Container Handling Operation Modeling and Estimation

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Abstract. This paper presents the initial research findings from the Klaipeda port quay crane monitoring activities related to the Blue economy development initiative in the Baltic Sea and demonstrates the effectiveness of the modelling of the spreader movement patterns. The use case study demonstrates the possibility to monitor the cargo handling processes using ICT sensory equipment and to address the problem of information system deployment in harsh industrial environments. Custom made monitoring and data transmission sensory units were developed and placed on the quay crane spreader and AGV to detect the movement speed and the accelerations in 3D space. Theoretical and use-case scenarios are presented and discussed briefly. Initial results suggested that crane operators' involvement in the control of the cargo movement produced incorrect control patterns (joystick movements) that delayed port operations. Each control movement of the joystick needs to have direct real-time feedback from the spreader (actual movement of the cargo). Feed-back control functionality will allow adjusting the spreader movement ac-cording to the operator and will decrease the cargo transportation time during constant breaks.

Keywords: Data acquisition · Communication technology · Engineering · Systems design

1 Introduction

Klaipeda Sea Port has distinguished itself in the Baltic Region due to its rapid increase in cargo flows and adoption of Blue Economy regulations and strategies, that require a decrease of CO2 and other harmful gasses in the industry surrounding the Sea Port and related to Port activities (including shipbuilding, bulk cargo transit, fossil fuel tranship, fishing and production). Many practitioners and action method-ology developers in the transport chain did research in this area. Ranging from communication and control systems application with deep insights and relevant reviews, economical calculations, and practical use cases [1–4]. Overall, the possibility to adopt new technologies in such closed environments is a rare opportunity. In practice, the realization of complex control solutions limited by cost efficiency in comparison to standardized and commonly used solutions [5, 6].

C. Klein et al. (Eds.): SMARTGREENS 2020/VEHITS 2020, CCIS 1475, pp. 279–289, 2021.
https://doi.org/10.1007/978-3-030-89170-1_14

The adoption of new ideas is difficult even to “modern minds” [7]. In practice, it is difficult to come close to working equipment and to acquire agreement for their monitoring on-site. The initial visual analysis suggested developing new ideas on how to lower fluctuations of the containers’ gripper. Its movements are random in nature, due to external impacts, such as wind or physical contact with other objects. It is difficult to predict such random deviations in practice [2]. In comparison, European ports such as Rotterdam or Hanover apply new systems for vibration decrease in the cables during lowering procedures. Dampening control systems decrease unnecessary strains arising during the accelerated movement of containers by synchronizing operators’ actions with the total lowering process engines and control units. Artificial Intelligence (AI) systems with stochastic algorithms for efficient learning and fast adoption to unlikely events are used in scenarios with high risks [1].

Control and coordination of opera-tor movement is a task for unconventional systems, mainly used to solve competence shortage problems in engineering, medicine, and explorations environments [8, 9]. Today, most Baltic Sea Region Ports handled automated systems, but only on the surface. Context procedures and IT operations automated in most “brutal” fashion. Equipment is bought, but not relied upon to solve critical tasks. That is why the inclusion of the quay crane even in modern ports is still innovation-theoretical. In reality, the crane opera-tor has to wait for the Automated Guided Vehicle (AGV) or the AGV has to wait for the operator to finish his unloading routine, even when the most modern control systems are used.

Klaipeda city Containers terminal (LKAB “Smeltė”) located in the Klaipeda Port is among the fastest-growing Sea Ports in the entire region. Container traffic volume has increased in Klaipeda Port in 2020 drastically, yet the operational efficiency has halted due to new EU and inner company regulations and globalization standards. The most effective means to enhance the container handling operations is to im-prove the existing systems by synchronizing the operations on a technological level, taking into account the technological deviations and the nature of the problems addressed by the personnel on-site. Essentially, it would in general improve the level of services provided, which can be realized by fully utilizing invested resources such as berths, cranes, yards, and handling equipment. Depending on the actual position of the AGV or the crane, decisions are made systematically to slow down the speed of movement so that the target point is reached at the same time by all involved bodies. This saves both energy resources and technical resources, and increases crane and consequently, the entire port efficiency.

