APPLICATION OF COMPUTER VISION METHODS FOR AUTONOMOUS CONTAINER LOADING PROCESS

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Abstract

Increasing worldwide container cargo flows encourage the introduction of new autonomous automation technologies at intermodal container loading terminals. One of the main problems of container unloading process form the ship using quay crane and Automated Guided Vehicles (AGV) is the positioning of the container on AGV which is still human-carried at most container terminals worldwide leading to a longer loading process. One of the areas that could improve the efficiency of container transportation is the visual inspection of containers during loading process. This paper investigates the possibilities to integrate computer vision methods in solving the problem of automated container positioning in container autonomous loading process. The paper proposes an automated container loading model that combines image acquisition, segmentation, recognition, distance measurement and control processes. The computer vision algorithms applied in the work are implemented in an experimental model and the results of the studies show that the proposed system could be integrated into the overall autonomous container loading process.

Keywords: *computer vision, container loading, autonomous container terminal, positioning*

1. INTRODUCTION

Currently, approximately 3% of container hubs are either semi-automated or fully automated (IContainers, 2018). In recent years, hybrid and pure electric Automated Guided Vehicles (AGVs) have been increasingly used. In the future, due to advances in battery technology and lower battery prices, as well as a clear area of AGV action, there will be a short-distance transition to fully electrical AGVs. Electric autonomous cranes for loading containers from ships on AGVs are not widely used due to stochastic processes influencing the crane loading process (different loading conditions of container cargo, weather conditions, ship size, loading time, loading trajectory planning, etc.). In order to evaluate the performance of such an autonomous system, it is necessary to develop a generalized mathematical dynamic model of the loading process of the system, which would evaluate the possible kinematic and dynamic characteristics of the container in the "quay-crane-stack" loading system and to include changing conditions during transportation (cargo mass, distance, AGV speed, weather conditions, etc).

In modern loading process assurance devices, physical work is performed by motors, hydraulics and other actuators. Most devices already have automatic control systems in place that control actuators with minimal operator input. Increasingly, intelligent control systems are also being deployed that can control devices more accurately and efficiently. No exception is the container crane, which could also be operated autonomously, but it is still operated by operators. Using the control panel, operators control the engines with the help of control levers, thus transporting containers from ships to AGVs. The operator monitors the entire process and controls the actuators in response to ongoing actions. Managing simultaneous loading and unloading of containers is a complex task because this operation demands coordination among the Automated Lifting Vehicles (ALVs), the Quay Cranes (QCs), and the Automatic Stacking Crane (ASCs) that transfer the containers from the stackside to the quayside or vice versa (Roy and de Koster, 2018).

Such a control system is not efficient because the whole loading process depends on the operator's focus on the task. The positioning accuracy of the gripper depends on the operator, as the control panel is far from the transported container. The oscillation of the crane spreader depends on the cable's length, due to the sway motion of the suspended load. Crane operators have to wait until the oscillation stops to twistlock the container (Parreño-Torres *et al.*, 2020). Therefore, the operator must closely monitor the

container and control the engines at the same time. An important point is placing the container on a transport platform, train wagon or AGV. Because the operator's cab is quite far from the container location, there is a problem with accurately positioning the container. To solve these problems the computer vision methods-based systems are being developed that enables automation of the loading process. It is reducing the human factor and optimizing the overall loading process.

2. RELATED WORKS

In the context of Industry 4.0, freight transportation industries are extremely interested in exploring the use of the emerging technologies, such as the fifth-generation cellular network technology (5G), high-resolution cameras, and connected and automated guided vehicles (AGVs), for next-generation automated container hubs (Chen *et al.*, 2020). Most of recent papers analyzing different approaches of the optimal scheduling including optimization problems solving, cooperation methods, multi-agent approaches (Chargui *et al.*, 2019; Han, Wang and Huang, 2019; Rahman and Nielsen, 2019; Zhong *et al.*, 2020). Yard crane and AGV scheduling in automated container terminal framework was presented by Chen X. et al. (Chen *et al.*, 2020). Authors construct a multi-robot coordinating/scheduling model for automated container hubs, decompose multi-robot tasks with inter-robot constraints using ADMM-based method and propose a real-time scheduling framework based on rolling-horizon method. They verify feasibility and efficiency in Putian container terminal in China.

