Development of Assistive Mobile Robots Helping the Disabled Work in a Factory Environment

Jung Won Kang, Bong Sung Kim and Myung Jin Chung

Abstract—**This paper introduces assistive mobile robots that help the disabled to work in a factory environment. The target users and the functions of the robot were determined based on varied survey results. The robots were developed through an iterative process of designing, development and evaluation. As a result, three assistive mobile robots were developed. The first version of the robot focused on the various functions. The robot is equipped with a robot arm and a forklift to support various tasks for the disabled. The second version was focused on the mobility. A mecanum wheel-based omni-directional drive mechanism was used to improve the mobility in small spaces. A foldable forklift was adopted to reduce the size of the robot. The omni-directional drive mechanism was also utilized on the final third version. An improved robot body frame was proposed to reduce the vibration caused by the mecanum wheel rollers. A multiple pillar-based foldable forklift was adopted to improve user convenience while using the lift. The developed mobile robots are expected to provide assistance to disabled workers in a factory environment.**

I. INTRODUCTION

A lot of previous researches on the subject of assistive robots for the disabled have focused on assisting the disabled with their routine tasks. An intelligent bed-robot system [1] and a care robot system [2] were designed to help the disabled perform their daily activities in an indoor environment. As a human-robot interface device, an eye gaze estimation system [3] was developed for easy control of a robot system. The robotic system known as FRIEND [4] and KARES II [5] are wheelchair-based rehabilitation robotic systems equipped with a robot arm. They were designed to help the disabled manipulate small objects such as food, a cup and a book.

On the other hand, assistive robots can give the disabled vocational opportunities so that the disabled live productive lives through their own vocations. That is, development of the vocational robot systems that help the disabled in their vocations has significant meaning considering the true meaning of the welfare. The RAID system [6] assists in removing books from a bookshelf, carrying documents, and serving drinks in an office environment. The WALKY system [7] is able to avoid obstacles while it maneuvers to deliver objects in a laboratory environment. The ProVAR system [8] receives orders using a speech recognition system and helps with office tasks including serving drinks and delivering documents, diskettes, and video tapes. Although these vocational assistive robots have been developed, their use is limited to an office environment. However, the types of tasks that the disabled perform differ from country to country due to regional differences in industrial structures. As an example, in South Korea, most employers prefer the disabled to work in a manufacturing environment. However, there has been little research dealing with the development of vocational robotic systems that can help the disabled in a factory environment. Therefore, in this research, mobile robot systems that assist the disabled when they work in a factory environment were designed and developed. Furthermore, the robots were evaluated in an actual factory environment. In this paper, the robots termed as Type 1, 2, already presented in [9][10][11], are reviewed, and the new robot system, termed as Type 3 is introduced.

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II. OVERVIEW OF OUR PROJECT

Our project began in March 2002. The criteria of the project were 'assisting the disabled as much as possible,' 'considering the actual employment situation for the disabled' and 'assisting with the most common tasks of the disabled'. To derive a specific mission, the demographics of the disabled, their actual employment situations, and their required tasks were surveyed. Based on the survey results, the target types of disabled individuals along with the functions of the robot were determined. As a result, the goal was determined as the development of an assistive mobile robot system that helps a worker with a limb disability perform tasks such as the assembly and carrying of boxes.

In year 2003, as an initial version, the mobile robot termed Type 1 was developed [9][10][11]. The robot focused on a range of functions. The robot was evaluated in existing manufacturing companies. Based on the evaluation results, the Type 2 robot was developed in 2004 [9][10][11]. The Type 2 robot was focused on the mobility. The mecanum wheel-based omni-directional drive mechanism was utilized on this robot. A foldable forklift was adopted to reduce the size of the robot. The Type 2 robot was also evaluated in actual companies. Based on the feedback of the evaluation, the third version of the robot was developed from 2005 to 2007 [12][13][14]. This robot is equipped with improved mecanum wheels as well as an improved robot body frame and a forklift system. Through the above iterative process of development and evaluation, assistive mobile robots capable of helping the disabled in actual factory environments were developed.

III. Mission Derivation

A. Mission Derivation

A survey was conducted to determine the target user and to understand their actual employment situations and the most common tasks.