In this article, we try to analyze the use case from the LKAB “Smelte” terminal, by estimating the operational efficiency of the loading procedures using the containers handling equipment (namely the quay crane and AGV).

2 Description of the Monitoring Equipment

In the experimental research DL1 - MK2 data logger/analyzer was used to acquire and transfer statistical data. It uses a three-axis accelerometer. Dynamical characteristics are examined, including acceleration, speed, and position. GPS antenna is used to increase accuracy. Movement speed detection accuracy set to 0.16 km/h due to technical reasons and data logging accuracy set to 1% due to irregularities in the electronics.

Figure 1 demonstrates the used equipment. Also, horizontal and vertical acceleration sensors have a standard industry set accuracy level of 0.05 m/s^2 with maximum detection acceleration set to 20 m/s^2. Higher speeds and accelerations are statistically unlikely due to technological and structural reasons.

Fig. 1. Demonstration of the secured case with DL-1 MK2 Datalogger [11, 12].

The mounting point was set on the spreader, shown in Fig. 2. This position was chosen as a more reliable and safer due to constant movements and obstructions, unnecessary hits in all areas. Battery life was not an essential part of the equipment. Its full capacity lifetime was enough to function regularly for the entire period of experimentation (8 000 mAh).

DL1 – MK2 data logger chosen because it allows all the data to be referenced to not just time, but also a position during the 3D movement. This allows the data to be interpreted in a strict understandable way, referenced clearly to the actual position and time stamp. Braking points and gripper usage was analyzed with the built-in 3-axis accelerometer enhanced for high downforce applications.

It is capable of detecting minute changes with a 100 Hz update rate on all attached sensors and accelerometer channels. It also provides 8 analog channels (with 0–20 V battery voltage) for sensor inputs ready for additional measurements and 2 CAN channel with up to 1 M baud rate with 14 CAN filter per channel (CAN 2.0 compatible). The logger itself has IP50 environmental protection (Fig. 2).

Fig. 2. Demonstration of the Data Acquisition sensory hardware placement on the crane spreader [11].

The spreader placement position was secured with handles, but due to the harsh working environment, it was decided to add additional protection via the secured hard plastic mounting case. The maximum power consumption is set to 1.6 W.

3 Theoretical Model of the Movement

To ensure a deeper understanding of the problem addressed in this work, we have analyzed the movement patterns for the quay cranes during the containers handling operations and made simulations with the lab tested equipment (Fig. 3). Here, on the right side of the figure under number - 1, we demonstrate the lab test-bed designed to simulate the movement pattern in a small-scale model, and under number - 2, we demonstrate the spreader with the movement control electronics attached.

We analyzed the theoretical part of the mechanics of the movement and the influence occurring during the actual procedures that affect the operator's actions (Fig. 4). These Figures provide casual movement patterns for loading and unloading procedures. Figure 4 also demonstrates the theoretical positional movement of the container unloading procedure which corresponds to the real-life case studies presented in Fig. 10.

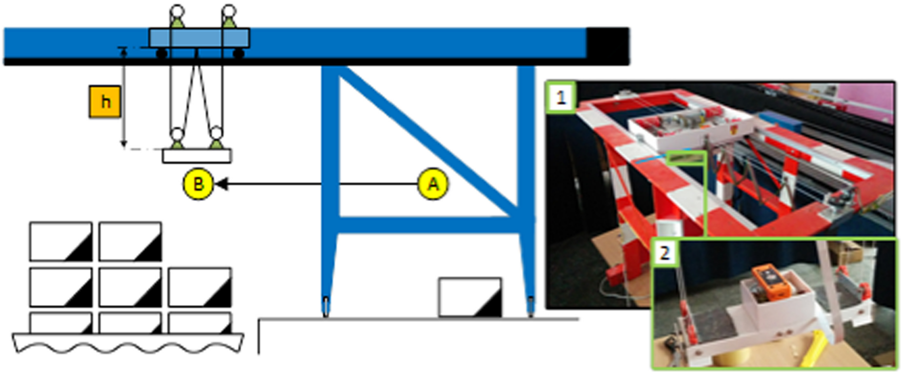


Fig. 3. Demonstration of the quay crane movement points (A and B) along the x-axis and the height *h* for y-axis movements [12].