Another group analyzing the stochastic modeling of automated container terminals (He, Tan and Zhang, 2019; Pan, Liang and Dong, 2019; Facchini, Digiesi and Mossa, 2020). The unloading and loading operations at a container terminal using automated lifting vehicles problem has been addressed by Roy D. and Koster R. (Roy and de Koster, 2018). Authors have developed an integrated analytical model for overlapping operations at a container terminal and integrated a novel iterative algorithm for solving the network. The model has been validated at heavy and non-heavy traffic conditions. A study on multi-ASC scheduling method of automated container terminals based on graph theory was analyzed by Lu H. and Wang S. (Lu and Wang, 2019). We aim to minimize ASC operation time and the waiting time of target container for loading and unloading. The ASC scheduling problem is transformed into a Job-Shop problem by graph theoretic model. Then the grid method is used to express the graph theoretic model, and the problem is solved by MPSO algorithm.

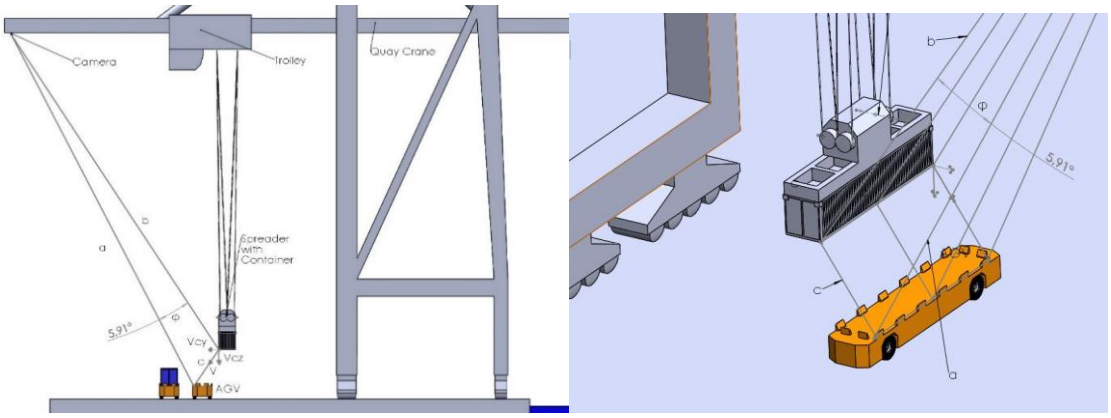
Authors showed that in the mixed pile mode, ASC scheduling problem didn’t consider coordination degree factor of ASC scheduling between the box areas, and further study the uncertainty scheduling problem with actual situation is needed. Despite the number of researches in the context of automated container terminals there is very few investigations on computer vision methods integration in to the container loading process.

3. MODEL OF AUTONOMOUS CONTAINER LOADING PROCESS

One of the main problems of container unloading process form the ship using quay crane and AGV is the positioning of the container on AGV. This problem occurs due to:

- The swinging of the container, because of the flexibility of the crane metal ropes;
- Influence of the wind force;
- None-exact AVG positioning on ground plane in respect to container;
- Quay crane is not fully automated, thus the operator is influencing loading process precision and time even under the remote control cases of the crane;
- The mass of the container;
- Visual clarity, due to the air conditions.

These disturbances are influential, thus most of them are stochastic and difficult to control. The aim is to reduce one of the one of the existing influences – making positioning of the container on AGV without including operators' actions and making it autonomous. This could be implemented by using visual recognitions systems with high-resolution cameras, mounted on crane end on port side with visual towards AGV and crane spreader with container. This camera is a feedback sensor to estimate the position of AGV and container. This feedback realization will give the distance information to the crane hoist and trolley drives for positioning of container on AGV. The main idea of the system is to use video camera (Fig. 1), which is attached to the port side end of the quay crane, with the visual recognition algorithm, to measure the distance "c" between the AGV and container bottom side line. This line is measured at 3 places – both ends of the container and the middle. This is needed to send the controller the error signal, which will allow to control dives for parallel landing on AGV.



a) b)

Fig. 1. Container loading process using camera

The parameters a and b – are the distances from the camera to positioning lines of container and AGV, in general these distances are different and the angle between them could be a secondary check of positioning accuracy of the container loading process.

