Preliminary Research on Intelligent Mobile Tool Cart for Industrial Manufacturing in a Factory Environment

Shengnan Gai, Qiang Luo and Shujun Chen

Abstract Intellectualization of manufacturing is a general trend due to the development of technology and science. This paper presents a preliminary research on intelligent mobile tool cart (IMTC) for working alongside workers in manufacturing process. Tool cart problem is considered as an exemplary intelligent mobile tool cart service system. A type of differential-driven mobile cart with a tool basket which is mounted on the top of the mobile cart compose the intelligent mobile tool cart. The IMTC is designed to provide workers with remote motion control and tools positioning services. Daily used instructions are exercised as commands to control the IMTC in the factory environment by using Leap Motion sensor for finger/hand position detection. The IMTC provides its real-time position information to the worker. To fulfill estimating the location of IMTC, QR localization method is proposed. We verified the features of the IMTC and feasibility of the proposed localization method through experimental trials.

Keywords Service robot · Intelligent mobile tool cart · Position detection
Gesture command

1 Introduction

In recent decades, we realize that the robot helps general public and plays a large role in our life. It is worth mentioning that the application of mobile robot has drawn much attention. Till now, researchers designed and implemented many successful mobile robot systems. Duan et al. [1] proposed a miniature wheel-track-legged mobile robot to carry out military and civilian missions. Thrun et al. [2] described an interactive four-guide robot for museum guidance. Engelberger [3] demonstrate a healthcare robot for convenience of hospital

S. Gai · Q. Luo · S. Chen (✉)
College of Mechanical Engineering and Applied Electronics Technology, Beijing University of Technology, Beijing, China
e-mail: sjchen@bjut.edu.cn

S. Chen et al. (eds.), *Transactions on Intelligent Welding Manufacturing*,
Transactions on Intelligent Welding Manufacturing,
https://doi.org/10.1007/978-981-10-7043-3_10

assistance. Garingo et al. [4] developed a wireless, mobile, robotic telemedicine system in the Neonatal Intensive Care Unit (NICU). In service robot area, researchers always choose human body, face, voice, arm, or leg as the research objective. Lee et al. [5] implemented human tracking by legs scanning from a moving robot to monitor a moving target person. Jung et al. [6] set human torso as research objective to allow a mobile robot track a desired human in front. Gai et al. [7] introduced daily used instructions as commands through a Kinect to control mobile shopping cart and provide consumer intelligent shopping services. Chen et al. [8] presented an interactive mobile robot only based on visual information to support face-to-face interaction between human and robot. Otsuka et al. [9] utilized voice for controlling robot head movements to guarantee robot behave the way human expect it to and offer natural spoken communication between human and robot. It is probably fair to say that the diversification of information to the mobile cart makes applicability of the mobile cart more extensive. However, the two legs in [5], the torso part in [6], the arm in [7] and face and arm combined in [8] provide relatively sweeping gesture commands to the mobile cart which is not suitable for an industry application. Besides, noisy industry environment might give rise to voice control invalidation.

This paper proposes a novel method for workers to control IMTC by employing hand/finger gestures commands. We attempt to use hands or fingers to express emotion and give orders. The commercialized Leap Motion sensor mounted on the operation platform is utilized to achieve the goal. The Leap Motion is able to detect two hands and ten fingers at once. It is used to provide position information of the hands and fingers with high precision in real-time and receive hand/finger gesture commands. Based on customs and understandable of human beings, we defined seven hand/finger gesture commands using the right hand to control the Intelligent Mobile Tool Cart (IMTC). Besides, a camera is installed on the bottom of the cart to detect the QR code from a QR marker streaks labeled on the ground. By decoding the stored position information from the QR code, the exact location of the cart can be realized accordingly. The QR localization method is proposed to provide stable location information to the IMTC. The feasibility of the QR localization method is verified through experiments.

This paper is organized as follows. The Intelligent Mobile Tool Cart and usage of Leap Motion sensor are introduced in Sects. 2 and 3, respectively. Section 4 presents and verifies QR localization method based on Wi-Fi network. Section 5 evaluates the performance of the proposed IMTC through experiment trials. Finally, the conclusion is organized in the last section.

