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Vision-based Alignment Control for Mini Forklift System in Confine Area Operation

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***Abstract*— This paper presents the proposed vision-based alignment control system for a Mini Heavy Loaded Forklift Autonomous Guided Vehicle (MHeLFAGV). The MHelFAGV developed for heavy spool pick-and-place operation and this operation divided into two processes; spool inspection and switching control input for MHeLFAGV alignment. In the spool inspection process, a vision camera is used and programmed to do the marking process on the spool centroid using the Haarcascade method. The images are captured in real-time using vision camera and automatically analyzing for marking the targeted spool in 1000ms. The vision data is continuously sending the coordination between the camera and the targeted spool. In order to bring those data from vision camera for vehicle action, a proposed alignment control system module is developed. This proposed vision-based control is designed to translate the information from the camera to the mecanum wheel driven sequences for autonomous motion appearing a copper spool and to ensure the forlift center of gravity aligned with copper spool. The indoor experiment was done on the MHeLFAGV system on detecting the targeted copper spool in front. The test validated the proposed vision-based control when vehicle able to appearing the target spool as input from the vision camera.**

Keywords—Vision-based control, real-time Haarcascade, omnidirectional vehicle, confined area

I. Introduction

Autonomous and semi-autonomous mobile robot has been a broad topic and extensively explored in robotics engineering field in realizing self-handled or robotized the certain vehicles or machines. Automated Guided Vehicle (AGV) or Automatic Guide Vehicle is one of the examples of mobile robot available in the market for industrial and manufacturing applications. AGV has interesting navigation features with the independently controllable system by using wire, marker, vision, laser or magnet line as a guide for navigation. Most of the AGV in the market were developed for heavy-duty tasks (more than 100kg of payload) and required a sufficient space (big size) whereby the area is commonly well prepared for AGVs deployment. It is different for the cases that AGVs setup on a new landscape that is not ready for a driven machine such as for confine and narrow warehouse area. Moreover some of the confined area in warehouses keeping heavy products and inventories which is very difficult to remotely handle.

There are several issues have been tackled to increase the efficiency of AGV including its autonomy such as steering [1-4] and flow control [5 -7], pick-and-place tasks, localization/mapping [8, 9] and energy efficiency [10]. These issues are according to the application that needs some improvement in inventory handling and management. For the case of confined area and massive inventory handling, the mechanism on the pick-and-place process is very crucial since small size and stable AGV mechanism are required. Several control approaches have done in the pick-and-place process by using intelligent control, adaptive control, vision/image processing, as well as event hybrid approach between control and vision/image processing techniques as reported in [11, 12]. Moreover, a pick-and-place operation that mostly used grasper or forklift unit also another part of the issue for such a system like AGV due to the application need.

A vehicle with a forklift unit mainly consists of two main parts which are a fork-loader unit system (also known as gripper and elevator) and a drive system. A fork-loader built with minimum two pointing outward acting as fingers to elevate and hold any targeted load. Generally, two axes of motion are used for a fork-loader for a pick-and-place task. Most of the current fork-lifter and heavy machine technology especially that required time consuming (fast and efficient) in mass production, had evolved to be more automated such as Remotely Controlled Vehicle (RCV) and Automated Controlled Vehicle (AGV). This technology major controlled by particular electronics system that able to minimize labor cost, time-consuming and increase the efficiencies in a long hour workflows.

Another issue raised in AGV for the confined area is to get proper alignment and adjustment in picking and placing operations. The proper alignment needs a better field of view (FOV) to ensure the grasper unit such as fork-lifter in MHeLFAGV adequately aligned with the target area in the object that needs to be picked. Harada *et al.* and S. Mehta *et al.* described Field of View (FOV) of a camera affects the

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positioning accuracy[13, 14]D. For better positioning accuracy, having large FOV would require larger targets but some objects require would be less[13, 14]. In order to recognize an object, a vision-based system using camera has been used broadly in mobile robot such as AGV system because of its reliability compared to other sensors[15]. Due to object properties, such as shape, material, color, etc., image processing techniques are applied to develop an efficient algorithm for object detection. However, the vision system has some flaws which can occur noise of an image, such as the existence of dust, lighting, occlusions, and distortions[16].

