AUTONOMOUS CONTAINER CRANE TO SIMPLIFY CRANE OPERATIONAL BASED ON IMAGE PROCESSING AND DISTANCE CALCULATION

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Abstract
The number of crane being used in loading and unloading is rising along with growth of shipping activity. However, the growing number of crane is not simultaneous with crane technology development. Crane operation requires the skilled operator to move containers from ship to shore or vice versa. This is not efficient because a container moving pace and the accuracy depend on operator’s skill, and also for a port to operate 24-hour needs to shift the crane operator. To reduce work accident due to crane operator error and to increase the optimum time of crane use significantly, we offer autonomous container gantry crane to simplify crane operation based on image processing and distance calculation. Using Convolutional Neural Network, and centralized crane operator, it will be able to reduce the number of crane operator and increase the accuracy that will affect crane productivity. It can be operated easily, efficiently, and in the future it is expected to solve the loading and unloading problem.

Keywords
Autonomous, Container Gantry Crane, Convolutional Neural Network, Productivity.

INTRODUCTION

Today, 90% of world's trade is transported via containers. Increase demand for speed to market, Container Crane (CC) faces constant pressure to reduce time during loading and unloading to increase efficiency (Henwood, 2006). There are five major typical decision problems arising the management of container terminal: berth allocation, CC scheduling, yard operations, transfer operation, and ship stowage planning. Slow flow during ship to shore and shore to ship operator leads to bottleneck effect to the rest of the process container handling. Hence CC operation needs to be better and efficient.

Most of the slow flow ship to shore and shore to ship caused by CC's skill. Operated by human, CC will have different pace and accuracy during operational time. Slow operator will cause container pile waiting to be loaded to ship and Prime Mover (PM) waits too long. This problem will disadvantage container liner due to high rises of berth cost. Port authority will also get number loss due to un-optimum vessel berthing. Nowadays, almost all of Container Terminal (CT), and PM are autonomous, yet CC is still manually operated by operator. Therefore, autonomous CC is needed. By using autonomous CC, it will increase CC's efficiency, CC's accuracy, and reduce cost due to a little number of operators needed.

The concept of autonomous CC is using sensors. Those sensors are camera and encoder. There are two cameras, the first one is for capturing selected container location and coloured circle mark on top of container. The second camera detects human presence and coloured circle mark under the container that carried by CC. Encoder calculates distance during crane movement. Those data transmitted to computer for further process. The operator located in the main room will be able to control all cranes in the port, make it easier to organize and needless people to operate.

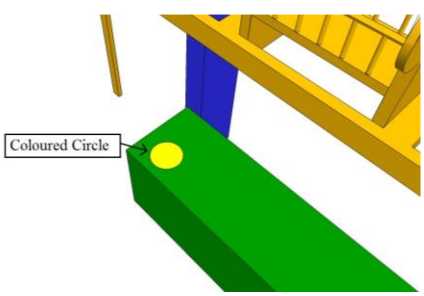

Figure 1.Coloured circle on top of the container.

RESEARCH METHODS

Human factors are the primary cause of error-induced accidents in port operations. For example, a report issued by Maritime New Zealand (2004) describes an accident involving a ship to shore crane when the spreader collapsed as a result of the support cables snapping. It was not possible to identify the exact cause of the accident though an "error of judgement" by the crane operator was perceived as the cause. Because the optimum arousal level and quality of performance will vary with task complexity.

Figure 2.Yerkes-Dodson curves (complex and simple task) and theoretical relationship between arousal and behavioural performance.

Great efforts have been made to improve the efficiency and safety of cranes. For example, some dynamic control methods have been developed to reduce oscillation and vibration and to ensure safety. Some experiments have shown that visual tracking control interface can improve efficiency and safety with great compatibility, compared to traditional interfaces like a control pendent or actuating joystick. Additionally, visual sensors (cameras) are able to provide position feedback, which can be used for tracking and controlling gantry crane and payload.

To increase autonomous CC's ability, the program uses Convolutional Neural Network algorithm to detect container and human presence because Convolutional Neural Network is more efficient and effective for object detection. Image processing is used to detect the coloured circle. This coloured circle will lead the spreader to the correct position to avoid error due to single sensor (encoder). Encoder will calculate the distance during crane and spreader movement.

