Advanced Container Transportation Equipment using Transfer Robot and Alignment System

Young Jin Lee*, Dong Seop Han**, Dae Woo Kang***, Duk Kyun Lee****, Geun Ghoi****, and Kwon Soon Lee†

Korea Aviation Polytechnic College*, Dong A University**, Bumchang Eng. Co., Ltd. ****, Dong A University†

airlee011@kopo.ac.kr*, imdshan@gmail.com**, dwkang@dau.ac.kr***, dklee@bumchang.co.kr****, kslee@dau.ac.kr†

Abstract. **In this paper, we proposed a horizontal-transfer robot system was designed using a hydraulic system and some electronic sensors, and a synchronized control method was applied to control each robot. An alignment system was also designed to align between the rail and a truck. The proposed system will be useful as an intermodal transportation system that is significantly considered an enhanced technique or future railroad logistics. The system can simplify the complicated job process in railroad-based transportation and, from an economic viewpoint, can reduce relevant logistic costs.**

I. Introduction

The traditional railroad-based transport has difficulty directly moving freight in door-to-door service compared to the road method in the highway. This is the main reason for the hesitation in using the railroad for such purposes. Moreover, most locomotives were recently changed into electric-driven systems with catenaries for the electrification of the railroad, instead of gasoline engines. Unfortunately, as these catenary systems built over trains interfere with crane works, new parallel loading and unloading systems should be developed to enhance the classical vertical systems [1, 2].

In addition, the job process of the railroad-based transport system is largely complicated because auxiliary works such as operation of shuttle cars and stacker cranes are unavoidable, particularly at the starting and destination points, to connect with the roadway. Such additional processes increase the unnecessary logistic cost and time loss. As such processes also demand a wider storage space, more equipment, and more operators, the continued use of the traditional methods may bring about significant problems. In recent years, in many advanced countries, new transport systems have been developed, including intermodal transfer systems such as Piggy-back, CargoBeamer, Cargo Domino, Flexiwaggon, and Modalohr [3-11]. As there have been few discussions about Piggyback or Roadrailer in South Korea, however, a structural-design study of a horizontally moving system, such as the parallel-type intermodal transportation system, has been developed by Dong-A University [11, 12]. This system can transfer a container box horizontally between a trailer and a freight wagon. Moreover, when the robot systems travel, an alignment system of the two cars is necessary for safe loading. In this paper, a horizontally moving equipment is suggested as a container transport robot. This system is controlled via synchronization and has an alignment system to align the railroad and trailer using electronic sensors (e.g., ultrasonic sensor, etc.).

II. Dual-mode Trailer System

A. Intermodal Transportation System

Because the problems of train only logistics complicated cargo handling and catenary, door-to-door service is impossible. In case of truck only logistics, the road traffic jam is severe because of increasing cars.

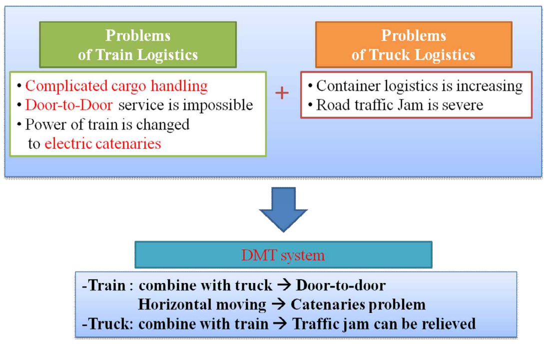


Figure 1. The problem of single mode transport system.

The intermodal transportation system (ITS) involves the transport of freight in an intermodal container or vehicle, using multiple modes of transportation (rail, ships, and trucks), without any handling of the freight itself when changing modes. This method can reduce the cargo handling time, damages, and losses, can improve the security, and allows freight to be transported faster. In relation to railroad transportation, in many countries, diverse studies on ITS have been conducted of late. Typically, this system can be classified into four types, as shown in Fig. 2: the parallel, cargo turning, piggyback, and Bogie changing types. The cargo-turning-type methodology involves transferring the container box by turning the wagon of the train. Modalohr is one of the best examples and is used in France. Even though this system has many advantages, it cannot be applied in South Korea because the height constraint does not allow it [11]. The parallel type is divided into CargoBeamer and Cargo Domino [13-17]. In the analysis based on reference [11], the horizontal loading and unloading system (e.g., Cargo Domino) showed better performance than the others.