2 Overview of Intelligent Mobile Tool Cart Service System

2.1 Introduction to Intelligent Mobile Tool Cart Service System

The Intelligent Mobile Tool Cart Service System is demonstrated in Fig. 1. Several devices including a Wi-Fi box, a Leap Motion, cart appliances, and QR marker streaks are interconnected to realize the intelligent service to the worker. The two major functions of the IMTC are cart remote motion sensing control and cart location-recognition services. The cart remote sensing motion control is realized by employing Leap Motion sensor. The Leap Motion provides an interface between the worker and the IMTC. Commands include Go Forward, Draw Back, Turn Left, Turn Right, Start/Stop, Acceleration, and Deceleration, which will be executed by IMTC in the experiment apart. Besides, during this process, IMTC speed adjustment could be achieved by employing Acceleration command and Deceleration command.

The location information is provided by QR code. A camera installed on the bottom of the cart attempts to detect the QR code when the cart passes through a QR code marker streak, and the QR position information will be decoded by employing ZBar. By implementing hybrid localization algorithm which will be described in Sect. 4, the worker will receive a real-time location of the IMTC.

2.2 Mechanism and Hardware

A tool basket often refers to a kind of storage to hold tools. The first tool basket was built in the early nineteenth century made of wool material. Noffsinger [10] developed a foldable tool cart. Mccauley et al. [11] designed a tool storage and bolt organizer device. Lately, Lin et al. [12] proposed a cart, which can store tools and parts in 2016. Nonetheless, those designs applied on the factory can only provide

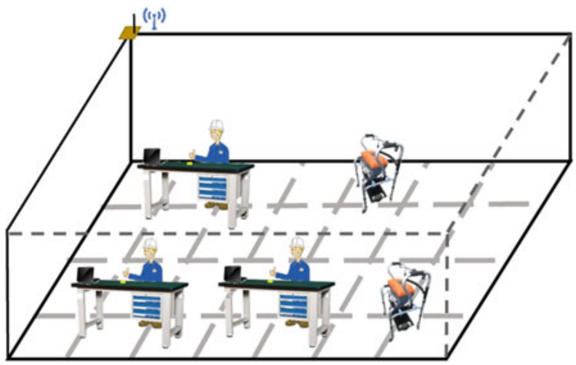


Fig. 1 Demonstration of IMTC service system in a factory environment

workers with convenience to some extent. Workers still need to interrupt working and leave the operation platform to take tools from a tool holder located apart from the operation platform.

To solve the problem, a novel intelligent mobile tool cart is developed as shown in Fig. 2. In a factory environment, the operation platform is equipped with a Leap Motion. And IMTC which is comprised of a tool basket, a camera, a LED lights, and a differential-driven mobile cart will be used in the factory environment to assist worker with providing intelligent service for industry manufacturing. Two motors drive the differential-driven wheels and provide the momentum to the IMTC. The tools, for example, chisels, screwdrivers, pliers, and so on, are hold in the tool basket which is installed on the top of the cart as shown in Fig. 2. A camera is installed at the bottom of the cart to detect QR marker and LED lights are fixed on the differential-driven mobile cart for better illumination. In this paper, the mounting position of the camera is higher than the LED lights. It will guarantee capturing at least one integrated QR code that could be detected by the camera in the range of the LED lights. Besides, a DSP controller for motor control, and two lead-acid DC batteries for power supply. The parameters of the IMTC are summarized in Table 1.

3 Sensor System

3.1 Description of Leap Motion

The proposed system using Leap Motion could detect the position of the hand/finger and receive gesture commands. Leap Motion is a motion sensing input device commercialized by Leap Company. The Leap Motion recognizes and tracks hands and fingers. The effective range of the Leap Motion extends from 0.025 to 0.6 m in distance above the device along Y axis and the angle of vision covers 150 degrees in default. Figure 3 shows the effective range of the Leap Motion.