The system for such synchronized positioning could be described using mathematical model for this process. Therefor some assumptions were assumed for creating the model:

- The camera is fixed to the crane bars with the gyro drives, which compensate the swinging effect of the crane top, thus stabilizing the camera video;
- The camera has zoom function, to have more accurate reading of container and AGV main planes and structures;
- The wind force has mainly influence on the sides $F_{W.XY}$ of the container and has influence on the possible swinging, thus vertical component $F_{W.Z}$ of the wind force is neglected;
- The synchronous positioning acts as control at distances near loading;
- AGV and container has active markers for better visual at any air conditions, at which unloading could be implemented;
- AGV has zero speed at positioning process;
- The container landing is done by two crane drives – hoist and trolley simultaneously.

So, the control system is the positioning system with special system feedback. The system structure is presented in Fig. 2.

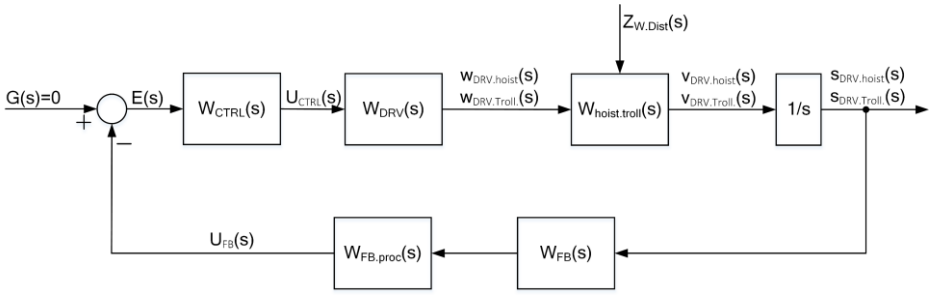


Fig. 2. Control system model of container loading with positioning using video camera as feedback

This control system starts working additionally, when the container and AGV are at a small distance, because controlling the lager distance does not add any value for the accuracy of container loading. The control system consists of controller $W_{CTRL}(s)$, which is implemented as an algorithm for reducing the error E(s) signal towards zero, thus creating a changing control voltage $U_{CTRL}(s)$ for the hoist and trolley drives ($W_{DRV}(s)$) for speed control $w_{DRV.hoist}(s)$ and $w_{DRV.Trol}(s)$. The linear speeds of trolley and hoist are $v_{DRV.Trol}(s)$ and $v_{DRV.hoist}(s)$ are controlled through the mechanisms, which are represented, by transfer function $W_{hoist.troll}(s)$. In addition, the container is affected by the external disturbance – wind and its direction denoted as $Z_{W.Dist}(s)$, which may cause additional swaying of loaded container.

In this article focuses on the feedback implementation, which has two parts: a) feedback sensor $W_{FB}(s)$, implemented using video camera and b) visual processing algorithm $W_{proc}(s)$, which converts visual information from video camera to the voltage to distance signal, which is need for the calculation of the error signal E(s).

4. COMPUTER VISION FOR AUTOMATED CONTAINER POSITIONING

The following external container parameter parameters are most commonly used to detect a container in the image captured by camera:

- The top of the container is rectangular;
- The surface coating of the container is profiled, i.e. all walls of the container have repetitive parallel lines that can be detected using the Hough transform;
- There are square holes at the top and bottom of the container for picking up and fixing the container on the platform.

As we can see from the Fig. 3, during the container lowering process, the container is placed parallel to the platform on which the container should be placed. Camera continuously grabs the loading process and transmit the image to a computer that recognizes the container and platform. After recognizing the container in real time, the remaining distance between the container and the platform on which the container will be placed is calculated. This data is transmitted to the control unit via the Bluetooth interface. The control unit calculates the speed at which the container crane motors must rotate or stop by generating corresponding signal to the motor control unit.