FINDING AND DISCUSSION

Loading and unloading container process involves CC operator, leasing man, and PM driver on the field. Every part contributes and supports one another. PM driver will lead the PM to the position under CC, to make the container to be picked up easily by the crane to put it on board to the container vessel.CC operator operates the crane, moving container from ship to shore and shore to ship. Leasing man working on board to buckle and unbuckle the lease that hold up the container to stay in the safe position.

CC needs to be modified with some added components such as cameras, encoders, camera mechanical system (extension rod), microcontroller, and computer. Camera will be installed in the spreader and bellow the crane's arm facing vessel from above.

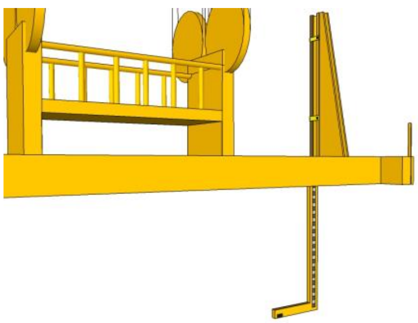

Figure 3.Extension rod for third camera.

First camera on spreader will read the coloured circle on top of the container and the second camera will be placed in the rod located in the spreader. This rod will go up when the container almost touch the object nearby such as another container or truck (PM), and go down when capturing coloured circle under carried container.

Encoder will be installed in two different locations. First encoder will be installed on crane's arm to calculate distance on z axis. The second encoder will be installed near the crane's tire attached to the rail to calculate distance on x axis. Micro controller collects the inputted data from all encoders and transmits it to the computer. Computer located in crane will process all of the data collected by cameras and microcontroller along with controlling the crane movement. The computer in crane connected with computer in main office by local area network. Computer located in main office working as a monitoring device.

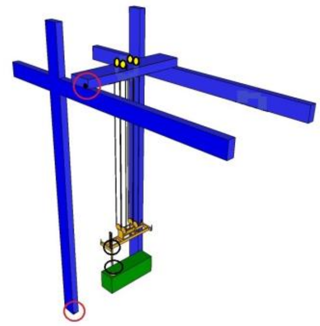

Figure 4.Red circles are the location of the encoders and black circles are the location of the cameras.

The program uses Convolutional Neural Network algorithm to detect crane and human presence. Image processing is used for detecting the coloured circle. This coloured circle will lead the spreader to the correct position to avoid error due to single sensor (encoder). Encoder will calculate the distance during crane and spreader movement.

Since CC operates automatically, there are several steps in the unloading process. First step to do in unloading process is input data from stowage plan. Data from stowage plan will be input to the program aimed the crane to understand which container to pick for the whole unloading process. Next step is the operator directs the crane to the container that is located in the far left of container stack. This container will be marked as (0,0,0) coordinate. Then it will calibrate the location of the PM by operator located in the main office. After calibrating both of PM and container on the container vessel, the operator will be able to leave the CC to operate by itself. On unloading process the spreader directed automatically to the container stack on board lead by the camera located on the spreader. The extension rod on spreader will pull up itself so it would not get hit by the container surrounding. After the spreader successfully carried out the container, the CC will lead to the PM's coordinate.

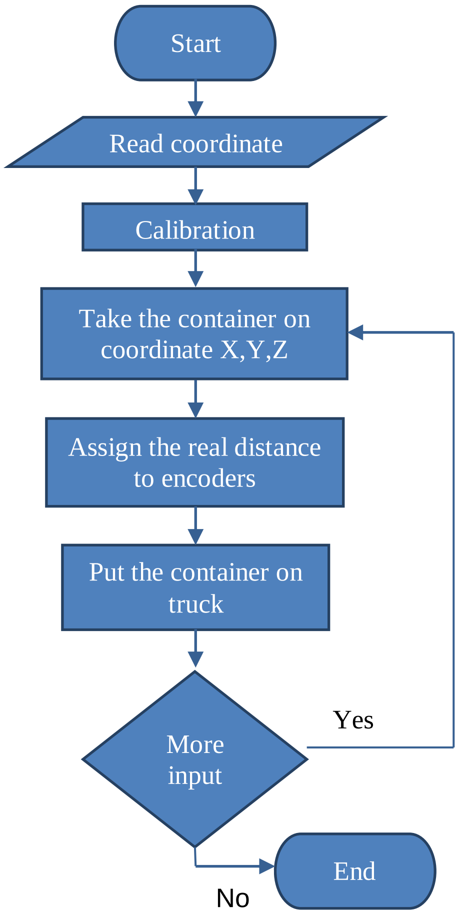

Figure 5. The general structure of unloading container process.

