See-Through and Spatial Augmented Reality - A Novel Framework for Human-Robot Interaction

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Abstract— **Autonomous and semi-autonomous mobile robots have been deployed to cooperate with humans in many industrial applications. These tasks require human and robot to communicate and present information quickly and effectively. Recent human-robot interfaces usually use a setup including a camera and a projector attached to the mobile robot to project the information to the floor or to the wall during the interaction process. However, there are some limitations to these interfaces. First, using a projector for projecting information seems to be fine for an indoor application. On the contrary, it is very difficult or even impossible for users to view this source of information in outdoor contexts. This makes the current framework inappropriate for many outdoor industrial tasks. Secondly, as the projector is the only device for exchanging information between human and robot, the human-robot interacting process is insecure and people who work in the same environment can control the robot in the same manner as the main operator. Finally, the current interfaces normally use mouse, keyboard or a teach pendant to provide task information to the robot. This approach poses some difficulties if the main operator is working in an industrial context where he is supposed to wear protective equipment such as gloves or helmets which make it hard to control a mouse or to type on a keyboard. This work proposes a new interface framework for human – computer interaction in industry that can overcome the current limitations of previous works. The framework uses a laser-writer instead of a projector which is suitable for both indoor and outdoor applications. Furthermore, the combination of see-through head-mounted display augmented reality and spatial augmented reality would provide the system a novel way to enhance the security level of exchanging information since the system now can separate the information presenting to the main user and to people working in the same environment. Finally, a novel hand-held device is incorporated to the framework which provides various input modalities for users to interact with the mobile robot. The device will allows the elimination of mouse and keyboard or teach pendants in industrial contexts.**

Keywords-human-robot interaction; augmented reality; spatial augmented reality; human robot-collaboration

I. INTRODUCTION

Mobile robots have been deployed in various scenarios such as material transportation, telepresence communication, sewer investigation or recue tasks. With the developments of sensor technology and advanced algorithms recently, mobile robots can automatically perform these tasks or cooperate and help human to finish the task. Consequently, robots are becoming more and more interactive in many areas especially in industry which leads to the need of user-friendly interface for both new and expert users. Since robots are working in the same environment with people, safety is also another concern. There are two main trends when it comes to the process of designing a human-computer interface (HCI). The first trend relates to the ideas trying to create robots that are able to mimic human appearances and behaviors. The ideas seem to be so fascinating and attractive for many researchers that many human-like robots are developing and testing all over the world despite how costly they are. However, trying to resemble human behaviors is normally a hard process and sometimes it is misleading. In daily life, we might need to use more than one channel of communication in case we cannot understand what others are trying to say. For instance, some people use their gesture to explain their ideas when talking to other people. As a result, it is really hard to design robot that can communicate with human using the human ways. The second important approach in design human-computer interface is to rely on visual communication using text, word or sound. This method is considered to be more reliable since all the exchange information is explicitly written, projected or displayed intuitively using some projection tools. This approach has been used to design some navigation robots [1], a guidance mobile robot [2] or a material transportation robot [3]. However, there are still some limitations relating to these interfaces as well. Firstly, all of them use a normal projector to project information on the floor as a way of communication or showing their intentions to people working in the same environment. This type of projector is normally very blurry which make it hard for us to see the projected graphics in a bright or outdoor scenario. Therefore, to deploy this projector in outdoor industrial applications is impossible. Secondly, because there is only one channel for exchanging information between these robots and the user (normally by projecting texts on the floor), the whole system may not be secured. Many people can control the robot in the way as the main user does. It is necessary to separate the task information for the main user and for the people who happen to work in the same environment to increase the system security.

Due to these current limitations of the second approach in design a HCI, our work will propose a novel framework that not only overcomes the current limitations but also adds some new features to the interface that facilitates the interaction process between human and robot. The rest of the paper is organized as follows: Section II will introduce some of the related work including augmented reality, spatial augmented reality and mobile robot. Section III will present our framework with hardware and software configurations. Next, section IV shows our experimental demonstrations for the proposed framework. Finally, the paper ends with conclusions in Section V.