(a) Parallel-rotating type

(b) Cargo-turning type

(c) Piggyback type

(d) Roadrailer type

Figure 2. Intermodal transportation systems.

III. Design of the DMT System

As it is expected that the proposed horizontal-type system can avoid the use of catenaries and can provide higher advantages from a logistic-cost viewpoint, this research was focused on the parallel-type ITS, and proposed an improved transport system. The DMT system consists mainly of two parts: a horizontal-transfer robot (HTR) and an alignment system (AS). The key of the DMT system is the horizontal-transfer robot installed on the wagon or trailer. The working procedure of the proposed ITS is shown in Fig. 3.

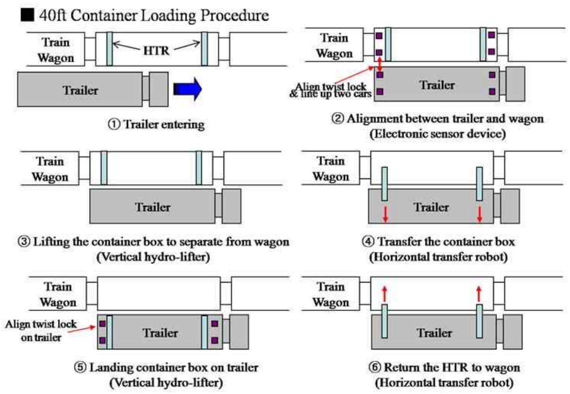


Figure 3. Operation procedure of the proposed ITS.

A container box is moved horizontally by the HTR from the wagon to the trailer or from the trailer to the wagon, without any overhead crane or reach stacker. In processes ① and ② in Fig. 3, the trailer should be aligned with the train wagon within the permitted clearance when a trailer is entering. Even if two cars are aligned within the permitted clearance (e.g., 320 or 350 mm), however, if the HTR loads a container from the wagon to the trailer or from the trailer to the wagon, the HTR will fall to the ground. This notwithstanding, the alignment within the clearance value and tolerance is very important because the HTR will autonomously trip on cars with a 40-ton container. This chapter mainly deals with HTR and AS.

A. HTR

HTR consists of a lifting part that separates a container from a cone on the trailer or wagon, and a horizontal-driving part for the loading and unloading of a container between a wagon and a trailer. This system is designed to deal with 20- and 40-ft containers. Therefore, the self-weight of the container is 40 ton, which is the maximum loading weight of the cargo in a wagon. This constraint would be adopted as the load condition for the design of the HTR. As a couple of HTRs are used for the loading and unloading of a container, one robot takes charge of the 20 ton weight. Accordingly, considering the dynamic-effect factor of 1.2, the container weight to be applied on each system should be 24 ton.

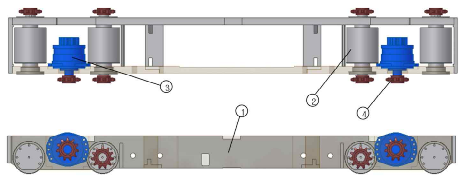
As the HTR suggested in this investigation lifts the under surface of the container and transfers it to a trailer or wagon, the height of the system should be below 300 mm due to the limitations in ROK. As a 300-mm space exists between a wagon and a trailer, this factor should be considered when designing the horizontal-driving part. The speed of the HTR and the lifting speed should be over 0.1 and 0.01 m/sec, respectively, because the total operating time for the loading or unloading of a container has to be less than 3 min to minimize the logistic costs and to reduce the time loss. These design conditions are shown in Table I.

Table I. Design conditions of the HTR

Parts	Design Conditions
Horizontal-driving part	▪ Capacity: 24 ton ▪ Moving distance: 2,800 mm ▪ Maximum speed: 0.1 m/sec
Lifting part	▪ Capacity: 24 ton ▪ Moving distance: 100 mm ▪ Maximum speed: 0.01 m/sec

1. Horizontal driving part

The horizontal-driving part consists of an underframe and four wheels because this system moves a 300-mm space between a wagon and a trailer, and is driven by two hydraulic motors due to its heavy weight and the constrained space in the HTR.