In order to determine the target user, several reports [15], [16], [17] by a government agency were investigated as they pertained to the disabled in South Korea. Among the total disabled, 55.1% (about 740,000 people) of the disabled have a crippled disorder, 8.7% suffer from cerebral paralysis, 10.5% have a visual disorder, 8.8% a hearing disorder, 0.8% a speech disorder. Among those who have a crippled disorder or who suffer from cerebral paralysis, the percentage of those with impaired use of their legs is high. Moreover, most of participating workers have crippled disorder regardless of the scale of the workshop, as shown in Table I. Based on these data, it was confirmed that workers who had crippled disorder were the majority. Therefore, those participants were determined as the target user in order to assist the disabled as much as possible.

In order to determine the type and functions of the robot, the actual employment situations and the most common tasks of the disabled were surveyed. To grasp the actual situation of employment of the disabled, vocational education facilities[1] and companies[2] that hire the disabled were visited. The survey results show that the disabled typically prefer computer-oriented jobs and mechanical jobs. However, the vocational fields in which employers utilize the skills of the disabled are mainly simple labor jobs [18]. According to these investigations, there are considerable gaps between the occupations that the disabled desire and those for which companies feels the disabled can fill. As a result, although many social organizations provide various vocational educations to the disabled, the disabled mainly perform simple labor in the actual employment situations. Therefore, considering the actual employment situation, it is desirable to develop a system to help the disabled to perform simple labor tasks such as the assembling and classifying of circuit parts, or the transport of objects.

TABLE I
DISTRIBUTION OF ACTUAL EMPLOYMENT FOR THE DISABLED[3]

Types of disorder	Large workshop	Small workshop
Limb impairment	82.0%	81.0%
Cerebral paralysis	0.2%	0.2%
Visual disorder	4.4%	3.1%
Hearing disorder	9.8%	6.2%
Speech disorder	1.2%	1.1%
Others	2.4%	8.4%

To know the most common tasks for the disabled at a work place, the literature [17] was cited. According to the report, the majority of handicapped workers have difficulty when they are carrying heavy materials. The report also showed that those with upper limb impediments want a robot system to serve as an arm while performing tasks that include fixing and loading. Those with leg impediments want a robot system to substitute for the function of the leg as much as it contributes in movement, loading, and other tasks. Therefore, it was found to be necessary to design a robot to transfer objects and perform dexterous tasks while moving around freely.

In summary, the goal of this work was determined as the development of assistive mobile robots that help the disabled worker with lower or upper limb disability or both lower and upper limb disability to perform tasks such as moving materials, assembling, and classifying circuit parts.

B. Target Environment Modeling

According to our survey result, most manufacturing factories consist of long tables equipped with a conveyor, a warehouse containing parts in boxes on pallets, safety lines around them, and aisles, as in Fig. 1 and Fig. 2. At the table space of each worker, boxes that contain parts are stacked on their left and right side. At each space, a worker performs dexterous tasks such as soldering and assembling at the worktable. When a worker does not have enough parts, he moves to the warehouse, and picks up boxes that contain the necessary parts. After returning to the worktable, he resumes working. More details of the target environment are described in [19].

Fig. 1. Overall view of the target environment

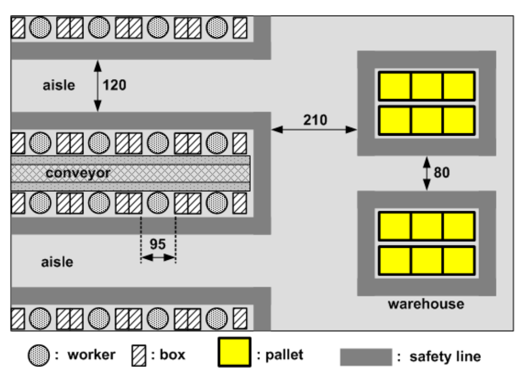


Fig. 2. Top view of the target environment (dimension : [cm])

[1] Bundang branch of Korea Employment Promotion Agency for the Disabled and vocational schools in Daejeon and Ilsan, Republic of Korea.

[2] Eleven factories including Mugunghwa Electronics and Immanuel Electronics which make mainly electronics, and Boram-Dongsan which mainly assembles the mechanical parts.

[3] Companies with more than 300 employees are classified as a large workshop.