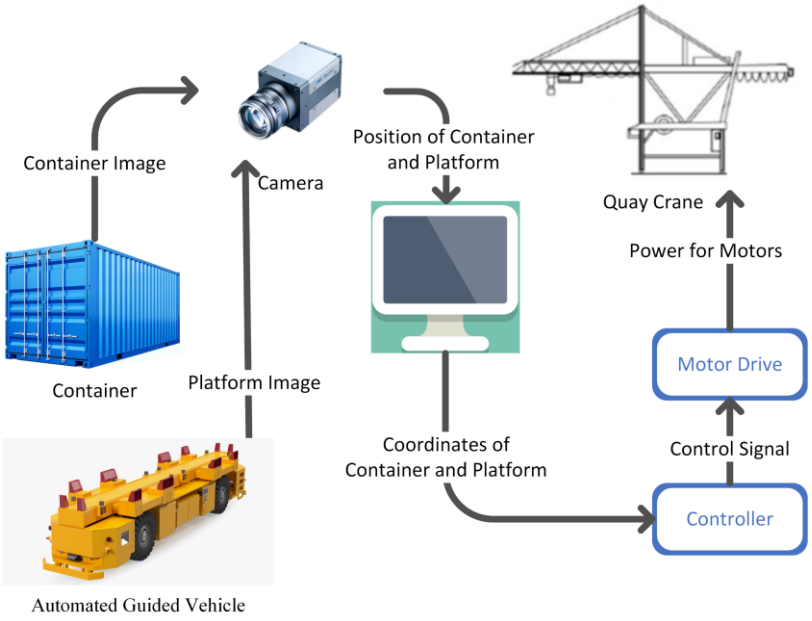


Fig. 3. Schematic diagram of computer vision based container loading crane control subsystem

The image analysis for shipping container loading process consists of several main steps:

- Image capturing - the image of the container is captured in the image matrix;
- Image preparation for analysis – image processing before recognizing the position;
- Image analysis - the edges of the container and the platform are detected and the coordinates are calculated;

It should be noted that all containers have a specific appearance feature that is, fixing-grabbing holes in all four corners of the container. In the image to be analyzed, all the holes are visible and they are darker in color than the environment. Therefore, holes can be detected using image thresholding method by analyzing all pixels above the set threshold value. This limit is selected by calculating the average image intensity. Once the boundaries of the container have been found and the four holes in the corners have been detected, and the height-to-width ratio of the container has been measured, the image information can be used for positioning process. All the operations are performed using two cameras or one camera. Similarly recognizing a placed container, it is important to recognize a raised container with a gripper. An optical image sensor can be used to detect the position of the container and more accurately position the gripper, which helps to more accurately determine the position of the container, the angle of rotation, the swing and the distance to the container platform. In Fig. 4 we can see the flowchart machine vision process for automated recognition of position of container and platform.

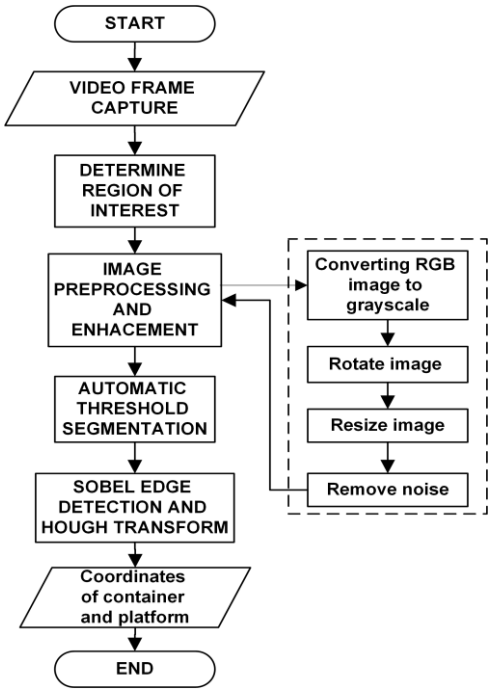


Fig. 4. The flowchart of automated visual inspection for container loading process