The same process will be enacted during loading process. First step is to input the data from stowage plan in order to CC to understand where the container from the PM will be stored on board the container vessel. Next step is to calibrate the truck position and coordinate on container vessel. After all of the calibration process, the operator will be able to run the program. The cameras both on spreader will lead the spreader to the PM location to pick up the container. Using coordinate the spreader will lead the container position on board based on stowage plan. The camera on the extension will detect the coloured circle on the container or on the base of the cargo hold compartment. Once it successfully detects the precise location of the container where it is supposed to be placed, the extension rod will pull up automatically to prevent the collision with containers surrounding.

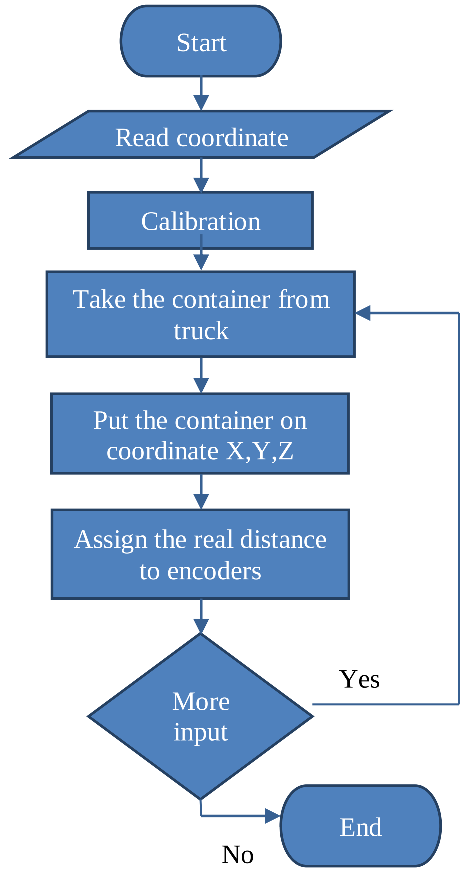

Figure 6. The general structure of loading container process.

First step to operate autonomous CC is calibrating the crane. Operator moves the crane to the far left of the container stack and nearer by the port. The container right below the camera is assumed that position is x = 0, y = 0 and the encoders reset the value to 0. Then the operator moves the crane to the truck to let the encoders calculate the distance between the container in position 0,0 and the truck. After that, autonomous CC ready to run sequence of command. Example: If autonomous CC is commanded to take container in position x = 2, y = 3 the crane will move until the crane is right on the container in that position. Then, the rod installed on the spreader moving down and then the camera below the rod is controlling the crane based on the circle below that camera. If the circle position is not right below the camera, the crane will move until the circle is right below the camera. If the coloured circle is located bellow the camera, the spreader is moving down. While the spreader is moving down, the camera below the rod still control the spreader to make sure the spreader hit the container on the right place. If the spreader is close enough to the container, the rod is moving up so it will not hit the container. The crane is slowing down so it will touch the container gently. The spreader moving down until the switch below the spreader is pressed by the container and the crane lock the container. To minimize the error of encoder calculation, encoders need to be assigned by the real distance. Real distance of x-axis is x*length of container, and real distance of y-axis is y*width of container. Then the container moving up and then takes the container to the truck based on distance calculation using encoders.

During the loading and unloading process there are some workers on board to unbuckle or buckle container leasing during CC operation. To answer the safety factor, this CC also modified by adding camera to detect human presence surrounding the spreader located in the extension rod, once the camera detect any human in dangerous area such as under the spreader it will stop automatically until there are no human under the spreader.

Related with the operation of the container gantry crane on the relationship between shift (biological clock) and performance operators:

Table 1.Parameters for the number of containers handled each hour for the four shifts (r = median of maximum number of handled container and minimum number of container, Δ= the different values of maximum number of handled container and minimum number od handled container)(Fancello, Fadda, & D'errico, 2008).