II. RELATED WORK

A. *See-Through Augmented Reality*

Augmented Reality (AR) is a category of mix reality technology that allows computer-generated information to be overlaid over real environment or real objects. Its applications range from entertainment, education, advertisements or tourism to robotic, medical sciences or manufacturing processes. In order to experience this technology, users are normally required to be equipped with an electronic system containing an embedded camera sensor such as smartphones, tablets or laptops. However, these devices only allow users to view computer-generated contents attached to the live video stream that shows real environment captured by the camera instead of looking the real environment by their naked eyes. Consequently, in recent years, see-through augmented reality glasses are developed as a more superior device for augmented reality applications. In 2013, Google started selling a prototype of their glass before it became available for commercial market on May, 2014. In 2015, Microsoft introduced their first AR glass called “HoloLens” in one of their event. They started selling their first development edition in 2016. Epson announced their Moverio BT-200 glass in 2014 at CES. Its second version called Moverio BT-300 was announced in 2016. Many other see-through glasses are introduced by different manufacturers such as Sony, Snap or Vuzix. Various applications have been developed using this see-through technology including medical guidance [4], [5], vision enhancement [6], game and training [7] or remote collaboration [8]. With the advances of the supported hardware and software, the future of see-through augmented reality technology is very promising.

B. *Spatial Augmented Reality*

Spatial augmented reality (SAR) is a branch of augmented reality that utilizes a beaming device to directly project graphical information on the real world. One important advantage of this technology is the elimination of smartphone, tablet or other wearable devices which reduces the complexity of the system setup. Additionally, a projector is included in the system setup to project information to the real world. Spatial augmented reality has proved it usefulness in many industrial scenarios where spatial information is the key factor. Some spatial augmented reality interfaces are implemented and apply to several automatic processes in shipping industry such as stud welding or spray painting of work pieces [9]. In these tasks, with the help of the projected information, the worker can intuitively and precisely identify the position or the area to perform the task. SAR becomes even more feasible when it is combined with some mobile robotic platforms. In 2011, a robot for guiding people by projecting instructions on the floor or the wall [10] is introduced. The setup includes a projector and a camera that are installed on top of the robot. The project illustrates the robot instructions on the floor while the camera monitors the targeted user. In material transportation field, an automatic navigation robot with spatial augmented reality function is built to safely operate in a shared industrial floor [3]. The ability to project the vehicle intention on the ground in front of the robot is considered to be very useful in term of increasing human’s awareness of robot operation. For example, this project [1] has proved that SAR has a great potential in providing robot navigation information to users. Also, SAR has improved the interface safety level as users can totally focus on their working scene while still being able to follow the instructions generated by AR glasses.

C. *Multimodal Handheld Device*

Human gesture is normally considered to be a natural approach to communicate with computer or robot. Consequently, many implemented interfaces have introduced a handheld device that is able to recognize user’s gesture as a mediator object between human and robot. There are two main approaches that have been used for designing the handheld system in the literature: imaged-based and sensor-based system. Imaged-based systems require the use of camera sensor to capture the pictures of the hand. Typical examples of imaged-based system are mobile phone [12], Microsoft Kinect [13] or Leap Motion Controller [14]. However, the accuracy this kind of system is normally subjected to some environmental problems such as finger occlusion. Sensor-based systems require the user to wear special electronic equipment for tracking the finger positions. Some examples of such system are electronic gloves [15] or Wiimote [16]. Although these devices can make the interface more tangible, the challenge is the cumbersomeness of wearing an additional device. Additionally, teach pendants are also introduced as a special device to help human to interact with industrial robots. However, these devices are quite heavy and are not suitable for people who have to wear safety equipment to work in industrial contexts.

III. METHODS

Our goal is to design a user-friendly interface for human to communicate intuitively with mobile robot in both indoor and outdoor scenario. Our product also provides some improvements in term of security aspect since industrial tasks are our target applications. Furthermore, our main users mostly consist of people working in an industrial environment who are supposed to wear protection equipment. As a result, the interface will take into account all limitations they have to face while using the interface. This is the reason why we try to eliminate the use of mouse, keyboard, monitor display, teaching pendants or any other devices that is hard to use while wearing safety clothes such as gloves. The following sections will introduce in details each component of our proposed framework.

A. *Laser Writer System for Spatial Augmented Reality*

The blurry problem of using a standard projector to project texts in an outdoor context can be solved by using a laser writer. Laser is an extremely powerful light source. Laser beams can provide a clearly display for both indoor and outdoor environments. With the help of a fast galvanometer, visual texts or shapes can be generated to be projected against a bright or dark background. However, these laser images are normally outlines due to the constraints of the galvanometer. Although the laser writer is unable to support filled drawings, the high contrast images it provides is still very helpful in a bright industrial environment for showing the robot status or intentions to people in the surrounding workplace. The section below shows the design and implementation of this laser writer.