IV. Development Of Assistive Mobile Robots

A. *Assistive Mobile Robot Type 1 - The First Version*

1) Designing & Development

When parts to be assembled are needed or when it is necessary to transfer materials, the worker moves the robot and picks up the materials. Therefore, a forklift system was adopted in the robot system. The forklift is mounted on the front of the robot. To satisfy the necessity of convenience when using the forklift and to ensure the stability of the forklift, a forward wheel driving/backward wheel steering mechanism was adopted. This mechanism is very stable, and many commercial forklift trucks use this mechanism. It is assumed that the disabled worker works while sitting on the chair of the robot. Therefore, the height of the chair of the robot should be lower than that of the worktable. Furthermore, it should be possible to rotate the chair up to a right angle to support tasks at the worktable.

The first version of the developed robot is shown in Fig. 3. Its system configuration is shown in Fig. 4. The mobile robot has two motors, one for driving and the other for steering. The forklift system also has two actuators to place and lift objects. A MANUS arm is installed onto the front of the robot. The robot arm is used to support some dexterous tasks such as circuit inspection and soldering. Each component of the robot, including the robot arm, the mobile platform, and the forklift, is controlled by a 2-axis joystick with several operation modes for that allow control of each component. For a table task, the robot has a revolving chair that is rotated manually. To ensure user safety, it also has four limit switches for emergency stopping and ten ultrasonic sensors to detect obstacles in the rear as a type of collision warning system. In addition, a camera is installed in the rear of the robot and a monitor connected to it displays the rear scene.

2) Evaluation

The robot was tested in the existing manufacturing factories, 'Boram-Dongsan' which mainly assembles the mechanical parts and 'Mugungwha Electronics' which mainly produces small electronic device. Two participants were randomly selected among workers with lower or upper limb impairments or both lower and upper limb impairments. After the user trials of the robot, the users were interviewed regarding the ease of controlling the robot, the forklift and the arm as well as the use of the user interface and the device as it pertains to user safety. Furthermore, comments from another fifty workers were gathered through a written survey. Fig. 5 shows the user-trials with the robot. The respondents said that the driving mechanism was appropriate when using the forklift mounted on the front. They also reported that they felt safe while moving around due to collision warning system. On the other hand, several shortcomings were identified. First, the size of the mobile robot and the turning radius of the robot need to be smaller, as the actual environment is small and has narrow spaces. The forklift system should be also smaller or capable of being folded electrically. Second, the chair needs to be rotated electrically. Third, it was reported to be difficult to control the robot arm, and this arm needs to be installed on a worktable. Finally, controlling each component using the joystick with several modes can confuse a worker. Therefore, a more intuitive and simpler user interface was required.

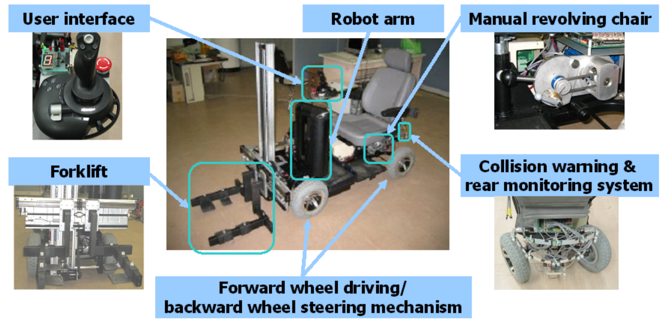


Fig. 3. Assistive mobile robot Type 1

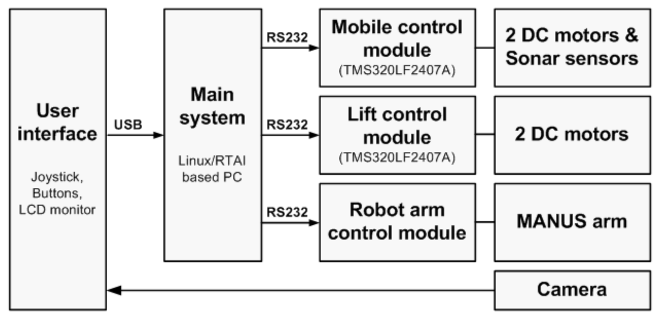


Fig. 4. System configuration of the Type 1 robot

TABLE II
SPECIFICATIONS OF ASSISTIVE MOBILE ROBOT TYPE 1

Size	650×1400×550 [mm] (Width×Length×Height)
Max. Speed(Mobile)	12 km/h
Max. Load(Mobile)	200 kg
Max. Load(Lift)	60 kg