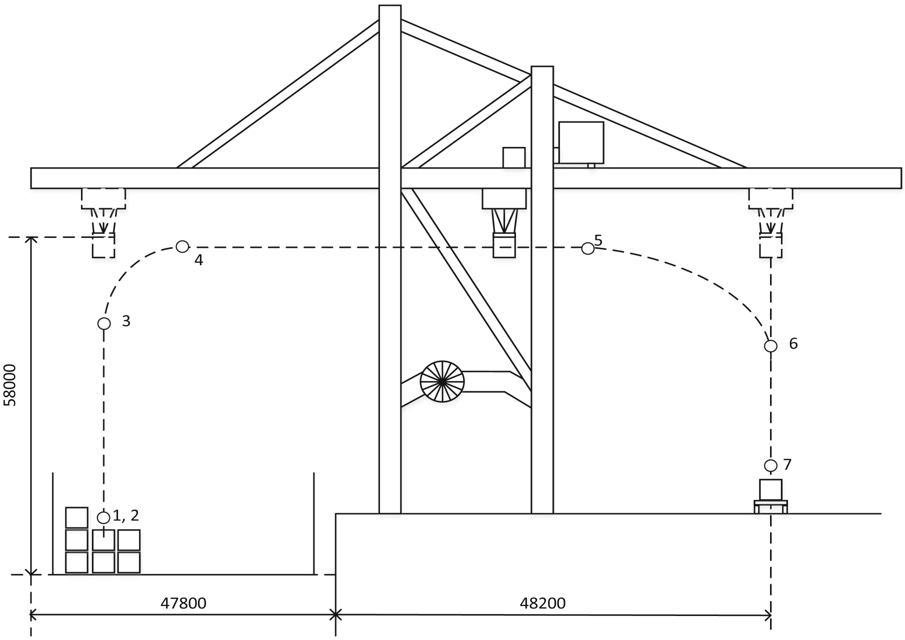


Fig. 4. Demonstration of the quay crane model with critical points of the movement of the spreader (1 to 7), showing the actual position of the container during these operations with the real.

The provided theoretical simulation model (Fig. 5) is yet to finish during the course of the project, but already, we can see the pattern of the movement, which in theory, could provide details and visual confirmation of the accuracy of the lab test-bed.

During the modeling phase, we have analyzed several velocity profiling models, and the best results were achieved using the S-shape velocity profiles, programmed suing MATLAB Simulink (Fig. 6).

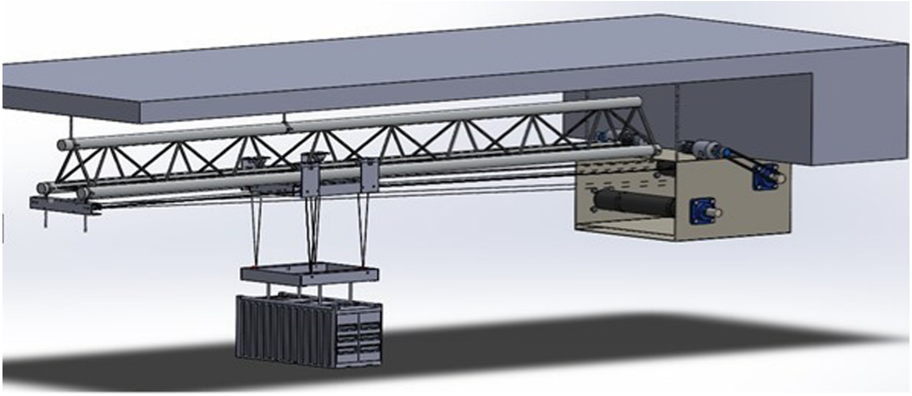


Fig. 5. Demonstration of the quay crane simulation model for the test-bed.