Therefore in many application that related to the vision-based control are involving servoing technique to provide robust maneuverability especially in tackling problem due to the nonholonomic constraints such as reported in [17, 18]. As for example, Wang *et al.* had improved the motion tracking of X-Y robots with proposed piecewise continuous controllers with observers. The robustness of output trajectory was achieved by the proposed controller with the sampled of delayed data from low-cost charge couple device (CCD) camera and encoders for joint rotational as a feedback inputs[19]. It is different from the approach from [20] where intelligent control and optimization were applied in visual input information to the controller. Yüksel had used extreme machine learning to approximating pseudoinverse of the interaction matrix without hidden layers, and Image-based Visual Servoing (IBVS) was modified as velocity controller with fast convergence gain input by fuzzy logic[20].

Therefore, this research and development have taken the initiative to involve on providing vision-based alignment control on omnidirectional AGV system named Mini Heavy Loaded Forklift Autonomous Guided Vehicle (MHeLFAGV) (patent applied)[21] in part of the picking and placing process of the heavy copper spool in confine warehouse. This omnidirectional AGV system able to move in four degrees of freedom (DoF) in which longitudinal (forward/backward), lateral (right/left), zigzagging, diagonal as well as spinning. This paper is organized starting from the overview on the MHeLFAGV systems, Vision-based alignment control with haar cascade method and workspace switching for MHeLFAGV cartesian of motion, field tests and experimental, and conclusion.

II. Overview of MHeLFAGV System

The idea of developing a customize AGV system named MHeLFAGV was come out from the constraint of handling several heavy copper spool in a confine warehouse at Vacuumshmelze (M) Sdn. Bhd. Moreover, the unavailability of a commercial AGV system for this application also became the motivation for the development of this AGV system. In detail, this AGV system was developed to encounter a problem to operate in a very confined warehouse with track size 170cm x 286cm and handling a payload ranging from 20 - 200kg. In order to withstand at about 200kg maximum, MHeLFAGV's chassis is made of a 3 millimeter thick hollow rectangular metal (986×700) millimeter at the bottom, supported by parallel and perfectly welded profiles at the top as shown in Fig.1.