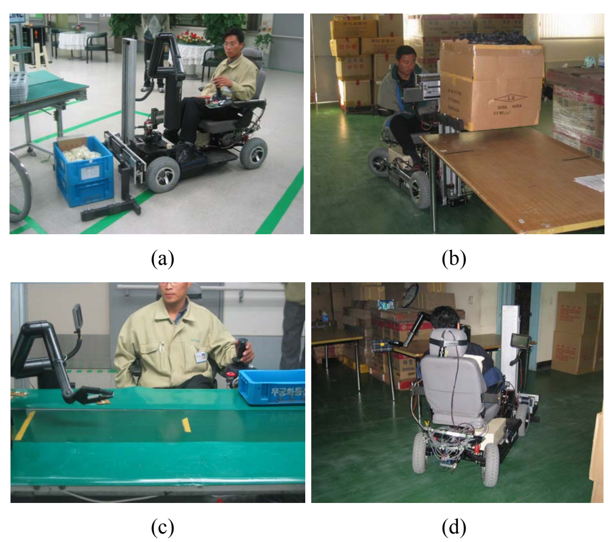


Fig. 5. User trials of assistive mobile robot Type 1
(a) Moving materials - lifting up (b) Moving materials - lifting down
(c) Working at worktable (d) Moving around

B. Assistive Mobile Robot Type 2 - The Second Version

1) Designing & Development

Based on the evaluation result of the first version, the second version of the robot was developed. As the robot arm is used primarily when performing tasks at the table and not as much when moving the robot around, the robot arm was installed on the table [20]. An electrically foldable forklift was used and mounted on the back to reduce the size of the robot. To improve the mobility of the robot in small and narrow spaces, an omni-directional drive mechanism was adopted. Among many types of omni-directional wheels, 'mecanum' wheels were used, as the use of four wheels guarantees the stability of the system.

Fig. 6 shows the second version of the developed mobile robot. The overall operation process is described in [19]. Fig. 7 shows its system configuration. As mecanum wheels are used, the robot can move in any direction by simply controlling the rotation of each wheel without steering them. When a user picks up objects using the forklift or when he works at the worktable, the chair can be rotated electrically to support lifting task or face the worktable. For user safety, a sonar sensor-based collision warning system that detects obstacles in the rear was used. As objects on the forks can be recognized as obstacles, a sonar sensor transferring device was added. By this device, sonar sensors are stretched so that they do not interface with the objects on the forks. The driving of the mobile robot is controlled by a three-axis joystick and the other components are switched and controlled by simple switches and buttons.

2) Evaluation

User trials of the second version were also conducted. The method of the user trials was essentially identical to that of the first version. Fig. 8 shows the user trials of the second version. The participants reported that it was a very good idea to adopt the omni-directional drive mechanism. They also reported that the size of the robot was sufficiently small. Although the test environment was small and narrow spaces, the participants could move easily in any direction. They also commented that it was very easy to use the user interface, as it was simple and intuitive. However, a number of problems were identified. As this robot did not have a suspension system, a user could experience vibration caused by the rollers of mecanum wheels. Moreover, noise was made by the rollers of the mecanum wheels. A problem with the user interface was also identified. As the joystick itself could also be rotated while the chair was rotating, it was not intuitive to control the robot using the joystick when the chair was rotated to one side. One issue with the forklift system was that it was inconvenient for a user when he tried to pick up parts from a box on the forks, as the pillar of the forklift blocked his arm movement as well as his sight. Furthermore, it was difficult to check the height of the forks when the user tried to place a pallet onto the forks. Finally, as the sensor transferring device was considered as a cumbersome device, participants tended not to use the device.