Generally speaking, the Leap Motion has a webcam-like structure and allows users to interact with it through a natural user interface by applying hand/finger

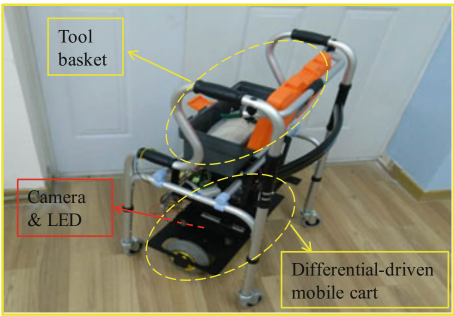


Fig. 2 Intelligent mobile tool cart

Table 1 Main specification of the tool cart

	Specification	Quantity
Motor	DC motor, 90 W, 18:1, Maxon (for driving shopping cart)	2
	DC motor, 25 W, 66:1, Faulhaver (for lifting DDTM)	1
DSP controller	dsPIC33FJ128 M	1
Motion controller	Leap motion, USB 2.0	1
Battery	Lead-acid, DC, 12 V	2
Camera	C270, USB 2.0, Logitech	1
Illumination light	LED lights	1
$W \times L \times H$	0.58 m × 0.9 m × 0.86 m	
Wheel radius	0.15 m	
Max speed	1.2 m/s	

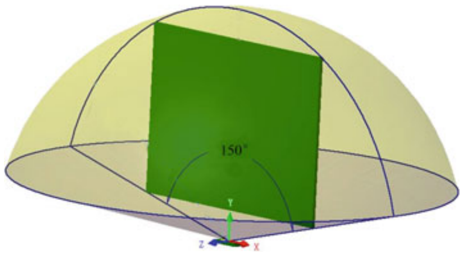


Fig. 3 Effective range of the leap motion

gesture commands detection. The novel control method of MTC using Leap Motion depends on advances in entities tracking, such as hands and fingers. If all or part of a finger is not visible, the finger characteristics will be estimated based on recent observations and the anatomical model of the hand. The natural user interface could be done by using kinds of programming language, such as C++, C#, Unity, Objective-C, Java, Python, JavaScript, and so on. And C++ was adopted in this paper.

3.2 Commands to Leap Motion

In this paper, the Leap Motion installed on the operation platform is used to detect hand/finger gesture commands of the worker. To read gesture commands, hand/finger detection should be set. In our experiment, we use right hand and its three fingers (index finger, middle finger, and ring finger) to recognize gesture commands. Depending on the effective range of Leap Motion we define seven commands, Go Forward, Draw Back, Turn Left, Turn Right, Start/Stop, Acceleration, and Deceleration. When the worker places his right hand with three fingers on seven different regions, shown in Fig. 4, within effective range, the corresponding gesture command will be recognized and sent to the MTC through Wi-Fi connection. The Mobile Tool Cart responding to Go Forward, Draw Back, Turn Left, Turn Right, Start/Stop, Acceleration, and Deceleration will be tested in Sect. 5.

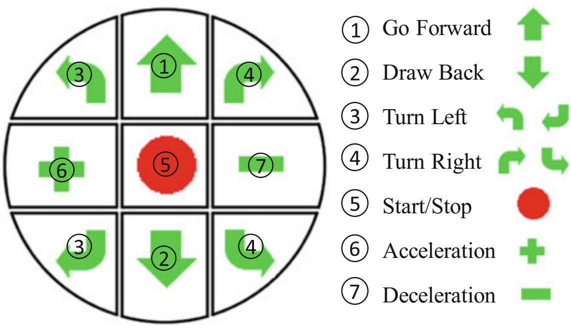
4 QR Localization Method

The Quick Response Code (QR Code) is a machine-readable optical label that contains information about the item to which it is attached. Due to its fast readability and greater storage capacity, the QR code gained more and more popularity. The famous applications of QR code include product tracking, item identification, mobile operating, code payment, website login, document management, and general marketing. In this work, we use QR code to locate the cart in the given environment. As described in Sect. 2, a camera is installed on the cart to detect the QR code from a QR marker streaks labeled on the ground. By decoding the stored position information from the QR code, exact location of the cart can be realized accordingly.

Success read and read time should be taken into consideration when we use camera to detect QR code. During the test trip when the cart passes through QR marker streaks, the success read is defined as the QR code number that is accurately scanned. The read time is defined as the total time that is cost to scan a QR code marker and decode the scanned QR code. Only when a QR code is detected by a camera successfully and gets precise decoding information at the same time, it is possible to get effective position information of the shopping cart. However, it is noted that camera is sensitive to light. In our research, the QR marker streaks are statically labeled on the ground and the camera is moving with the cart. The cart velocity affects both the success read and the read time. In order to determine the influence of lights and shopping cart velocity on the success read and read time, we performed experiments in the following.