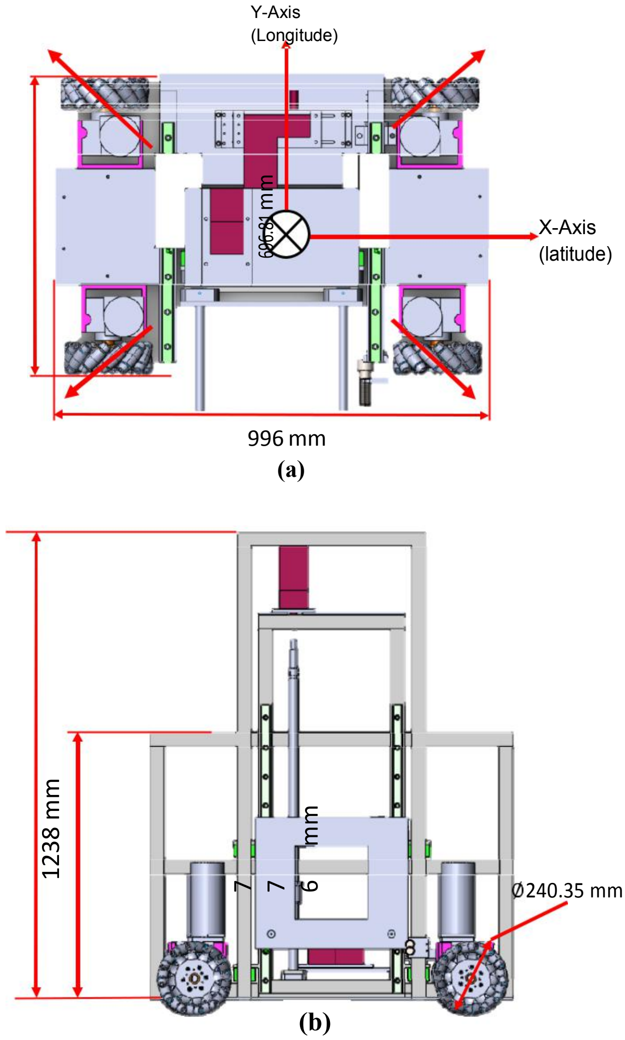

Fig. 1. MHeLFAGV Overall Dimension; (a) Top view, (b) Side View

On the other hand, an industrial scale mecanum wheel was configured as a driven element for MHeLFAGV to provide an omnidirectional mechanism and to solve nonholonomic constraint in a confined area[22]. In order to ensure the mecanum wheel always touching with the floor and adapting uneven terrain, a suspension is designed for MHeLFAGV. This design is crucial to ensure the necessary omnidirectional motions. As shown in Fig. 2 an absorber unit was installed and configured which flange is used at the bottom of the mounting to wheel holder and rod for mounting with the chassis. For the case of grasper unit fork-loader is designed with (225×400×1000) millimeter size, held by 4 L-squared aluminum plate welded to the side for suspending the platform to an adequate position. This platform material also made from hollow rectangular metal same as used for chassis design. Also, this platform will be the crucial part in moving the fork-loader in and out to pick the spool. Thus, the welded parts need to be very precise in a 90 -degree angle to maintain a good movement. An overview of the MHeLFAGV system mechanical structure is shown as Fig.3.

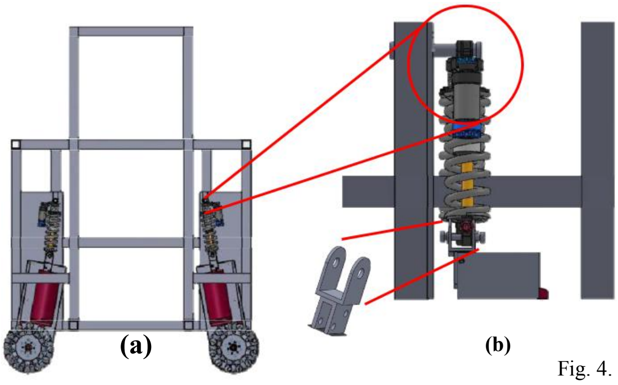

Fig. 2. Absorber and Suspension system design for MHeLFAGV chassis design: (a) MHeLFAGV frame view, (b) zooming view on absorber mounting.

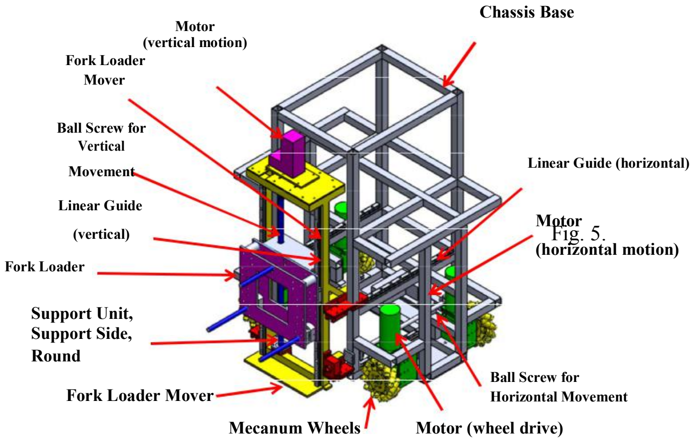

Fig. 3. MHeLFAGV system structure overview

III. Vision-based Alignment Control

For the case of MHeLFAGV, the target is to allocate the AGV system properly in front of the targeted copper spool before the picking process as shown in Fig. 4. In this process, a fork-lifter unit of MHeLFAGV is aligned at the center of the targeted spool so that the fork can be appropriately slotted on each triangle side of the spool as shown in Fig. 5. The fork-lifter design[21] had considered all industrial copper spool shape and diameters.