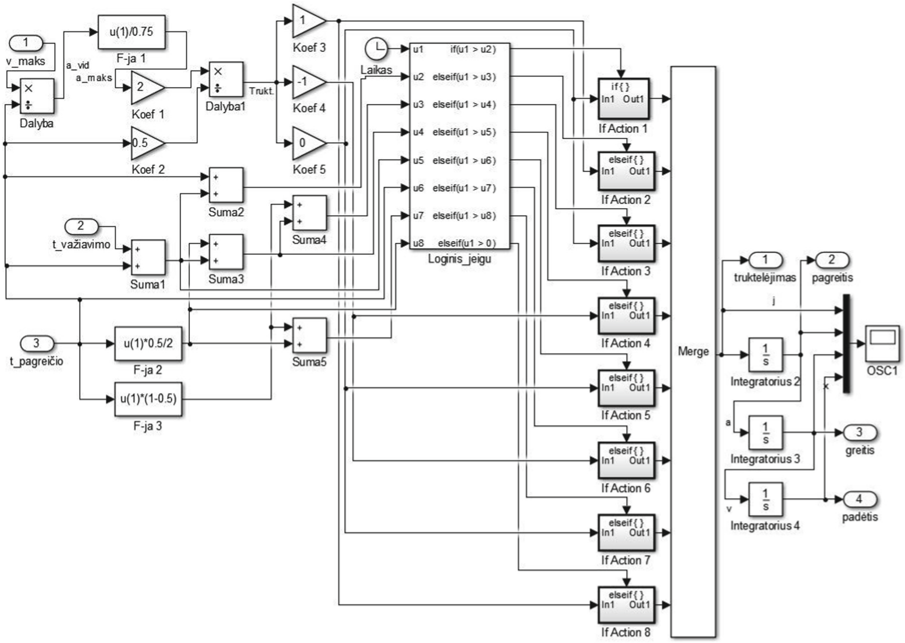
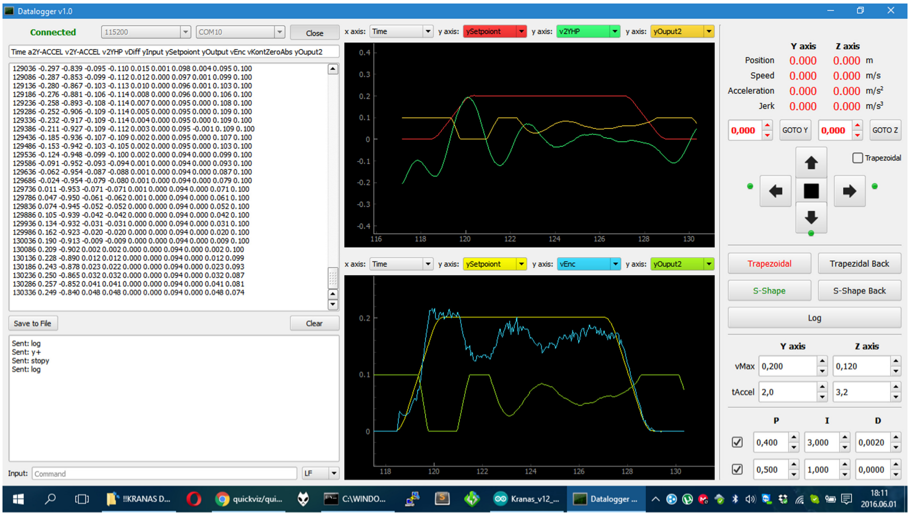


Fig. 6. S-shape velocity profiling block internal structure for the test-bed lab experiments.

The Simulink model has been tested with an S-shaped entry profile when the crane trolley control system is an open type (without feedback) and the crane spreader is with the load with a rope length of 1.9 m and the traveling speed is 0.2 m/s. The following Fig. 7 demonstrates the developed Simulation software used with the S-shape profile to simulate the velocity decrease during movements on the test-bed.