1 : Frame 2 : Driving wheels
3 : Hydraulic motors 4 : Chain & Sprocket

Figure 4. Horizontal-driving part of the HTR system.

The power of the motor is transferred by the chain and sprocket to the wheels due to the large distance between the motor and the wheel shaft. When the rolling friction coefficient is 0.05, the required thrust force of the system for horizontal driving is a minimum of 2 ton. Hence, the wheel diameter was made 180 mm considering the outer diameter of the sprocket. Therefore, when the maximum driving speed is 0.1 m/s, the number of revolutions of the wheel is 10.6 rpm. The normal force (N_w) applied to each wheel is as follows:

$$N_w = \frac{\left(\frac{W_c}{2} + W_{TS}\right)}{4}. \quad (1)$$

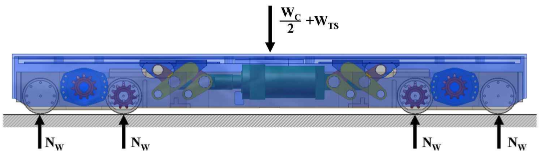


Figure 5. Forces applied to the HTR.

The horizontal thrust force (F_T) generated from the torque of the wheel (T_w) should be larger than the rolling friction force ($F_{f,R}$). Thus, the torque that is needed to drive the wheel is as follows:

$$T_M \geq r_w(\mu_R N_w) = r_w\left[\frac{\mu_R}{4}\left(\frac{W_c}{2} + W_{TS}\right)\right], \quad (2)$$

where r_w is the radius of the wheel, μ_R is the rolling friction coefficient, W_C is the self-weight of the container, and W_{TS} is the self-weight of the HTR. As one hydraulic motor rolls two wheels, the minimum required torque of the motor (T_M) should be two times the torque so that the wheel could be driven. Using equation (2), the minimum torque of the motor can be calculated as follows:

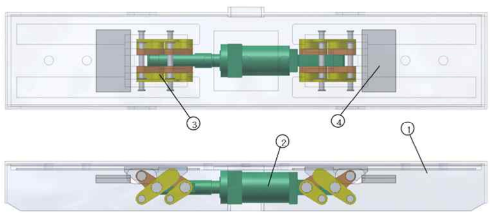
$$T_M = r_w\left[\frac{\mu_R}{4}\left(\frac{W_c}{2} + W_{TS}\right)\right] \quad , \quad (3)$$

$$= 2 \times 0.09\left[\frac{0.05}{4}\left(\frac{40 \times 10^3}{2} + 1 \times 10^3\right)\right] = 47.25 kg \cdot m$$

where r_w = 90 mm, μ_R = 0.05, W_C = 40 ton, and W_{TS} = 1 ton.

2. *Lifting part*

To stably separate the container from the cone, the bucket has to be kept at a level where the bucket can lift a 40-ton container.



1 : Bucket 2 : Hydraulic cylinders

3 : Linkage 4 : Stopper

Figure 6. Lifting part of the HTR.

Accordingly, the "y>" combination-type linkage was adopted to keep the balance, and this linkage is driven by a hydraulic cylinder. The force (F_C) of the hydraulic cylinder that is needed for it to lift the container is as follows:

$$F_C \geq \frac{4V}{\tan\theta}. \quad (4)$$

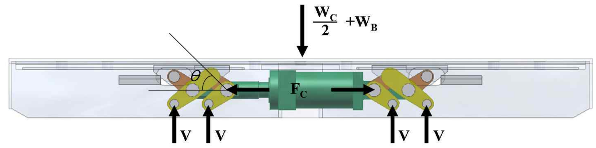


Figure 7. Forces applied to the hydraulic cylinder.

When the angle of linkage on the horizontal axis is 45°, the maximum force is applied to the cylinder. Using equation (4), the force (F_C) can be calculated as follows:

$$F_C \geq \frac{4V}{\tan\theta} = \frac{4\left(\frac{W_C}{2} + W_B\right)}{4 \times \tan 45^\circ} = \frac{4\left(\frac{40}{2} + 0.5\right)}{4 \times \tan 45^\circ} = 20.5 ton, \quad (5)$$

where W_C = 40 ton and W_B = 0.5 ton. At this time, when the driving pressure is 280 bar, the required minimum force of the cylinder to lift the container is 20.5 ton.