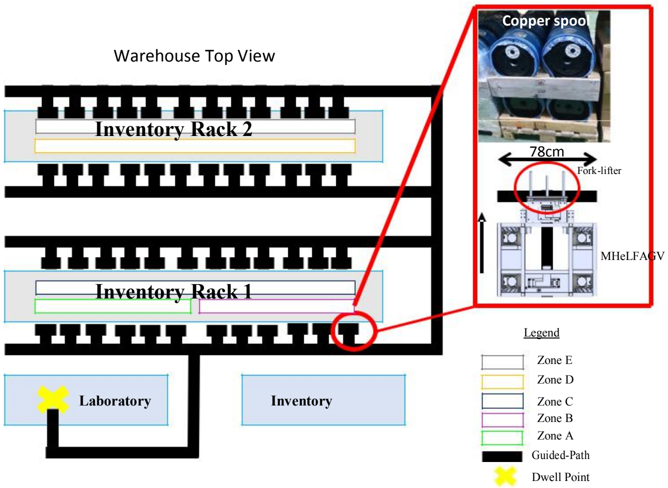

Fig. 4. Example of the situation of alignment required by MHeLFAGV in picking heavy spool operation

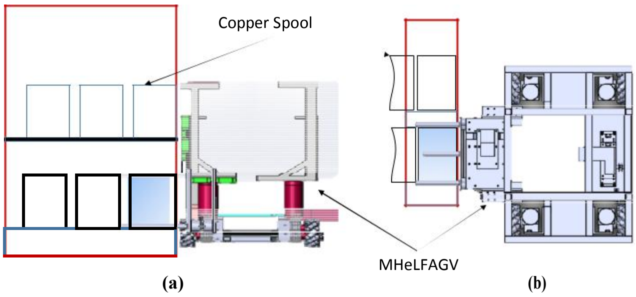

Fig. 5. Example of picking process situation by MHeLFAGV after fork-lifter alignment

A. Real-time Haarcascade in Spool Detection

Haarcascade is fundamentally a classifier which is utilized to distinguish the protest in which being prepared from the source (image). The Haarcascade is by superimposing the positive picture over an arrangement of negative pictures. The preparation is by and large done on a server and different stages. Better outcomes are acquired by utilizing the best pictures and expanding the measure of stages for which the classifier was prepared. Haarcascade or Haar -like[23] method is a key favorable position object over most different highlights is its figuring speed. For this application, the real-time camera with individual processing unit is used to embed the Haarcascade algorithm process as shown in Fig.6. Haarcascade trained classifier by utilizing recent captured images and classifier from this learning procedure, and it has utilized for the recognition process. Moreover, image finds features scanning the spool picture for all zones for matching process in the Haarcascade algorithm and returns a rundown of bouncing box rectangles tuples (x, y, w, h) around those highlighted spool areas.

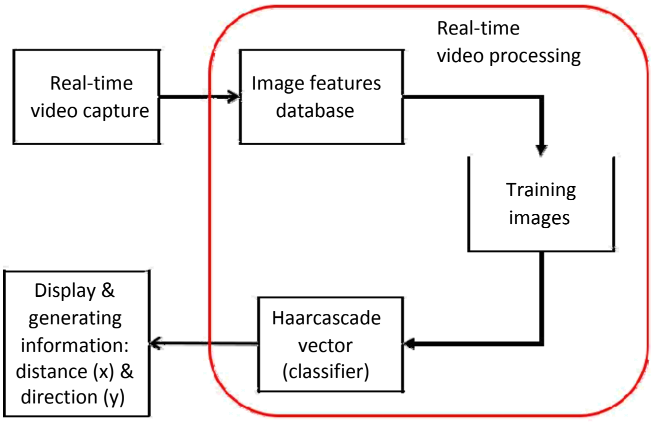

Fig. 6. The process flow of real-time Spool inspection with the Haarcascade method.