As we can see from the picture above, the image is captured during the container loading process, preprocessed, segmented and container defect recognition process is applied. The thresholding function is the simplest method of image segmentation, in which the pixels of image are segmented according to their intensity value. The threshold setting function converts the initial gray input image to a bi-level image using the optimal limit. The threshold setting algorithm is efficient enough to preserve the logical and semantic content of the image. There are two types of threshold image binarization algorithms: the global threshold algorithm and the local or adaptive threshold algorithm. The global thresholding is used with a single threshold *T* for all pixels in the image and it is obtained by:

$$g(x,y) = \begin{cases} 1, if\ f(x,y) > T \\ 0, if\ f(x,y) \leq T \end{cases} \quad (1)$$

Where *g* is the matrix of binarized image and *f* represents an input image with a pixel intensity at a position *(x,y)* of the image. A local or adaptive threshold setting algorithm is used when different pixel settings are used for different local areas. It depends on the corresponding neighboring (x, y) values. In the case of local and adaptive threshold, we calculate individual threshold values T for each pixel:

$$g(x,y) = \begin{cases} 1, if\ f(x,y) > T(x,y) \\ 0, if\ f(x,y) \leq T(x,y) \end{cases} \quad (2)$$

Hough transform can be used to detect parallel straight lines (Cha, Cofer and Kozaitis, 2006; Yoon, Hwang and Cha, 2010; Mukhopadhyay and Chaudhuri, 2015). Each detected line in the xy plane can be described as:

$$x\cos\theta + y\sin\theta = \rho \quad (3)$$

where, θ is the angle of the Hough transform filter line and the x axis, ρ is the distance to the closest line.

5. EXPERIMENTAL RESULTS AND DISCUSSION

National Instruments (NI) Vision Builder software package was chosen for image recognition and processing. This software package provides the ability to process images captured directly by camera.

It also has the ability to communicate directly with external devices via the RS232 interface. Easy data transfer to other devices helps to easily install the developed software package in a control subsystem.

Fig. 5 illustrates implemented algorithm of container loading distance measurement and positioning using NI Vision Builder. The application uses the initial setups to configure camera and image capturing settings, and the program loop for image acquisition, container loading distance measurement and control signal generation for quay crane model.

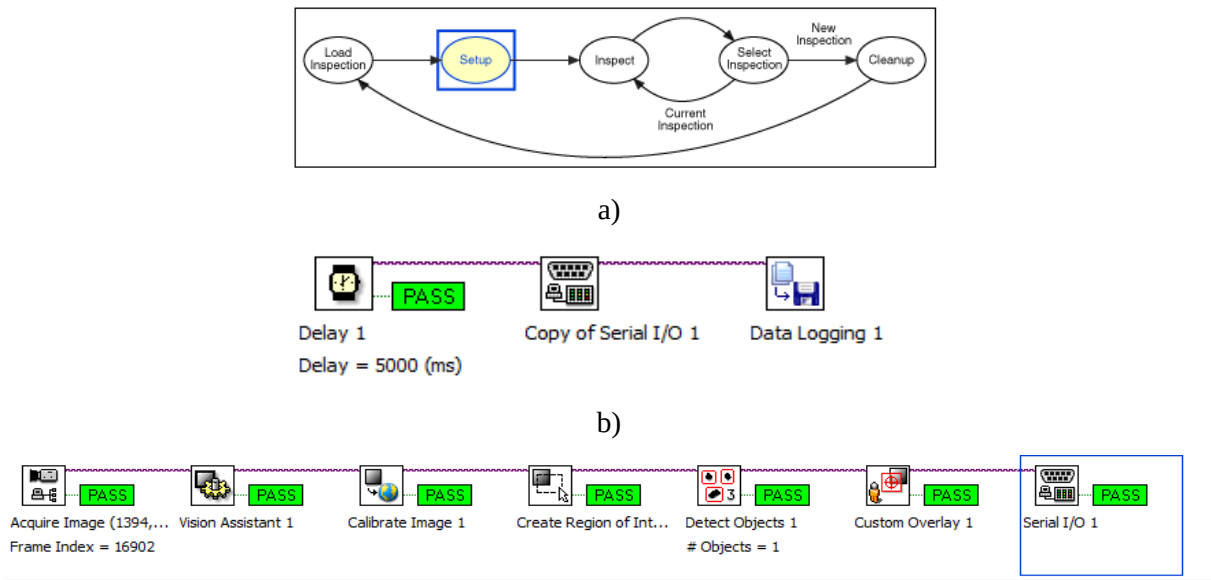


Fig. 5. Implemented algorithm of container loading distance measurement using NI Vision Builder: a) general sequence of program loop including setup and inspection steps; b) block diagram of initial program setup; c) block diagram of image acquisition, container loading distance measurement and control signal generation for quay crane model.