1) Laser writer hardware design: This laser projector contains three main components: a laser controller board, a RGB laser source and a galvanometer. The diagram in Fig.1 lists all the important hardware components for the design process in details as well as the connections between these modules to control the operation of our laser writer.

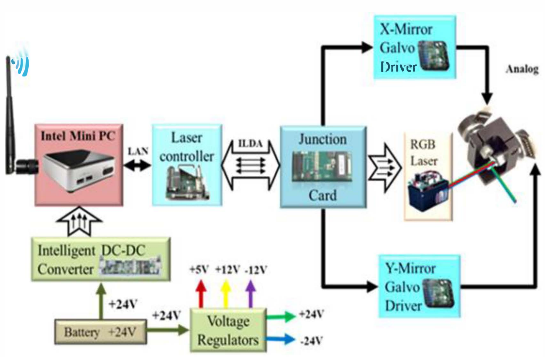

Figure 1. Laser writer main component diagram.

The laser graphic image is generated from a personal computer as shown in Fig. 1. This image will be sent to the laser controller board. This board reads the received information from the PC and converts it into two categories of information: RGB laser modulation and galvanometer orientation. The information will be wired directly to the drivers of the corresponding components including the RGB laser driver, X-Mirror galvanometer driver and Y-Mirror galvanometer driver. As a result, we are not only able to control the intensity of the RGB laser but also to adjust the position of the laser beam with respect to a particular surface. There is a limit at the number of points the system can bounce while creating an image. Therefore, if the image contains more points than the laser writer can afford, there will be some distortion effects.

2) Image Generation: To transfer a laser image from the computer editor program to the laser controller board, the ILDA (International Laser Display Association) format is used to save the laser image information as shown in Fig. 2. ILDA format allows the import of user's computer-generated images laser frame. Each frame contains the positions in Cartesian coordinate and RGB values of each point in the image. The ILDA file will be sent to the laser controller board using an ILDA converter cable. For each point in the laser frame, its saved information in the ILDA file will be converted into Red, Green, Blue intensity values and a galvanometer mirror angular orientation in both vertical and horizontal plane. The data are transferred to the correspoding driver modules as illustrated in Fig. 2.

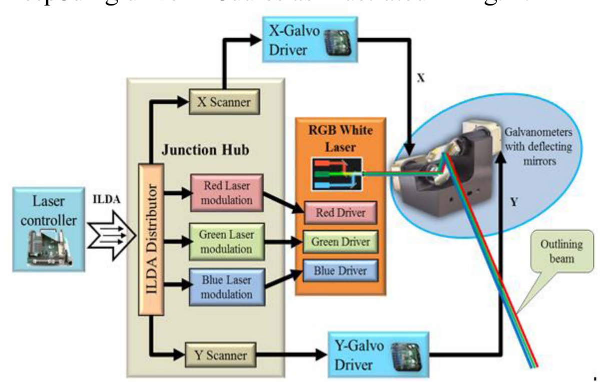

Figure 2. Laser writer functional block diagram.

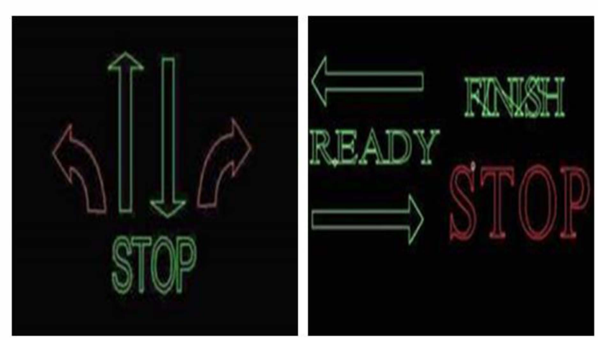

Figure 3. Laser generated images using editor software.

Finally, as the laser writer scans through all the points in the laser frame, the outlining beam will overlay a particular laser shape over the projected surface. Fig. 3 shows some results of generating some laser texts and shapes using an editor software that might be useful for displaying the mobile robot status in a specific industrial context. The results of projecting these images on the floor are shown in Fig. 4.

Figure 4. Projecting laser images on the floor.

In the above figures, the laser writer has shown its capability of providing high-contrast texts or shapes that can be easily seen by people who share the same workplace with the robot. This leads to our decision to use this kind of device as the first communication channel for the robot to share its intentions with human. The second interaction channel will be mentioned in the next section.