Also, during the simulation and test-bed experimentations, due to the absence of a controller, the spreader was delayed in responding to the control task, while using the



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Time a2Y-ACCEL v2Y-ACCEL v2YHP vDiff yInput ySetpoiont yOutput vEnc vKontZeroAbs yOuput2
129036 -0.297 -0.839 -0.095 -0.110 0.015 0.001 0.098 0.004 0.095 0.100
129086 -0.287 -0.853 -0.099 -0.112 0.012 0.000 0.097 0.001 0.099 0.100
129136 -0.280 -0.867 -0.103 -0.113 0.010 0.000 0.096 0.001 0.103 0.100
129186 -0.276 -0.881 -0.106 -0.114 0.008 0.000 0.096 0.000 0.106 0.100
129236 -0.258 -0.893 -0.108 -0.114 0.007 0.000 0.095 0.000 0.108 0.100
129286 -0.252 -0.906 -0.109 -0.114 0.005 0.000 0.095 0.000 0.109 0.100
129336 -0.232 -0.917 -0.109 -0.114 0.004 0.000 0.095 0.000 0.109 0.100
129386 -0.211 -0.927 -0.109 -0.112 0.003 0.000 0.095 -0.001 0.109 0.100
129436 -0.185 -0.936 -0.107 -0.109 0.002 0.000 0.095 0.000 0.107 0.100
129486 -0.153 -0.942 -0.103 -0.105 0.002 0.000 0.095 0.000 0.103 0.100
129536 -0.124 -0.948 -0.099 -0.100 0.002 0.000 0.094 0.000 0.099 0.100
129586 -0.091 -0.952 -0.093 -0.094 0.001 0.000 0.094 0.000 0.093 0.100
129636 -0.062 -0.954 -0.087 -0.088 0.001 0.000 0.094 0.000 0.087 0.100
129686 -0.024 -0.954 -0.079 -0.080 0.001 0.000 0.094 0.000 0.079 0.100
129736 0.011 -0.953 -0.071 -0.071 0.001 0.000 0.094 0.000 0.071 0.100
129786 0.047 -0.950 -0.061 -0.062 0.001 0.000 0.094 0.000 0.061 0.100
129836 0.074 -0.945 -0.052 -0.052 0.000 0.000 0.094 0.000 0.052 0.100
129886 0.105 -0.939 -0.042 -0.042 0.000 0.000 0.094 0.000 0.042 0.100
129936 0.134 -0.932 -0.031 -0.031 0.000 0.000 0.094 0.000 0.031 0.100
129986 0.162 -0.923 -0.020 -0.020 0.000 0.000 0.094 0.000 0.020 0.100
130036 0.190 -0.913 -0.009 -0.009 0.000 0.000 0.094 0.000 0.009 0.100
130086 0.209 -0.902 0.002 0.002 0.000 0.000 0.094 0.000 0.002 0.100
130136 0.228 -0.890 0.012 0.012 0.000 0.000 0.094 0.000 0.012 0.099
130186 0.243 -0.878 0.023 0.022 0.000 0.000 0.094 0.000 0.023 0.093
130236 0.250 -0.865 0.032 0.032 0.000 0.000 0.094 0.000 0.032 0.087
130286 0.257 -0.852 0.041 0.041 0.000 0.000 0.094 0.000 0.041 0.081
130336 0.249 -0.840 0.048 0.048 0.000 0.000 0.094 0.000 0.048 0.074
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Sent: log
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	Y axis	Z axis	
Position	0.000	0.000	m
Speed	0.000	0.000	m/s
Acceleration	0.000	0.000	m/s²
Jerk	0.000	0.000	m/s³

☐ Trapezoidal

	Y axis	Z axis
vMax	0,200	0,120
tAccel	2,0	3,2

	P	I	D
☑	0,400	3,000	0,0020
☑	0,500	1,000	0,0000

Fig. 7. Developed software for the simulations.

PID controllers, dynamic error reached a mere 1.3% that does not significantly affect system operations. The velocity of the load oscillations reaches almost 0.15 m/s and it dampens with the 7.7% percentage decrease for each amplitude of the oscillation with the 0.374 Hz frequency. We acknowledge, that in current systems, AI enriched control models may prove effective, but to the mechanical nature of the problem, the S-shape profile proved to be far more effective in real-time scenarios on the test-bed [12]. So, the conclusion is drawn, that future research will address the AI enrichment of the control units while making comparative analysis with the S-shape profiling method.