The light condition of experimental environment is set as four cases; adequate illumination with using LED lights, adequate illumination without using LED lights, inadequate illumination with using LED lights, and inadequate illumination

Fig. 4 Hang/finger gesture commands within leap motion effective range



without using LED lights. The experiment was carried out under these four different light cases, respectively. As shown in Fig. 5, there are ten QR marker streaks labeled on the ground. The distance between two neighbor steaks is 0.5 m and the position of the first steak is (0, 0.5). The cart is initially located at the origin position (0, 0) marked by green dot in Fig. 5. The cart starts from the origin position and passes through ten QR marker streaks.

When the cart passes through each QR marker streak, we decode the QR position value P_{QR} and odometry position value P_{odo} at the same time. However, it is noted that the odometry position value is greater than the absolute position of the QR marker streak. This is because camera detection and QR code decoding take some time which is demonstrated in Fig. 6. Their total time (i.e., time latency) is defined as read time given by

$$T_{rt} = T_{odo} - T_{QR} = \frac{P_{odo} - P_{QR}}{v},$$

where P_{odo} is the measured odometry value when QR code position is received, and P_{QR} is the corresponding QR code position value. v is a constant value at the desired velocity of the cart for one test trial. In this experiment, five specific velocities ranging from 0.4 to 1.2 m/s were tested. Each test trial was executed ten times by setting the same cart velocity under the same illumination case. The experiment results of success read average under four different illumination cases in different velocity is shown in Table 2.

From Table 2, adequate illumination condition gives rise to outstanding QR code success read under the same cart velocity by comparing adequate illumination condition with inadequate illumination condition. And by using LED lights the success read is improved by 3–7.6% comparing with without using LED lights.

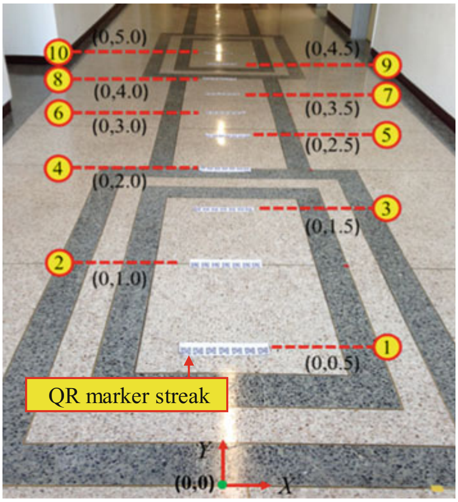


Fig. 5 Test environment of QR code

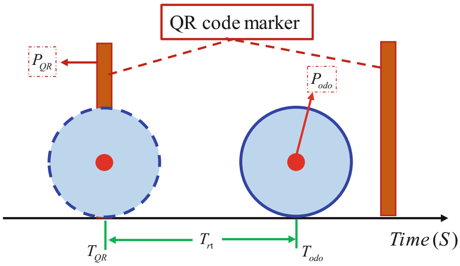


Fig. 6 Demonstration of QR localization method

Table 2 Success read test for different illumination case

	Adequate illumination		Inadequate illumination	
	LED (%)	Without LED (%)	LED (%)	Without LED (%)
0.4 m/s	100	100	60	35.46
0.6 m/s	100	100	36.52	0
0.8 m/s	100	100	0	0
1.0 m/s	100	97	0	0
1.2 m/s	100	92.4	0	0

The IMTC will be applied to an adequate illumination environment, so in this paper, we just take adequate illumination case into consideration. By employing LED lights to improve the performance of QR code detection, the corresponding read time is summarized in Table 3.

From Table 3, we can see that the read time is relatively stable under the same velocity of the cart. And as the velocity of the cart increases, the read time grows slightly as well. All read time in Table 3 are less than 0.4 s in all speeds under consideration and the cart velocity limitation is low (1.2 m/s), so it is reasonable to using QR positioning information to provide cart location in real application.