B. See-through Augmented Reality Glass

There are two main reasons for us to include an augmented reality glass to this novel interface. Firstly, as mentioned in the previous sections, there is a need of creating another way to interact with robot for the main user due to some security purposes. It is recommended not to expose all the robot operation parameters or administration commands to everybody especially in an industrial context. Secondly, see-through AR glass has the capability of allowing users to monitor what is displaying on the glass screen while still focusing on their task scene. In the past, users usually are required to look at a computer screen or a teaching pendant to read the instructions and interact with the robot. With the introduced see-through device, they are now able to observe their working environment with augmented information at the same time and space. This is a very convenient and important feature of the device since the user are not be distracted from working scene while controlling or configuring the mobile robot. For this project, the Epson Moverio BT-200 see-through glass is chosen to be included into our framework. This AR glass contains one camera for tracking function. The device runs Android operating system version 4.0.4. For the purpose of demonstration, the system will try to detect an AR marker pre-arranged on the real scene with the attached camera and overlay the corresponding computer-generated images using the position of the marker. Fig. 5 shows the first version of the Epson Moverio BT glass. The process of rendering augmented reality contents using augmented reality glass is illustrated by the flow diagram in Fig. 6. The camera will continuously capture the real environment to detect the position and orientation of the AR marker. This information will later be used to align the computer-generated images with the video stream captured by the device camera. Fig. 7 shows a screenshot of our AR application running on the Epson glass with a marker attached to the mobile robot. The displayed graphics are generated using only the internal hardware and software components that are integrated to the Epson Moverio BT-200. Since the system uses the marker tracking method for creating augmented reality content, the user is supposed to look at the marker in order to view the augmented graphical images.

Figure 5. Epson Moverio BT-200 Augmented Reality Glass.

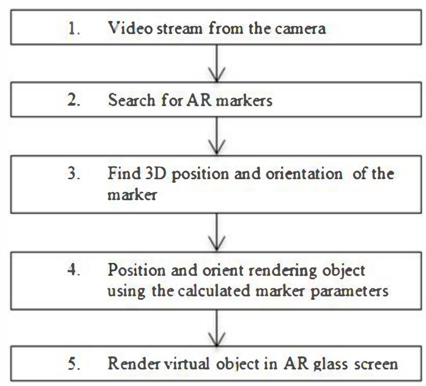

Figure 6. AR content creation using marker tracking diagram.

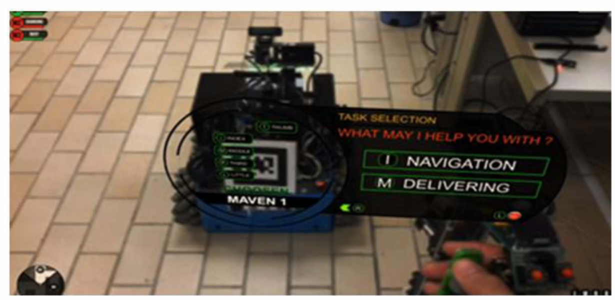

Figure 7. AR application on Epson Moverio BT-200.

In short, with the help of the new generation of AR glass, our interface can afford to provide a new intuitive, secure and convenient way to control the mobile robot which is an important improvement of our interface in comparison with previous projects.

C. Multimodal Handheld Device

As mobile robot is being used in many different tasks and scenarios, its operation mode can vary from autonomous, semi-autonomous to manual control by users. This demands our interface to have the features that allow the main user to perform the following requirements.

- Monitor the operation of the robot and intervene if necessary.

- Control the robot manually or semi-autonomously depending on the tasks and working scenarios.
- Help the robot to finish the task in a semi-autonomous scenario.
- User-friendly and convenient even if the user is wearing safety clothes.

These requirements have inspired us to design a novel handheld device as an extension to the previous human-mobile robot interface. It is important to keep in mind that this device must allow users to send commands to robot naturally regardless of the industrial working environment constrains. Consequently, the following input modalities are incorporated into the device.

- Hand gesture mapping.
- Haptic buttons.
- Laser pointer.

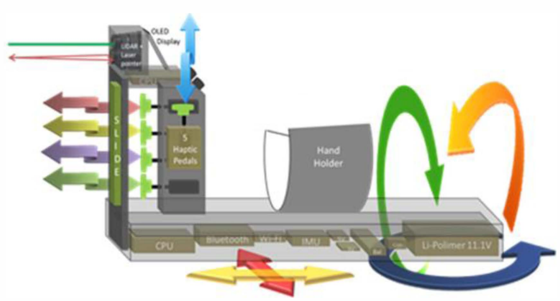

Figure 8. A sketch of our handheld device.