3. *Control algorithm of HTR*

Fig. 8 shows the algorithm of the unloading procedure to convey the container from the wagon to the trailer. Information data about the alignment of the twist lock (cone) on the trailer and wagon should be sent to the HTR controller before moving the HTRs between the wagon and the trailer.

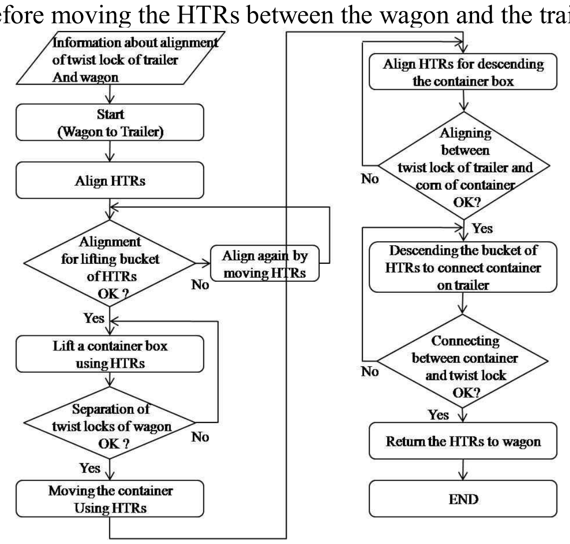


Figure 8. Control algorithm of HTR (unloading procedure).

4. *HTR design*

The main components of the HTR are a lifting hydraulic cylinder, a bucket, and two horizontal-driving hydraulic motors. The lifting cylinder can lift a 40-ton container box at 0.01 m/s to remove the twist lock. The bucket was designed to support the under frame of the container while the HTRs are moving. The horizontally driving motors carry a container box horizontally with the proportional hydraulic-valve controller. Fig. 9 shows the assembled HTR.

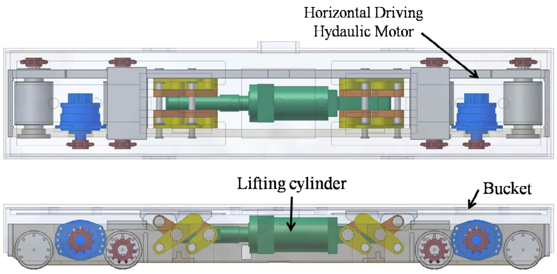


Figure 9. Assembled HTR.

Four HTRs are installed on the wagon or train and convey a container between the wagon and trailer, as shown in Fig. 10.

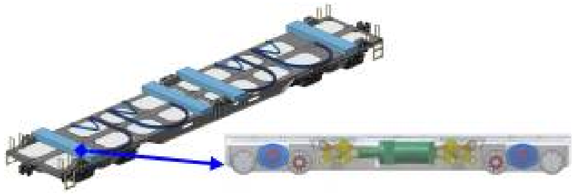


Figure 10. Installation position of the HTR.

As two HTRs are used when a container is carried, encoder sensors are used to synchronize the speed of the two robots, and to measure the distance of the trajectory for docking the container on the cone of the trailer or wagon after the arrival in the destination. Photoelectric sensors are used for driving control, such as acceleration and deceleration.

B. Design of the Alignment System

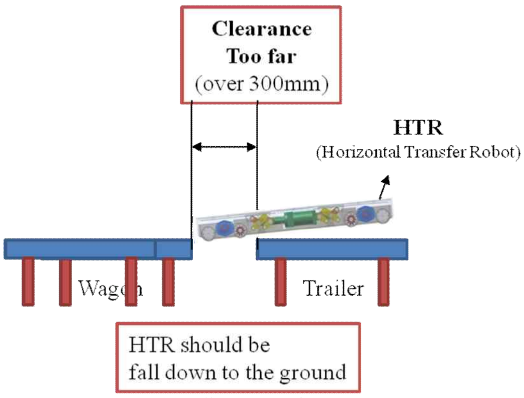
As mentioned in the previous chapter, when loading a container using HTR, as shown in Fig. 3, the wagon and trailer should be aligned under a permitted condition, as shown in Fig. 12. The following are the clearance and tolerance conditions required for the alignment of the DMT system:

(a) Alignment of two cars: repositioning the wagon and the trailer using two ultrasonic sensors and CCD cameras

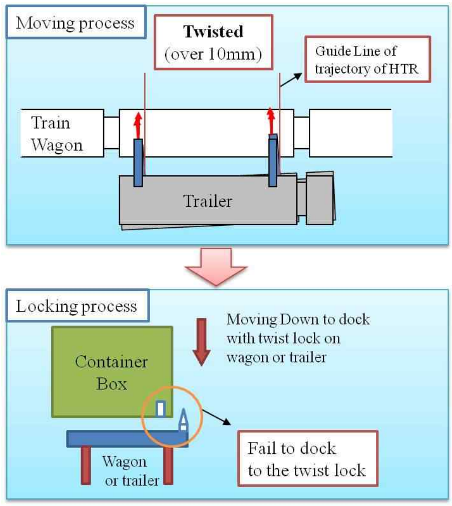
- Clearance: 300±10 mm

(b) Alignment of the twist lock: aligning the wagon and trailer using 16 photosensors

- Tolerance: under 20 mm



(a) Alignment of two cars



(b) Alignment of the twist lock

Figure 12. Alignment of two cars.

The alignment system that was designed measures the distance and distortion ratio between the trailer and the wagon using an electronic sensor device (e.g., ultrasonic sensor, photosensor). This gives the necessary information to the driver of the trailer to help him stop his car under the permitted conditions.

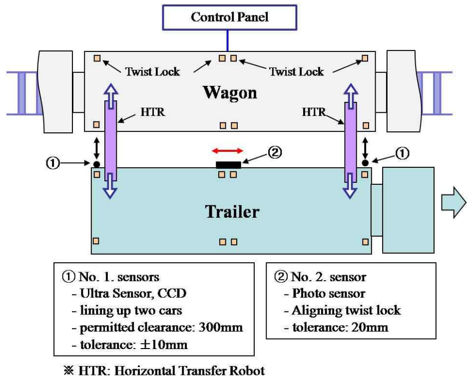


Figure 13. System layout of the positioning system between a trailer and a wagon.

As shown in Fig. 14, two ultrasonic sensors and two CCD cameras were applied to each trailer to measure the distance between the wagon and the trailer, and the driver can see the measured value at the LCD monitor in the driving room.

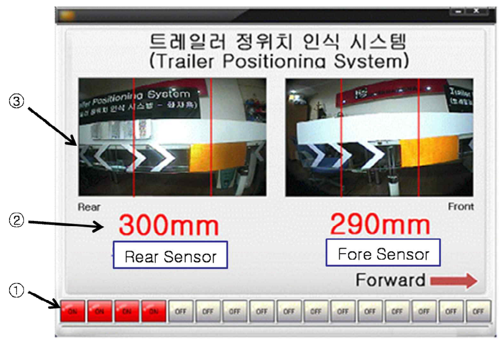


Figure 14. Display of the alignment process.

In Fig. 14, ① shows the photo sensor's output, ② the distance between the wagon and the trailer as detected by an ultrasonic sensor, and ③ the CCD images. From the above information, the driver of the trailer gets the alignment information and can stop the vehicle beside the wagon, with a tolerable distance. The deviation between the rear and fore sensor should be under 20 mm. All the lamps of ① in Fig. 16 are indicated by the red color, and the twist locks on the wagon and trailer are aligned. Fig. 15 shows the final alignment status of the real trailer and wagon. The twist locks on the wagon and trailer are aligned, and the clearance between the trailer and the wagon is set at the permitted value.

(a) Aligned twist lock (b) Two aligned cars

Figure 15. The two alignments between the trailer and the wagon.

Fig. 16 shows the algorithm of the alignment of the DMT system.

