduling all working RSs based on the wireless inter-crane communication networks and DGPS technologies can reduce unwanted turns and moves.

In the future it is planned to extend our method using more robust time synchronization and mutual exclusion techniques.

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BEZVADU KOMUNIKĀCIJAS TĪKLA PIELIETOJUMS OSTAS DARBA EFEKTIVITĀTES UZLABOŠANAI

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Kopsavilkums

Industrija un zinātnes kopiena ir pievērsusi ļoti lielu uzmanību, lai jūras transporta sistēmās iekļautu mākslīgā intelekta komponentes, jo tās var sniegt dažādas priekšrocības. Viens no interesantākajiem tematiem šajā jomā ir konteineru transportēšanas un uzglabāšanas plānošanas metodes. Šajā darbā tiek piedāvāta jauna metode vairāku celtņa darba plānošanai jūras konteineru terminālos. Tā kā viena no galvenajām problēmām šajos terminālos ir neefektīva resursu - piestātņu celtņu, pacēlāju un autoceltņu izmantošana, metodes pamatā ir bezvadu datu pārraides tīkli komunikācijas starp celtņiem nodrošināšanai un celtņu dinamiska lokalizācija, izmantojot DGPS tehnoloģiju. Optimizēta iekārtu izmantošana nodrošina efektīvāku cilvēkresursu izmantošanu, kā arī uzlabo visu konteineru termināla procesu ātrdarbību.

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