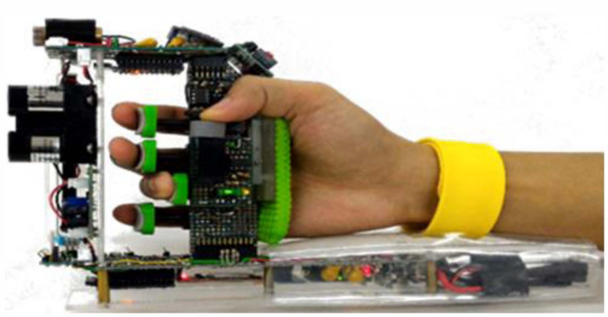

Figure 9. The first prototype of the handheld device.

Using hand gesture is considered to be a naturally way to interact with the robot as we use hand gesture to express our thinking every day. To press or to release a haptic button is a simple, reliable and intimate process for both novice and expert users. Furthermore, people get confused sometimes while receiving the target for a task or a process from others. As a result, they normally point directly to the target to make it more intuitive for others to understand their information. This explains why laser pointer will be extremely natural and useful for the interaction between human and mobile robot. All of the mentioned features are taken into account, designed and implemented in the one-handed wearable device shown in Fig. 7. A lot of sensors are included to support these above interaction modalities. A green laser pointer is attached on top of the device for pointing action. A 10-degree of freedom inertial measurement unit (IMU) is embedded and programmed for mapping human gesture to robot operation. Five haptic buttons corresponding to five fingers are designed and arranged for controlling the system. With all of these function integrated into one device, the system provides the users the option to choose and combine these comfortable inputs to perform their industrial tasks. Fig. 8 shows our sketch for the multimodal handheld device while Fig. 9 introduces our first prototype.

It is also important to notice that the device allows the main user to control it with only one hand which can greatly enhance the safety for the operator during an industrial task. Fig. 10 provides a detailed hardware description with all components used in our first prototype.

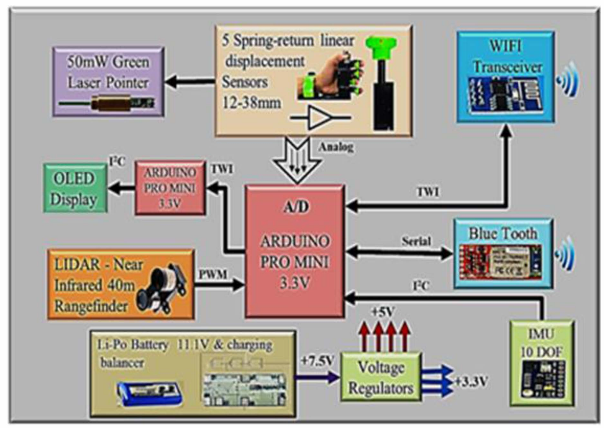

Figure 10. The handheld device hardware block diagram.

In summary, a novel multimodal handheld device is presented for the interface between human and mobile robot. The device is conceptualized and implemented to enable the transfer of different input modalities from human to robot. The device can be used not only in the scenario of human – mobile robot interaction but also other industrial contexts.

D. MAVEN Robotic Platform

For this project, the MAVEN robot [11] is chosen to interact with human in our framework. This holonomic mobile robot contains 4 mecanum wheels which allow it to move forward with a limited speed of 0.6 meters per second. The maximum rotational speed that MAVEN can achieve is about 0.9 radians per second. A minicomputer is attached to the robot to control robot navigation functions and other peripheral services. The embedded computer runs the Robotic Operating System (ROS) which contains many libraries for mobile robotic platform. Various sensors are integrated to support robot's operation including a camera module, a Hokuyo laser rangefinder, an MJPEG server, a path planning and navigation module. Especially, the laser – based writer that is mentioned before is attached on top of the robot as illustrated in Fig. 11. With this configuration, this robot will be able to project its moving directions, shows its warning signs or displays its current status while working in an industrial context. The operation of this system explains why it is call "spatial augmented reality" since it is capable of augmenting the surrounding environment with visual information generated from a computer system. The technology provides an intuitive way to enhance the safety of people sharing the same working environment with the robot as they are able to observe and predict the robot motion which allows them to adjust their action to avoid any potential collisions. Fig. 12 shows an example of using this mobile robot – laser writer system to project texts on the floor

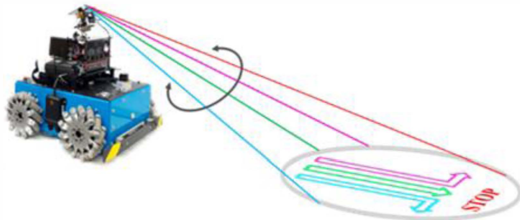

Figure 11. MAVEN robot is equipped with a laser writer.