Table 3 Read time test for different velocities

	0.4 m/s	0.6 m/s	0.8 m/s	1.0 m/s	1.2 m/s
1	0.338	0.338	0.325	0.324	0.332
2	0.348	0.295	0.299	0.345	0.372
3	0.353	0.337	0.305	0.347	0.355
4	0.253	0.363	0.326	0.345	0.363
5	0.313	0.358	0.331	0.35	0.39
6	0.32	0.312	0.37	0.356	0.355
7	0.33	0.342	0.346	0.348	0.34
8	0.28	0.335	0.34	0.334	0.361
9	0.288	0.308	0.323	0.327	0.342
10	0.313	0.332	0.329	0.342	0.353
M	0.314	0.332	0.329	0.342	0.356

5 Experiment

In order to evaluate the effectiveness of the proposed control method of Intelligent Mobile Tool Cart, two experiment trials are conducted. The first experiment was in a factory similarly environment and the second experiment was in a real factory environment. Both of the two environments were Wi-Fi enabled.

5.1 *Experiment 1 (Leap Motion Based Control Method Performance Test in a Factory Similarly Environment)*

Initially, the tester stood in front of the operation platform and the Intelligent Mobile Tool Cart located beside the operation platform. The tester put his right hand within the effective range of the Leap Motion and gave commands to IMTC through Wi-Fi communication. We tested each command 50 times. If the tester put his right hand with three fingers in region 2 of the Leap Motion, the IMTC executed Draw Back command as shown in Fig. 7. If the tester put his right hand with three fingers in region 4, the IMTC executed Turn Right command as shown in Fig. 8. Repeated the experiment procedures mentioned above in the other 5 regions and recorded the experiment results. The Start/Stop command is used to initialize the system when it appears at the first time, and call for stop action when the Start/Stop command appears after the other commands.

The upper three figures of Figs. 7 and 8 demonstrate the reaction of MTC when the MTC executes Draw Back command and Turn Right command, respectively. In the bottom three figures, the first figure shows the specific command gesture, the second figure shows corresponding command region with respect to the Leap Motion and the third figure shows the interface window. The frame rate of three