4 Experimental Measurement Results

The number of container loading and unloading measurements set to 278, due to port operations strict rules and cooperation agreements for the measurement period. Crane operators were warned that measurements took place during their working hours to avoid legal problems. During the meeting with the working crane operators and truck drivers (who are also AGV operators), discussions were made to address the importance of these measurements and to see the vector of improvement. Some of the crane operators even expressed appreciation for the research. Each measurement had its deviation and irregularity, considering the operator "best choice" scenario set by the operational manual. The following Figs. 8, 9 and 10 demonstrate the actual position of the ICT sensory unit during the case study in Klaipeda sea Port and the accelerations of the shipping container during movements.

The following figure shows the same pattern movement described by the theoretical model and the simulation using the velocity S-shape profiles. Each container varied in mass, therefore, the average mass of 20 metric tons considered for the mean calculations. At this exact measurement, the mass of the container was measured at 19.220 kg. Figures demonstrate 7 stages of operational consideration:

1. Container raising with hooking;
2. Vertical raising of the container;
3. Bias raising of the container;
4. Horizontal transportation of container;
5. Bias lowering of the container;
6. Vertical lowering of the container;
7. Container placement on the transport means (truck or AGV).

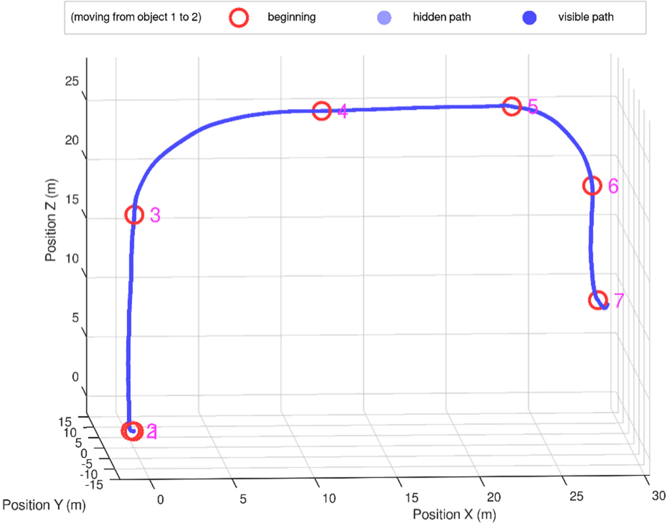

Fig. 8. Spreader position detection and movement points during the container unloading operation from the ship [13].

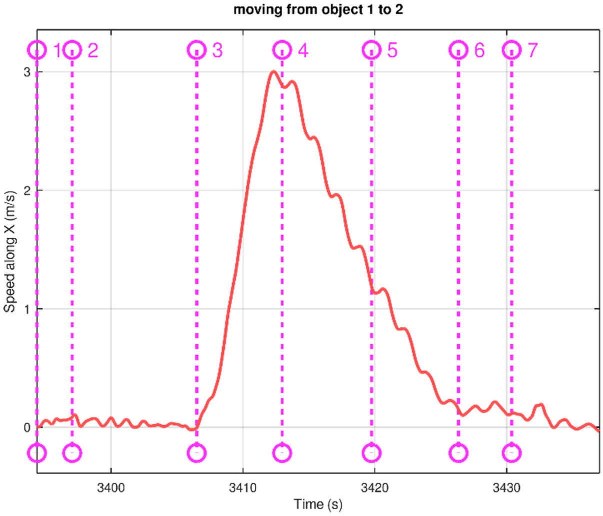

Fig. 9. Demonstration of spreader speed actual values during the 7 stages of operation [13].