When loading container is detected, the Sobel edge detection operator is used to detect the container, and the Hough transformation is used to detect the vertical lines of the container wall and the base line of the container. When a container is detected, the platform on which the loading container will be placed is searched. When both objects are detected, the remaining distance is measured and transmitted to the control unit. Fig. 6 illustrates container model loading distance measurement, which is transferred to quay crane control model.

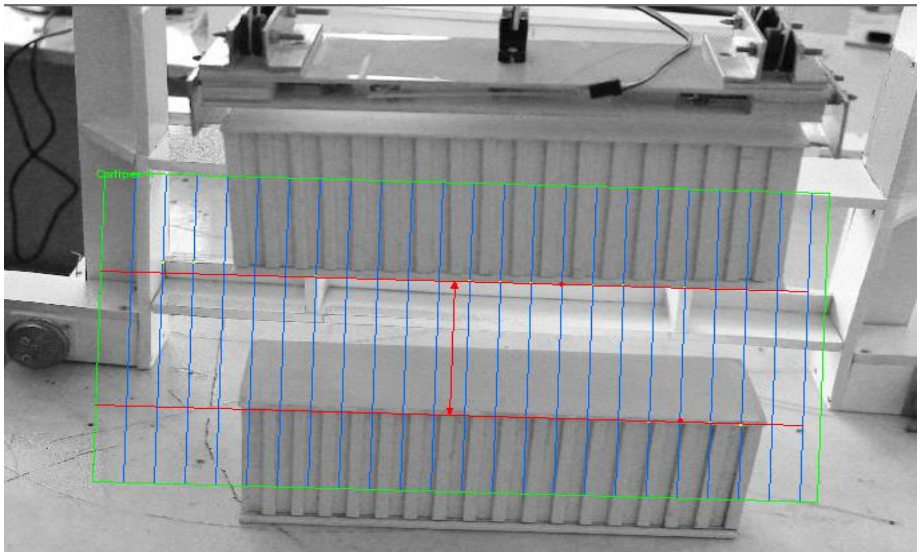


Fig. 6. Machine vision-based container model loading distance measurement using NI Vision Builder

Using container loading process model, the input signal of the control system model in this case is G(s)=0, thus the error signal streams towards zero value by controlling Hoist and trolley drives of the crane. This could be seen in Fig. 7 at the output signal diminishes. The selected distance for the control analysis was 3 meters and we can see that target position of container is reached.

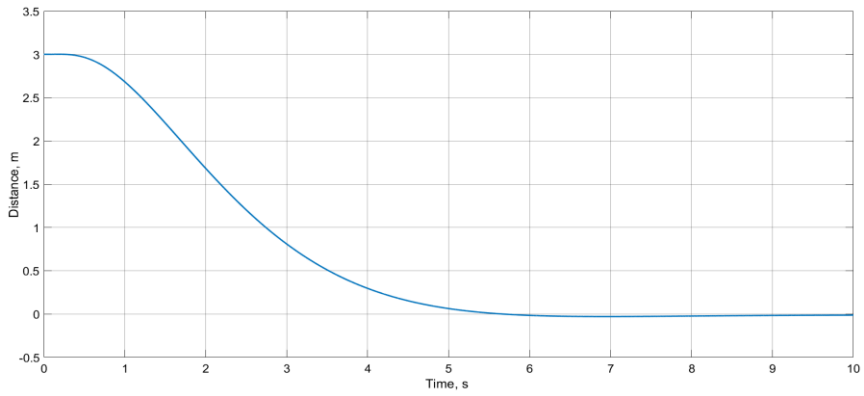


Fig. 7. Calculated container and AGV distance using loading process model

6. CONCLUSIONS

In this paper the general automated container loading model was proposed that combines image acquisition, segmentation, recognition, distance measurement and control processes, depending on the possible kinematic and dynamic characteristics of the container in the "quay-crane-stack" loading system and to including changing conditions during transportation (cargo mass, distance, AGV speed, weather conditions, etc). The computer vision algorithm was proposed and implemented in experimental model of container loading on AGV process. The experimental implementation and results showed that the proposed computer vision-based container and AGV distance measurement method could be integrated into the overall autonomous container loading process.