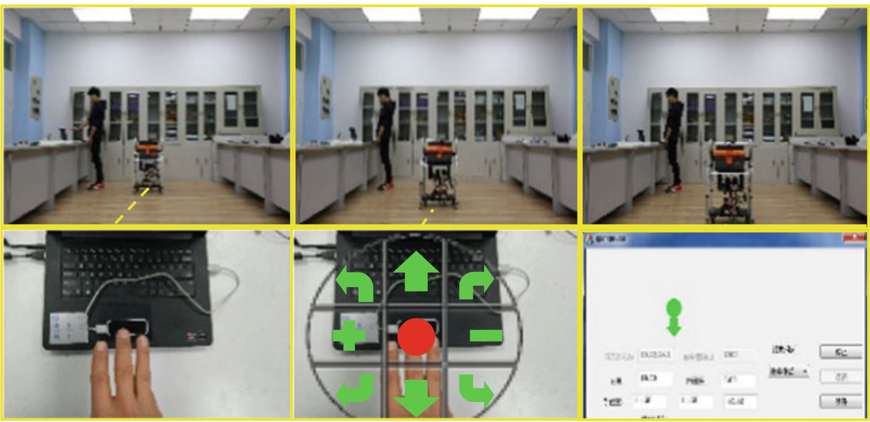


Fig. 7 Draw back command of MTC

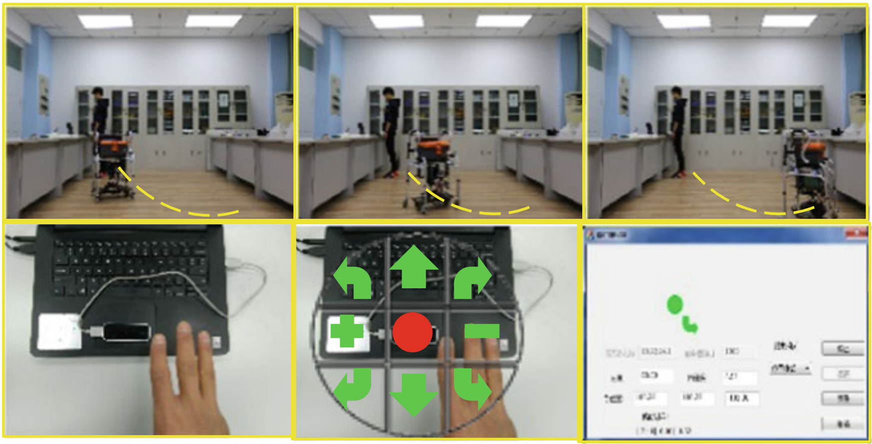


Fig. 8 Turn right command of MTC

cameras of Leap Motion is 290 FPS, the IMTC reaction speed due to the time of completing the gesture and information transmission through Wi-Fi. A single commend could be detected and transmitted within 0.5 s which was also confirmed in the experiment. And the experiment result is summarized in Table 4.

As shown in Table 4, the tester gave IMTC Draw Back command 50 times, the IMTC executed correct operation command 46 times, incorrect operation 2 times and no action 2 times. The accuracy of the Draw Back command is 92%. The tester gave IMTC Turn Right command 50 times, the MTC executed correct operation command 46 times, incorrect operation 3 times and no action 1 time. The accuracy of the Turn Right command is 92%. As demonstrated in Table 2, the IMTC executed correct operation above 90% among seven commands. Based on the experiment results, we can say that IMTC makes responses effectively when receive different commands.

Table 4 Experiment result

No.	Command	Correct	Incorrect	No action	Accuracy (%)
1	Go Forward	47	1	2	94
2	Draw Back	46	2	2	92
3	Turn Left	45	2	3	90
4	Turn Right	46	3	1	92
5	Start/Stop	46	1	3	92
6	Acceleration	46	3	1	92
7	Deceleration	47	2	1	94

5.2 Experiment 2 (Leap Motion Based Intelligent Mobile Tool Cart Movement Performance Test in a Real Factory Environment)

Based on the Leap Motion, the performance of the developed Intelligent Mobile Tool Cart was tested in Engineering Research Center of Advanced Manufacturing Technology for Automotive Components, Ministry of Education which is located in Beijing University of Technology. The experiment environment is demonstrated in Fig. 9.

The tester stood in front of the operation platform and the Intelligent Mobile Tool Cart was set at initial position beside the operation platform as shown in Fig. 9. Tester using the proposed hand/finger gesture commands to control IMTC. The IMTC started to move from initial position and arrived at A, B, C, and D position in sequence. When IMTC passed through A, B, C, and D, trajectory of the IMTC was a "S" shape curve which is known as complex path shown in yellow dashed line in Fig. 9. And all the seven hand/finger gesture commands designed in this paper were employed during this trajectory. Figure 10 shows experimentation process in detail. In Fig. 10a–d demonstrate the movement of IMTC from initial position to A position, from A position to B position, from B position to C position, and from C position to D position, respectively. During whole experiment process, the designed hand/finger gesture commands worked sensitively and reliably. And IMTC could accomplish the desired path from initial position to D position steadily. From experiment 2, it is marked that the proposed hand/finger gesture commands could achieve desired function and provide worker with a simple and new working experience.