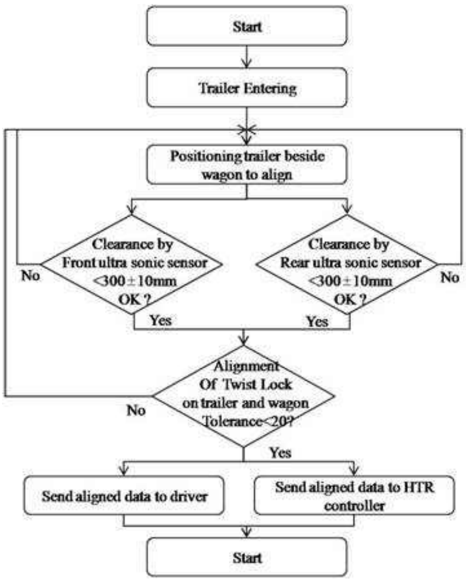


Figure 16. Alignment algorithm of the DMT system.

IV. EXPERIMENT RESULTS

A. Pilot System

To evaluate the performance of the alignment system, a real-scale pilot trailer and a real-scale wagon were manufactured. The developed alignment equipment was installed in the pilot trailer, as shown in Fig. 17.

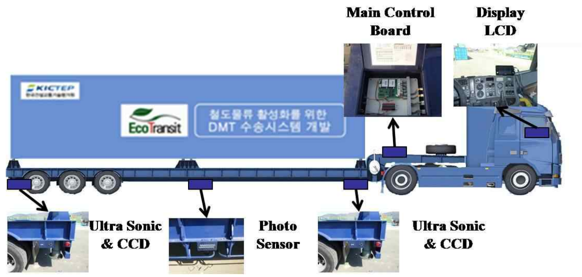


Figure 17. Installation position of the alignment system.

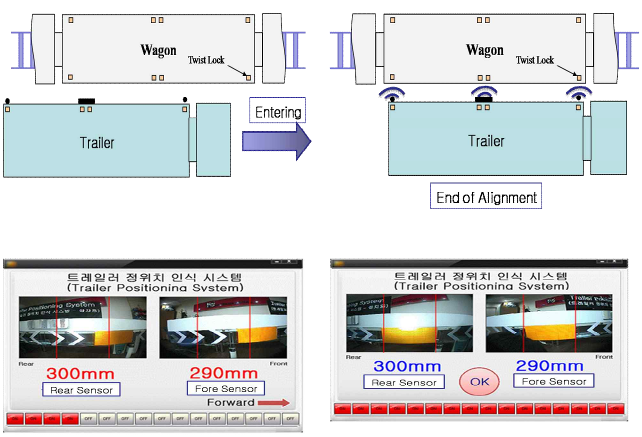
B. Test of the Alignment System

Table II shows the specifications of the alignment system. Three atmega128 microprocessors were used for the main controller and other interface boards. The RS485 protocol was mainly used for the communication system.

Table II. Specifications of the position control system

Sensor	Specifications	Function
Ultrasonic	•Vendor: Sensortec/ROK, STMA-701ND •Operating range: 30-6,000 mm •Frequency: 40 khz •Used no.: 2/trailer	Alignment of two cars
CCD camera	•Sensor: 1/3 CCD •Pixel: 768*494 •IP grade: 68 •Used no.: 2/trailer	Alignment of two cars
Photosensor	•Vendor: D51-AP series, Italy •Detection method: polarized light reflect •IP grade: 67	Twist lock alignment
Display panel	•CPU: AMD Geode LX800 •LCD: 7" TFT (800*480) •Communication: RS232, RS485	For the driver
Controller	•Main controller: CPU - Atmega128 •Ultrasensor board: CPU - Atmega128 •Communication board: - CPU: Atmega128 - Communication: RS485 & RF - RF chip: A3007B, 424~447 Mhz	System control

Fig. 18 shows the alignment process: (a) status of trailer entry; and (b) achieved alignment status.