Shift	**₱**	**Containers handled/hour**					
		1st	2nd	3rd	4st	5st	6st
1st	Max	30	27	26	32	28	29
	Min	19	18	12	14	13	13
	r	24	22	19	23	21	21
	Δ	11	9	14	18	15	16
2nd	Max	31	36	38	48	33	35
	Min	12	12	16	15	14	11
	r	**21**	**24**	27	31	23	23
	Δ	19	24	22	33	19	24
3rd	Min	16	19	13	18	16	14
	r	**24**	**25**	23	24	27	23
	Δ	16	13	20	12	22	18
4th	Max	40	40	32	31	29	27
	Min	15	15	18	16	18	8
	r	27	27	25	23	23	17
	Δ	25	25	14	15	11	19

In the first part of the 2nd shift (between the first and second hour) performance increases by 12.85 % (from 21 a 24), almost twice as much as the 6.63 % (from 24 a 25) in the 3rd shift for the same time .This can be explained by the fact that at that time in the morning the operator is more physically and mentally alert and certainly concentrates better than during the rest of the day.

Based on the data collected from one of the international ports in Indonesia, especially operated by conventional CC, the loading and unloading process of ST ISLAND container vessel (IMO number 9532276) with 27061 tones Gross Tonnage, 199 m Loa, 270-470 berth meter, and unloading process started at 21.00 of 01/02/2018 until 10.30 of 01/03/2018. Four CC were used during ST ISLAND's loading and unloading process with Maximal Outreach from Sea Side 37.25 meters (13 rows). There were three shifts with the total of 12 operators. Total unloading process is 16.17 hours including operator's performance factor (Jadwal Sandar Kapal Terminal Petikemas Surabaya).

Using autonomous CC only needs a single operator to operate all CCs on the port, so then with the same case with ST ISLAND's unloading process only need 3 operators without any operator's performance factor. The operator only needs to calibrate the CC in every 2 hours to ensure CC's accuracy

The data below are the comparison between conventional CC and autonomous CC within one year operation collected from Container Terminal of Teluk Lamong, East Java. The operator cost calculation is multiplication of minimum wage in Surabaya, total CC's operator, and number of days within a year, assumed it is 360 working days. Since there are added electronic component such as camera, encoder, computer, and microcontroller, the cost calculation are the multiplication of wattage consumption of each electrical component, energy cost consumption per hour, working hour, and number of days within a year, assumed it is 360 working days (Silalahi, Elton K., et al, 2016).

Table 2. Cost comparison between conventional CC's operator and autonomous CC's operator within a year operation.

Number of Month	Monthly Wage	Conventional CC	Autonomous CC
12	3,583,312.61 IDR	20	6
Total Cost		859,995,026.40 IDR	257,998,507.92 IDR

Table 3. Added cost for autonomous CC's operational.

Item	Quantity	Wattage	Energy Cost Consumption * Daily Working Hour * Working Days	Total Cost
Camera	20	0.0075	8,009,492.4 IDR	1,201,423.86 IDR
Computer	11	0.0132	8,009,492.4 IDR	1.162,978.30 IDR
Encoder	20	0.00003	8,009,492.4 IDR	4,805.70 IDR
Total				2,369,207.85 IDR

Table 4. Comparison of operational cost calculation between conventional CC and autonomous CC within a year.

Cost Parameter	Conventional CC	Autonomous CC
Operator	859,995,026.40 IDR	257,998,507.92 IDR
Added Feature	0.00 IDR	2,369,207.85 IDR
Total	859,995,026.40 IDR	260,367,715.77 IDR

From the calculation above shows 599,627,310.63 IDR margin gap of cost between conventional CC and autonomous CC within one year operational.

CONCLUSION

Autonomous CC is a conventional CC that modified into driverless automatic CC. Using added components such as two cameras, two encoders, one computer, and single microcontroller in each CC, the conventional CC will work automatically controlled from the main office. So then the implementation of autonomous CC will be able to reduce CC operator from 10 operators to 3 operators on each shift. The operator of autonomous CC is also safer than conventional CC since they are working indoor. Undoubtedly, the using of autonomous CC is very effective to cut down the operational cost of a port. Based on the case in Container Terminal of Teluk Lamong the using of autonomous CC will cut down the price to 599,627,310.63 IDR each year, from 859,995,026.40 IDR can be reduce to 260,367,715.77 IDR. The use of autonomous CC will benefit many parties, such as ship owners, port, and shipping company. In the further, Autonomous Container Crane can be developed so it does not require signify modification on the container to make it very flexible if applied in the feeder port that mostly found in eastern Indonesia. Therefore the use of autonomous CC can accelerate the rate of the maritime economy to support Indonesia as world's maritime axis.