The algorithm will restore an unfilled rundown if no highlights are found. Here x data is used as face-to-face distance MHeLFAGV to spool and y data is used for side-to-side distance MHeLFAGV to spool as shown in Fig.7.

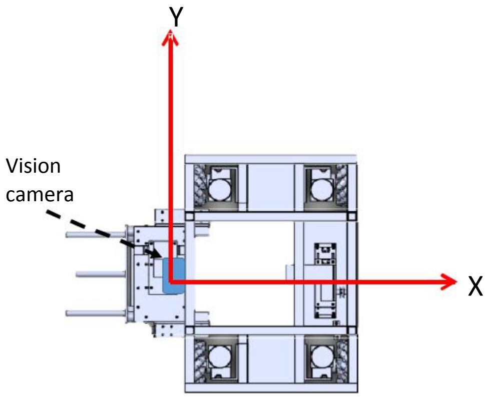

Fig. 7. Vision camera coordination and reference frame at the MHeLFAGV unit

B. Vehicle Alignment Control with Vision Input Range

In the overall MHeLFAGV control system, proposed alignment control is classified as a secondary module that can be switched using the remote control as shown in Fig. 8. This simple switch module was programmed to route the signal input either solely from the remote control or the vision camera. For the alignment control mode, the x and y data will be transferred online through serial communication to the mainboard of the controller unit of MHeLFAGV, and the process is shown as Fig.8. The mecanum wheel drive switching module is developed concerning the real-time data from the camera. The switching sequence of mecanum wheels according to the camera vision input is tabulated as Table 1.

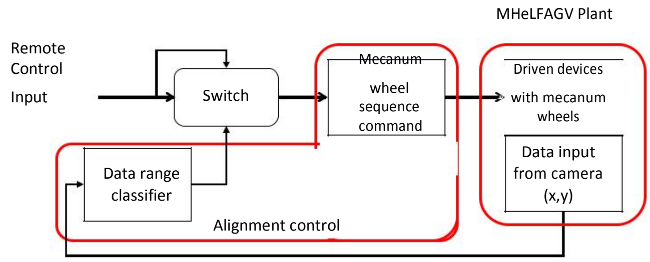

Fig. 8. Functional blocks of Alignment control for the MHeLFAGV system

With experimental and calibration, the minimum value of the x-axis camera (X_{min}) was set to 200mm, and the maximum value (X_{max}) was set to 400mm from the camera to the targeted spool. On the other hand, the center position of the y-axis (Y_c) camera was set to 87. However, for real-time implementation the center range was determined,86.5 < Y_c < 87.42 . The detection flow can be illustrated as Fig.9.

TABLE I. ALIGNMENT CONTROL ALGORITHM

X-axis switching condition		Y-axis switching condition		Wheel 1	Wheel 2	Wheel 3	Wheel 4	Vehicle Motion
$in < X_{min}$	$in > X_{max}$	$Y_{cmin} < Y_c < Y_{cmax}$		STP	STP	STP	STP	STOP
		$in < Y_{cmin}$	$in > Y_{cmax}$					
$X_{min} < in < X_{max}$		$in < Y_{cmin}$		CC	CC	CC	CC	FOWARD
		$in > Y_{cmax}$		CCW	CCW	CCW	CCW	BACKWARD
		$Y_{cmin} < Y_c < Y_{cmax}$		CW	CCW	CCW	CW	LEFT SHIFT
		$Y_{cmin} < Y_c < Y_{cmax}$		CCW	CW	CW	CCW	RIGHT SHIFT