Figure 12. MAVEN projects its current status "STOP" on the floor.

E. Human-Robot Dialog

With two different channels of communication for two different types of target user, two kinds of dialog are applied to the interface.

1) Mobile robot – Passer-by users interaction using SAR: In this category of interaction, our main task is to assure that people in the surrounding environment is aware of what the robot is doing and respond with the correct actions. Therefore, it is important for the robot to clearly project information that is easy to understand even if people see them for the first time. There is work [1] shown that shape like arrows are extremely useful for robot to indicate its intentions to human.

2) Mobile robot–Main User interaction using See-through AR glass: This interaction method requires the main user to take responsibility for providing robot with input parameters in order to perform the task. In the traditional models of interaction, the main operators are required to have expert knowledge so that they are able understand and take care of every individual steps to complete the task while the robot only takes a role as a "servant" who accepts all the information from the user and performs the task. On the contrary, in our framework, the role of the robot will be enhanced to become a competent "partner" to the human and we call this a "Master-Partner" relationship. This idea will be implemented in the form of robot providing task suggestions to the user at every phase of the process. This approach will allow novice users to control the interface properly even if it is their first time.

IV. Experiments

The completed setup for this framework is shown in the Fig. 13.

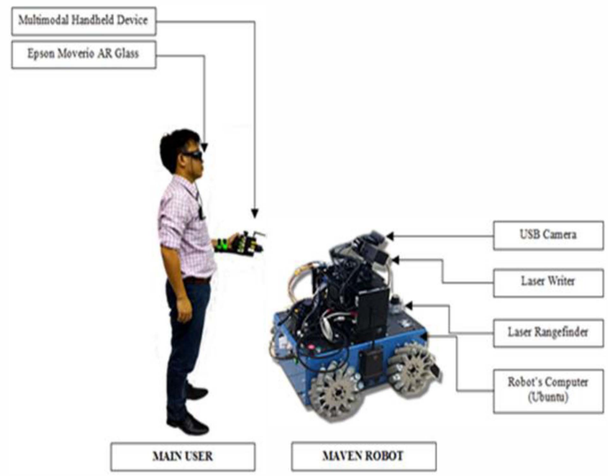

Figure 13. The implementation of the proposed human-robot framework.

In the developed interface, all of the designed and implemented components are aimed to facilitate the communication between human and mobile robot. As illustrated in Fig. 13, the main user is equipped with two main devices:

- Multimodal handheld device.
- Augmented reality glass.

On the other side, the MAVEN robot is equipped with a laser writer to project augmented information. With this setup, the main user is able to control the robot via see-through augmented reality glass and wearable handheld device while the robot can communicate with people working in the same environment using laser-writer spatial augmented reality. For demonstration purposes, the interface is used to perform two simple tasks in navigation: manual navigation with visual feedbacks and semi-autonomous navigation with visual feedbacks.

TABLE I. List of Commands the Main Operator Can Perform with the Handheld Device to Control MAVEN and the Corresponding Responds from the Mobile Robot

Operator	**Robot**	
	Robot's movement	***Robot's projection***
Rotate left	Turn left	Turn-left arrow
Rotate right	Turn right	Turn-right arrow
Press index button	Move forward	Forward arrow
Press both index and middle buttons	Move backward	Backward arrow

A. Manual Navigation with Visual Feedbacks

In this demo, the main target is to illustrate the following processes:

- The main user configures and manually controls the mobile robot using see-through technology and the handheld device.

- MAVEN robot sends feedbacks to passer-by people by projecting laser graphics on the floor

With the embedded IMU sensors and haptic buttons, our interface allows the main operator to perform the following actions to control the mobile robot as shown in Table I.