CONFLICT OF INTEREST

The existence of autonomous CC does not cause any disadvantages to one of the parties. Port, ship owner, and shipping company will be involved in mutually benefit. The addition of the coloured circle at the top of the container can use weather proof sticker material and does not cause any significant changes in the form of the container. The conventional CC operators can be redirected to the other stations such as container handling at the terminal since the number of port capacity is rising.

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BIOGRAPHIES

Wikandhana S. Rajasa was born in one of the Indonesian port city, Semarang 22 years ago. He is currently an undergraduate student of Institut Teknologi Sepuluh Nopember of Surabaya, Indonesia. He is studying for Naval Architecture and taking Ship Building Engineering as his field of concern. Rajasa known as Mechanical Coordinator of Barunastra ITS Team, Institut Teknology Sepuluh Nopember's Roboboat Team that focus on autonomous ship prototype and has won several competitions. Won at the first place on national roboboat competition held by The Ministry of Research, Technology, and Higher Education of Indonesia. He had also won on the international level held by AUVSI Foundation completed on the fourth place. Now he is preparing international roboboat competition that will be held by AUVSI Foundation in Daytona Beach, Florida. He has submitted papers for several competitions. He is also a member of Indocor Institut Teknologi Sepuluh Nopember Chapter. Rajasa is also a former member of student association and had served on Research and Technology Department.

Septia R. Sari is currently undergraduate student of Institut Teknologi Sepuluh Nopember of Surabaya, Indonesia. Was born ini Nganjuk, September 22nd 1996, she is studying for managerial and operational aspects of the ship or maritime operations that focus on shipbuilding techniques, seaports, economies, logistics, information system and mathematical reflection of real maritime life in the transport sector. Septia known as head of the student association and served on Research and Technology Department. She is now doing her final project with the title Analysis of the Effectiveness of Port Infrastructure Development to Improve Port Utility: Case Study Sri Bintan Pura Port, Riau Indonesia. She is also a member of the Indonesia Infrastructure Finance research team in the waste treatment sector. She has won the rector trophy at the National scholarly competition in Universitas Negeri Surabaya, Indonesia and was ranked fourth in the International competition organized by Sembcorp Marine, Singapore.

Muhammad S. Habibie, often called Habibie, is the third year Naval Architecture students, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember (ITS). He came from a modest family, but he is not discouraged in taking education. He is determined to take higher education than his parents someday, and hopefully he can become engineers in ship design so he can contribute to Indonesia maritime. He argued that Indonesia maritime must be improved, therefore it takes people who are experts in their field. Beside college activity, he also did some activity outside the college. He was once a delegation of Indonesia Marine Summit 2017 for ITS and had followed the RC Boat race in Deconbotion Marifest event. Although he had been defeated, he remains optimistic to become a champion in the following event next year. He is also one of the activists in the field of humanity, one of humanitarian activities that he was in was "Pelajar Mengajar Surabaya". Every Saturday, he went to Kenjeran Coast to teach the children there. Beside of being an activist in the field of humanity, he also active in the Himatekpal (Student Union of Naval Architecture) as Chairman of the Human Resources and Development Division.

Rasyid Fajar is an undergraduate student of Institut Teknologi Sepuluh Nopember Surabaya. He is currently on his second year studying in Informatics Engineering. Fajar is also the member of Barunastra Roboboat ITS Team on the Electrical and Programming Division as computer vision programmer and algorithm designer. On his second year of college he joined a national programming competition held by Department of Informatics Engineering Institut Teknologi Sepuluh Nopember as one of the committees on the material and content division. He has won a national roboboat competition held by University of Diponegoro, Semarang on the first place and second place. He is currently making the programs for autonomous ship and autonomous drone for his participation in the International Roboboat Competition held by AUVSI Foundation in Daytona Beach, Florida together with Wikandhana Rajasa.