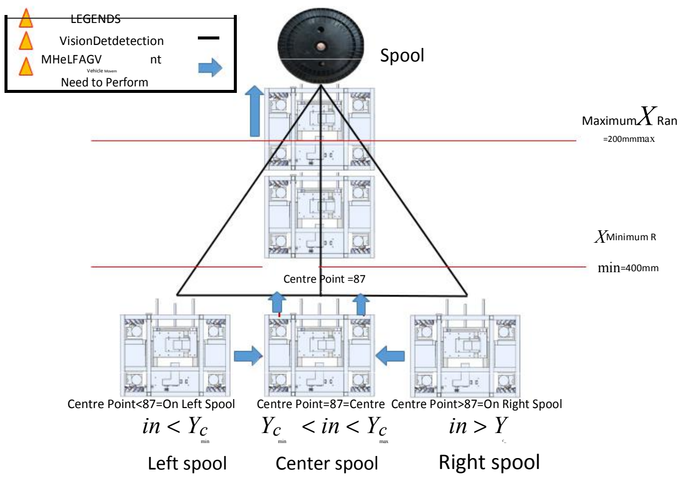

Fig. 9. The flow of spool detection

Fig. 11. Implementation of proposed vision-based control on MHeLFAGV system

IV. Experimental and Results

The proposed vision-based control was implemented in embedded system with real-time MATLAB® SIMULINK-to-Arduino. The performance of navigation system has been evaluated indoor only since the systems scope only covered for indoor cases.

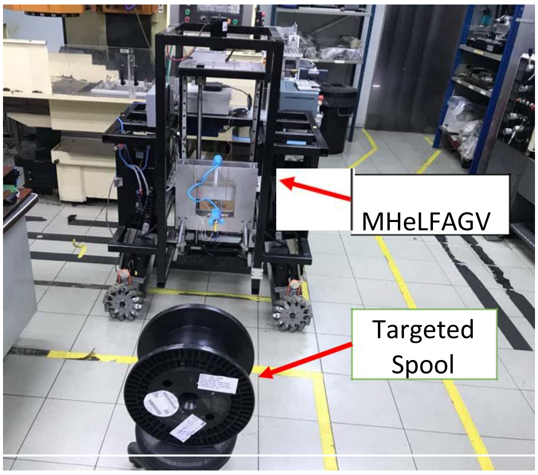

Fig. 10. Experimental setup

The experiment was setup as shown in Fig. 10 where the camera is hold at the center of MHeLFAGV unit and put a bit far from the spool. However the distance is not out of camera region since this alignment control system will be used and activated only when MHeLFAGV almost near tothe targeted spool. Therefore this experiment was intense to coordinate as maximum as possible the distance between MHeLFAGV and the targeted spool in order to validate the proposed alignment control method. As shown in Fig.11, the MHeLFAGV was enable with autonomous mode in which vision-based control was activated. The first and second snapshots in Fig.11 shows the proposed vision-based control with Haarcascade and alignment control having a searching moments before nearing the spool in the third snap. Moreover Fig. 11 shows there have some overdriven scenario that makes MHeLFAGV having two sides of movement before appearing spool. In image processing point of view, Haarcascade method able to process to detect center of spool although there having some disturbance occurred in the second inspection process as depicted in second figure in Fig.12.

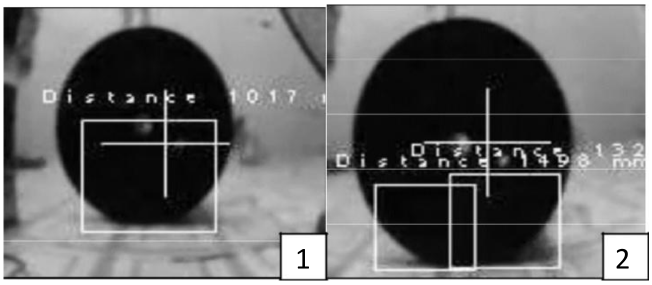

Fig. 12. Sample of image recognition by vision camera using Haarcascade method

V. Conclusion

The implementation of alignment control on MHeLFAGV system has been presented. The real-time Haarcascade method has been validated as image processing method on detecting the center of targeted spool. This method shows fast enough as feedback input to the alignment control in vehicle mainboard controller. On the other hand, the data from the camera vision capable of localizing the vehicle from the coordination of the camera. This can become the future progress for this project in improving the precision of vehicle motion with sensor-vision fusion technique.

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