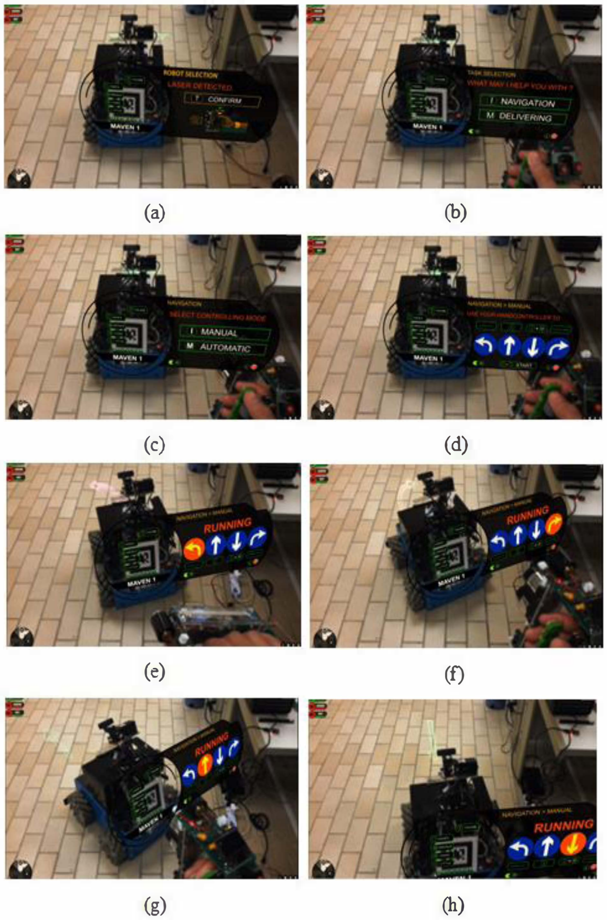

Figure 14. The demonstration of manual control task using the proposed interface framework: (a) Select the robot with thumb button. (b) Select the task. (c) Choose the navigation mode. (d) Manual mode instructions. (e) Turn the robot to the left. (f) Turn the robot to the right. (g) Move the robot forward. (h) Move the robot backward.

The images in Fig. 14 describe the manual control process in more details. In 14(a), a marker is attached to the robot as the reference position for displaying augmented reality contents. With the help of the augmented reality glass running on our augmented reality application, the main operator will be able to see a GUI which displays detailed instructions of how to select tasks and control the robot. In this image, the robot suggests the user to press thumb button to confirm his decision to take over this robot. In 14(b), the system suggests possible tasks that can be performed by the robot. Also, the user can press the index finger to choose the navigation task or middle finger for choosing the delivering task. In the next step, the system asks the user to identify the controlling mode for the navigation task as shown in 14(c).

In 14(d), a menu with some arrows is displayed in the AR glass as the user has chosen to use the manual mode. In this setting, the user is instructed to use the mention actions in table 1 to control the robot. The robot's intention will be displayed by two communication channels: AR glass and laser writer. Fig. 14(e), 14(f), 14(g), 14(h) show the robot turn left, right, move forward and backward under the control of the user. While the laser writer projects the corresponding arrow on the floor, the augmented reality glass highlights the correct icon for robot navigation. As a result, both main user and passerby people are aware of the operation status of the mobile robot. This demonstration has shown the capability of our proposed interface to divide the system information into two different channels and direct them to different targets to improve the security level for the human-robot interaction process.

This demo also illustrates how gesture mapping and haptic buttons are useful in combination with augmented reality technology to finish an industrial task. In the next demo, we will show how the laser pointer input takes an important role in defining the input parameter for the human-robot interface.

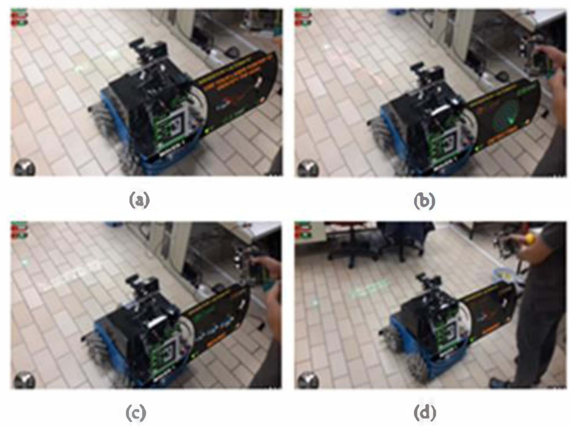

Figure 15. The demonstration of semi-autonomous operation mode with laser pointer input: (a) Semi-autonomous mode instructions. (b) Use laser pointer to choose a goal point. (c) Robot moves to the goal point. (d) Robot stops at the goal point and project its "FINISH" status to the floor.