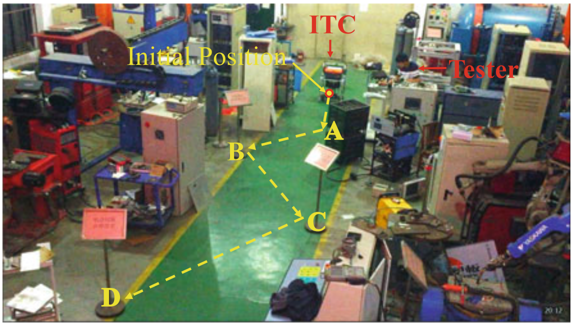


Fig. 9 Experiment 2 environment

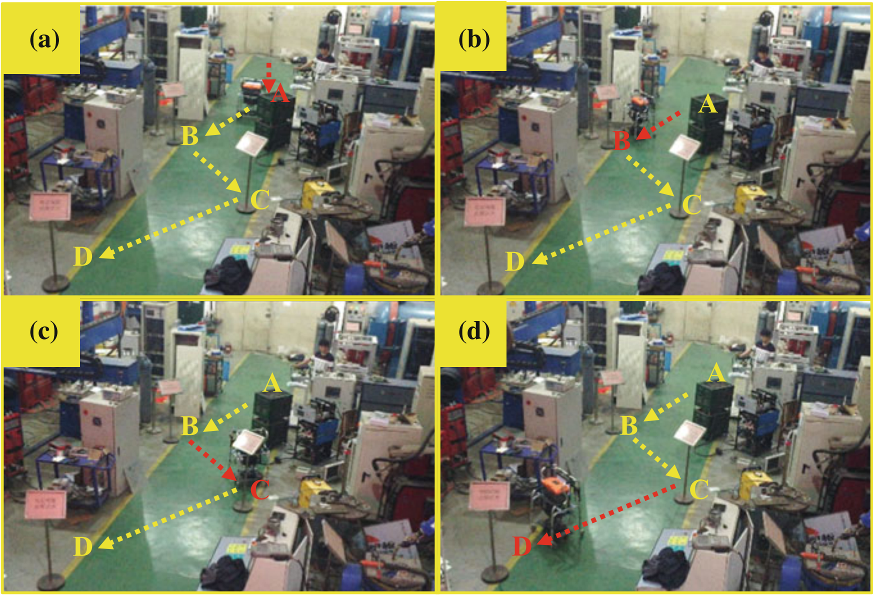


Fig. 10 Demonstration of experiment 2

6 Conclusion

The paper developed a novel intelligent mobile tool cart (IMTC) to move to an advance stage in providing assistance to workers. The worker would be serviced by remote motion control and cart location-recognition services. In this paper, a novel method for reading hand/finger gesture commands using Leap Motion to control a mobile tool cart is proposed and implemented. We achieved the task that IMTC responded to the defined seven gesture commands, such as Go Forward, Draw Back, Turn Left, Turn Right, Start/Stop, Acceleration, and Deceleration successfully. Real industry environment experiment verified stability of the developed IMTC, reliability and sensitivity of the proposed control method. Besides, a QR localization method is proposed and verified to provide real-time location information of the IMTC to the worker. The response time is controlled within 0.5 s. As a conclusion, the proposed IMTC with the proposed remote sensing motion control method and QR localization method achieved anticipated goal of simplifying the working process and providing intelligent service to workers.

References

1. Duan X et al (2007) Development and analysis of miniature wheel-track-legged mobile robot. Chin J Mech Eng 20:24–28
2. Thrun S et al (1999) MINERVA: a second generation mobile tour-guide robot. In: Proceedings of the IEEE international conference on robotics and automation IEEE, vol 3, pp 1999–2005
3. Engelberger JF (1999) Health-care robotics goes commercial: the helpmate experience. Robotica 11:517–523
4. Garingo A, Friedlich P, Tesoriero L et al (2012) The use of mobile robotic tele-medicine technology in the neonatal intensive care unit. J Perinatol 32(1):55–63
5. Lee JH et al (2006) People tracking using a robot in motion with laser range finder. In: Proceedings of IEEE/RSJ conference on intelligent robots and systems, pp 2936–2942
6. Jung EJ et al (2012) Control algorithms for a mobile robot tracking a human in front. In: Proceedings of IEEE/RSJ conference on intelligent robots and systems, pp 2411–2416
7. Gai S et al (2013) Mobile shopping cart application using Kinect. In: Proceedings of IEEE international conference on ubiquitous robots and ambient intelligence, pp 289–291
8. Chen L et al (2014) Stereovision-only based interactive mobile robot for Hu-man-Robot Face-to-Face interaction. In: Proceedings of international conference on pattern recognition, pp 1840–1845
9. Otsuka T, Nakadai K, Takahashi T (2010) Voice-awareness control for a humanoid robot consistent with its body posture and movements. Paladyn 1(1):80–88
10. Noffsinger AA (2004) Foldable tool cart. US Patent 10217225, Aug 2004
11. Mccauley KG (2014) Tool storage and bolt organizer device. US patent 13755679, Feb 2014
12. Lin YH (2016) Cart for storage of tools and parts. US Patent 15144796, Dec 2016