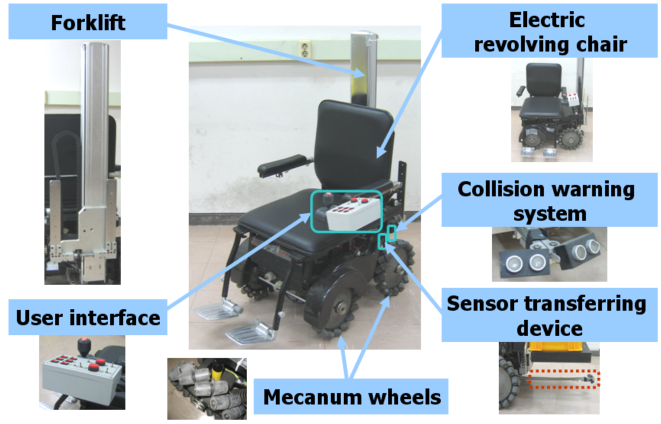


Fig. 6. Assistive mobile robot Type 2

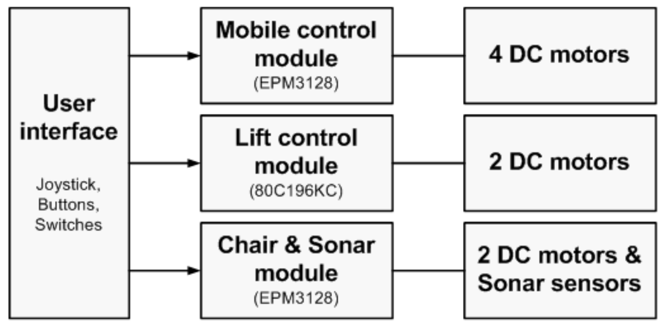


Fig. 7. System configuration of the Type 2 robot

TABLE III

SPECIFICATIONS OF ASSISTIVE MOBILE ROBOT TYPE 2

Size	760 × 1180 × 510 [mm] (W×L×H)	
Max. Speed(Mobile)	Translation	5 km/h
	Rotation	45 deg/s
Max. Load(Mobile)	120 kg	
Max. Load(Lift)	30 kg	

Fig. 8. User trials of assistive mobile robot Type 2

(a) Transferring to our robot (b) Moving around

(c) Working at worktable (d) Moving materials - lifting up

C. Assistive Mobile Robot Type 3 - The Third Version

1) Designing & Development

The third version of the robot was developed based on the evaluation of the second version. A mecanum wheel-based drive mechanism was also used, as the usefulness of this mechanism was verified through the evaluation of the second version. To reduce noise from the rollers of the wheels, bearings were inserted into each roller. Fig. 10 shows the designed body frame of the robot. To reduce the vibration caused by the mecanum wheels, a suspension system was adopted. To apply the suspension system to the robot, a Y-shaped body frame was designed. To satisfy the condition in which each mecanum wheel should make contact with and be parallel to the ground, a four link suspension structure was designed for each wheel.

The developed robot is shown in Fig. 9. For user convenience while controlling the robot, a simpler and more intuitive user interface compared to that of the second version was designed. As the rotation state of the chair is inputted to the mobile control module, as in Fig. 11, the user can easily control the robot using a joystick regardless of the rotation state of chair. To solve the problem in which the pillar of the forklift blocks the arm movement and sight of the user, a multiple pillar-based forklift system with an adjustable height was designed [21]. As the height of the pillar depends on the height of the fork, the forklift system can provide more convenience, which mitigates the drawbacks of the second version. The height and speed of the fork are controlled by a one-axis joystick. When a material is loaded onto the forks, the lift system can tilt depending on the weight of the material. This, however, has safety implications. Thus, a lift tilting system in which the user could tilt the lift was designed. This system offsets the tilting caused by the weight of the material on the forks. To provide a convenient means of checking the height of forks, a laser pointer was attached to the bottom of the forks. For user safety, a camera that monitors the rear area was added. On the other hand, the sonar sensor-based collision warning system and the sensor transferring device were removed as they could not be used conveniently.

2) Evaluation

A self-evaluation of the third version was conducted. Fig. 12 shows the user trials with the third version. As the bearings were inserted into each roller, the rollers revolve smoothly without noise. Moreover, vibration was reduced significantly due to the suspension system. Control of each component becomes easier due to the simple and intuitive user interface. The user can control the mobile platform using a three-axis joystick, the height of the fork using a one-axis joystick, and all other components, including the revolving chair, the tilting system, and the folding/unfolding of the forks are controlled by simple buttons and switches. The user can also check the remaining charge of the batteries, and can observe the rear scene through the small LCD monitor. The operation of the forklift system was also optimized. As the height of the lift system depends on that of the fork, the pillar does not block the arm movement and sight of a user when the user picks parts from the box at the worktable. The laser pointer at the bottom of the forks helps the user to check where the fork is positioned, although it actually depended on the illumination condition of the test environment.