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REFERENCES

1. Cha, J., Cofer, R. H. and Kozaitis, S. P. (2006) 'Extended Hough transform for linear feature detection', *Pattern Recognition*, 39(6), pp. 1034–1043. doi: https://doi.org/10.1016/j.patcog.2005.05.014.
2. Chargui, K. *et al.* (2019) 'A reactive multi-agent approach for online (re)scheduling of resources in port container terminals', *IFAC-PapersOnLine*, 52(13), pp. 124–129. doi: https://doi.org/10.1016/j.ifacol.2019.11.163.
3. Chen, X. *et al.* (2020) 'Yard crane and AGV scheduling in automated container terminal: A multi-robot task allocation framework', *Transportation Research Part C: Emerging Technologies*, 114, pp. 241–271. doi: https://doi.org/10.1016/j.trc.2020.02.012.
4. Facchini, F., Digiesi, S. and Mossa, G. (2020) 'Optimal dry port configuration for container terminals: A non-linear model for sustainable decision making', *International Journal of Production Economics*, 219, pp. 164–178. doi: https://doi.org/10.1016/j.ijpe.2019.06.004.
5. Han, X., Wang, Q. and Huang, J. (2019) 'Scheduling cooperative twin automated stacking cranes in automated container terminals', *Computers & Industrial Engineering*, 128, pp. 553–558. doi: https://doi.org/10.1016/j.cie.2018.12.039.
6. He, J., Tan, C. and Zhang, Y. (2019) 'Yard crane scheduling problem in a container terminal considering risk caused by uncertainty', *Advanced Engineering Informatics*, 39, pp. 14–24. doi: https://doi.org/10.1016/j.aei.2018.11.004.
7. IContainers (2018) *The future of automation at terminals and ports*. Available at: The future of automation at terminals and ports (Accessed: 5 June 2020).
8. Lu, H. and Wang, S. (2019) 'A study on multi-ASC scheduling method of automated container terminals based on graph theory', *Computers & Industrial Engineering*, 129, pp. 404–416. doi: https://doi.org/10.1016/j.cie.2019.01.050.
9. Mukhopadhyay, P. and Chaudhuri, B. B. (2015) 'A survey of Hough Transform', *Pattern Recognition*, 48(3), pp. 993–1010. doi: https://doi.org/10.1016/j.patcog.2014.08.027.
10. Pan, Y., Liang, C. and Dong, L. (2019) 'A two-stage model for an urban underground container transportation plan problem', *Computers & Industrial Engineering*, 138, p. 106113. doi: https://doi.org/10.1016/j.cie.2019.106113.
11. Parreño-Torres, C. *et al.* (2020) 'Minimizing crane times in pre-marshalling problems', *Transportation Research Part E: Logistics and Transportation Review*, 137, p. 101917. doi: https://doi.org/10.1016/j.tre.2020.101917.
12. Rahman, H. F. and Nielsen, I. (2019) 'Scheduling automated transport vehicles for material distribution systems', *Applied Soft Computing*, 82, p. 105552. doi: https://doi.org/10.1016/j.asoc.2019.105552.
13. Roy, D. and de Koster, R. (2018) 'Stochastic modeling of unloading and loading operations at a container terminal using automated lifting vehicles', *European Journal of Operational Research*, 266(3), pp. 895–910. doi: https://doi.org/10.1016/j.ejor.2017.10.031.

14. Yoon, H. J., Hwang, Y. C. and Cha, E. Y. (2010) 'Real-time container position estimation method using stereo vision for container auto-landing system', in *ICCAS 2010 - International Conference on Control, Automation and Systems*.

15. Zhong, M. *et al.* (2020) 'Multi-AGV scheduling for conflict-free path planning in automated container terminals', *Computers & Industrial Engineering*, 142, p. 106371. doi: https://doi.org/10.1016/j.cie.2020.106371.