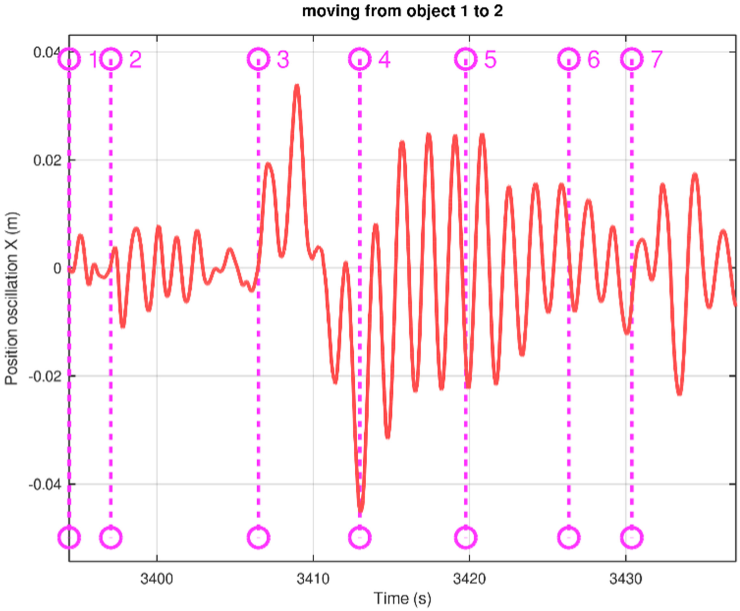

Fig. 10. Demonstration of spreader and container sway oscillation during the 7 stages of operation [13].

The following figures demonstrate the actual speed values during these 7 stages for the process, described in earlier that correlate with the theoretical research findings [11, 12]. These figures demonstrate the spreader and container sway oscillation values. These values are of high importance, because higher values correlate with the actual speed of the operation during the 7th stage, by lowering the speed of container positioning on the transport means or AGV. The overall transportation process is then prolonged to compensate the sway and keep up with the work standard for the safety of cargo and security of operation.

These operations are mostly synchronized with the on-site AGV operators and working standards to keep up with the ship unloading procedure. Yet, due to technological reasons, delays occur daily.

5 Conclusions

Initial results suggest that during the operator did not maintain the same speed during the horizontal transfer of the container. The operator made sudden joystick control movements to stop the transportation process for a short period. Figure 10 demonstrates the ladder shape of the speed values, which correlates with the initial suggestion. This is due to operator mistake, lack of experience, and unsynchronized actions between AGV or truck and the crane. Each ladder produces additional oscillation, which is kept up to the final 7th stage. The operational standard regulates the maximum speed of the spreader movement. Due to these factors, each container was transported with an average of 8.1

s delay for the 278 measurements, and the average speed of operation was calculated as 40.4 s. This indicates that the working efficiency of the operation is only 80%. Each crane is capable of delivering much more container if the operator movement is controlled by a system with pre-defined control models.

The developed theoretical model shows that the movement patterns are strict, and serious deviations occur during the control phase at each point. Authors strongly suggest using the modeling samples from the lab tested equipment and try to evaluate the possibilities to adapt using AI enriched control models in crane joystick control systems. Such a system can help operators in critical control situations and thus, decrease the stress on the system and decrease the operational time for a single cycle. Initial data collection results suggest that operational stability depends heavily on the optimization of operation control through inner transport chain management and regulations.

In other words, the productivity and efficiency of the crane rely on the operator experience. Faults done by operators are not corrected in a due manner, though new regulations and systems are applied. This, in turn, allows constant mistakes to happen and will provide other operators with false context data.

Authors also would like to indicate the high importance of the research done by the EU, to stimulate the adoption of the Blue Economy regulations for Ports to crease the CO2 emissions [10]. The use case study provided in this research was also described in brief in [13] and can help to eliminate the human-machine boundaries for future control systems for heavy industry. These are the primary results gained after the initial testing of the equipment in the terminal. In the future work will include the examination of the AGV control models, as well as new methods to collect data, ranging from 5G to LoRaWAN networks. Additional AI models will be developed and taught during the experimental phase with the AGV and spreader to detect movement patterns remotely with a less than dynamic 1% error.

Acknowledgements. This research has received funding from European Regional Development Fund (project No 01.2.2-LMT-K-718–03-0001) under grant agreement with the Research Council of Lithuania (LMTLT).

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