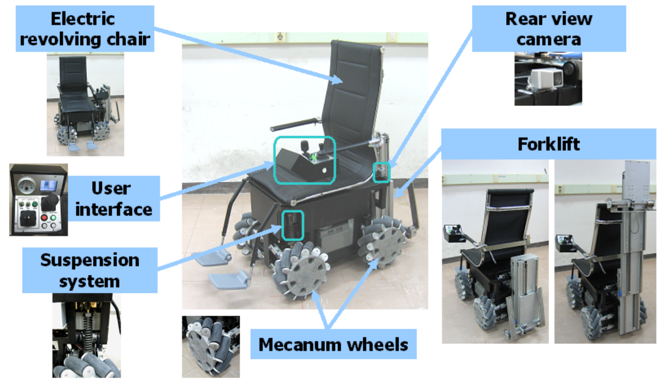
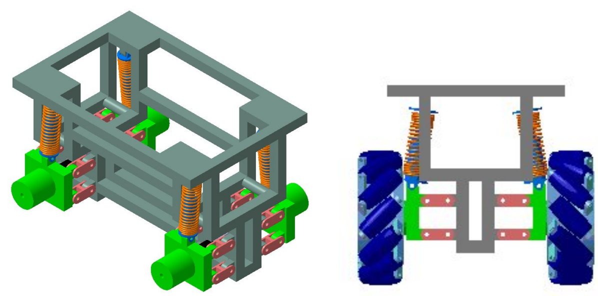


Fig. 9. Assistive mobile robot Type 3



(a) (b)

Fig. 10. The body frame of the Type 3 robot
(a) Body frame with a suspension system (b) Body frame with wheels

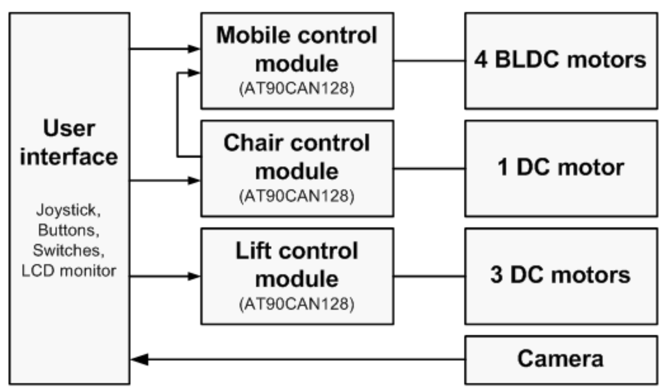


Fig. 11. System configuration of the Type 3 robot

TABLE IV
SPECIFICATIONS OF ASSISTIVE MOBILE ROBOT TYPE 3

Size	680 × 1280 × 570 [mm] (W×L×H)	
Max. Speed(Mobile)	Translation	5 km/h
	Rotation	45 deg/s
Max. Load(Mobile)	250 kg	
Max. Load(Lift)	30 kg	

(a) (b) (c) (d)

Fig. 12. User trials of assistive mobile robot Type 3
(a) Moving around (b) Moving objects - lifting up
(c) Moving objects - after tilting (d) Working at a worktable

V. Conclusion

In this paper, the assistive mobile robots that help the disabled to work in a factory environment were presented. The criteria of this research were 'assisting the disabled as much as possible,' 'considering the actual employment situation of the disabled' and 'assisting with the most commonly performed task of the disabled'. Based on these criteria, a survey was conducted to determine the target user and to understand their actual employment situations and the most common tasks.

The three types of robots have been developed and improved through the iterative process of designing, development, and evaluation. These robot systems are expected to provide practical assistance to the disabled workers and help to satisfy their desires and fulfill their potential so that they can become productive members of society. It is expected that this will result in an increase in the working population of the disabled.

The videos about our robots are uploaded in our website. Please refer to http://rr.kaist.ac.kr/project_workrobot.htm

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