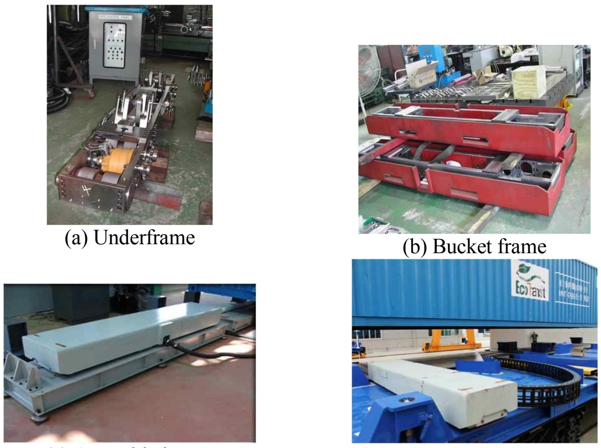


(a) Trailer entering (b) Achieved alignment status

Figure 18. Alignment process.

C. Test of HTR

Two HTRs were manufactured by real scale to evaluate their performance in carrying a 40-ton container box.



(a) Underframe (b) Bucket frame (c) Assembled HTR (d) Installed HTR

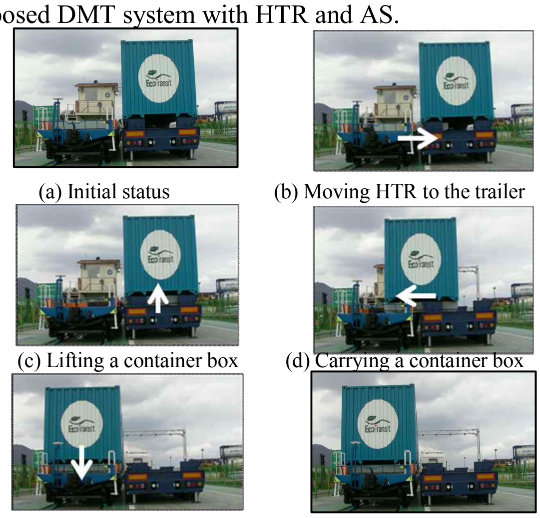
Figure 19. HTRs.

The specifications of the HTR are shown in Table III.

TABLE III. HTR SPECIFICATIONS

Parts	Specifications	Function
HTR	▪Vertical-lifting part - Hydromotor: 58 kg·m - Minimum torque: 47.25 kg·m - Lifting speed: 0.01 m/s - Lifting stroke: 120 mm - Solenoid valve: proportional valve ▪Horizontal-transfer part - Hydromotor: 58 kg·m - Force: 20.5 ton - Speed: 0.1 m/s - Diameter of wheel: 180 mm - Position sensor: encoder (Sumtak IRS5) - Solenoid valve: proportional valve ▪Total weight: about 1.5 ton	Lifting and carrying a container
Controller	▪Main controller - CPU: Melsec-Q 7 series - Communication: RS485 and wireless RF - Data sampling: 20 msec	System control

Fig. 20 shows the experimental testing process of the proposed DMT system with HTR and AS.



(a) Initial status (b) Moving HTR to the trailer (c) Lifting a container box (d) Carrying a container box (e) Dropping a container box (f) Finish status

Figure 20. Experimental tests using HTR (unloading procedure).

Fig. 20(b) shows the HTRs being moved to under the container, (c) the lifting procedure by HTR, (d) the conveyance of the container, and (e) the docking process between the cone on the wagon and the container. With 30 containers, the switching time of DMT was only 45 min, as opposed to 78 min in the conventional system. This means that the proposed system provides a 42% switching time reduction.

V. CONCLUSIONS

In this paper, an innovative intermodal transportation system (ITS) named “dual-mode trailer (DMT)” was proposed, based on a horizontally moving robot. This system is a combined intermodal system linking the road and the railway transport system. It is believed that this system can enable the railway system to provide just-in-time service and can enable the on-the-road system to provide door-to-door delivery service. The proposed system is very useful under the high-voltage catenary system by virtue of its horizontal-transfer mechanism. It has been reported that the operation and maintenance costs of DMT will be lower by as much as 59% (KRW0.9 billion for one year) compared with the existing system. Finally, the most important contribution of the proposed system is its 90% CO_2 emission reduction compared with the cargo trucks on the road. It is believed that this system will be applied as an ITS in the near future due to its numerous merits.

ACKNOWLEDGEMENT

This work was supported by Korea Institute of Construction & Transportation Technology Evaluation and Planning.

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