B. *Semi-Autonomous Navigation with Visual Feedbacks*

In this second demo, the idea is to illustrate the use of laser pointer input from the main user to perform a task in a semi-autonomous scenario. Basically, the main user needs to use the laser pointer to identify a goal point for MAVEN. The robot will then project appropriate visual feedbacks and move to the destination. With see-through augmented reality system, the operator can select this mode of operation in the same manner as demonstrated in the first demo. However, the instruction on how to control the robot will be different. In 15(a), the AR glass shows that the robot is in semi-autonomous control mode, and it suggests the user to provide a goal point input using the laser pointer. In 15(b), the main user is providing a goal point by turning on the laser pointer and holding the index finger button in the pressed state. A feedback arrow from the laser-writer is projected and follows the laser dot thanking to the camera sensor attached on top of the laser-writer. This is an intuitive way to guarantee that the mobile robot is correctly receiving destination information from the user. In 15(c), the user pressed index and middle finger at the same time according to the instruction to confirm his goal point. As a result, the robot status changed to "MOVING" which was updated in both AR glass and on the floor. Finally, the robot stopped shown in 15(d) and projected "FINISH" word on the floor and waiting for the next instruction from the main user.

In this section, our implemented interface has shown how it can be used to help human to interact with mobile robot in a specific industrial scenario with some experimental results. The handheld device is also under further development to make it lighter, nicer and contain more inputs for different industrial tasks.

V. Conclusion

A novel framework is introduced which is capable of solving the current limitations in current human-mobile robot interaction interface. The system proposes the use of a powerful laser writer that can project very clear graphics in both indoor and outdoor environments. Although many see-through augmented reality and spatial augmented reality interfaces have been developed in recent years, a system that utilizes both technology has never been investigated before which makes our work novel. The security level of the interface has been improved as augmented reality information is divided into two different channels. Also, the awareness of people sharing the same working environment with the mobile robot is enhanced with the help of the implemented laser writer. The system is able to suggest available options to the human and wait for the selections from the human. This approach is considered to be a more user-friendly alternative to that of inputting the entire task's parameters using the traditional mouse and keyboard. Multimodal one-handed device is also presented as a solution for the current industrial constrains where human operators are required to wear protection equipment and avoid using two-handed to manipulate a Human-Interface-Device (HID) such as teaching pendants.

In future work, we will conduct a usability testing to evaluate the effectiveness of our interface and further improve the proposed framework using user's feedbacks.

Acknowledgment

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References

[1] Michael D. Coovert, Tiffany Lee, Ivan Shindev, Yu Sun, "Spatial augmented reality as a method for a mobile robot to communicate intended movement," Computers in Human Behavior, vol. 34, May. 2014, pp. 241–248, doi:10.1016/j.chb.2014.02.001.

[2] T. Sasai, Y. Takahashi, M. Kotani and A. Nakamura, "Development of a guide robot interacting with the user using information projection — Basic system," 2011 IEEE International Conference on Mechatronics and Automation, Beijing, 2011, pp. 1297-1302, doi:10.1109/ICMA.2011.5985849.

[3] R. T. Chadalavada, H. Andreasson, R. Krug and A. J. Lilienthal, "That's on my mind! robot to human intention communication through on-board projection on shared floor space," 2015 European Conference on Mobile Robots (ECMR), Lincoln, 2015, pp. 1-6, doi:10.1109/ECMR.2015.7403771.

[4] X. Zhang, G. Chen, H. Liao, "High Quality See-Through Surgical Guidance System Using Enhanced 3D Autostereoscopic Augmented Reality," in IEEE Transactions on Biomedical Engineering , vol.PP, no.99, pp.1-1, doi:10.1109/TBME.2016.2624632.

[5] S. Tano et al., "Simple augmented reality system for 3D ultrasonic image by see-through HMD and single camera and marker combination," Proceedings of 2012 IEEE-EMBS International Conference on Biomedical and Health Informatics, Hong Kong, 2012, pp. 464-467, doi:10.1109/BHI.2012.6211617.

[6] Chunjia Hu, Guangtao Zhai and Duo Li, "An Augmented-Reality night vision enhancement application for see-through glasses," 2015 IEEE International Conference on Multimedia & Expo Workshops (ICMEW), Turin, 2015, pp. 1-6, doi:10.1109/ICMEW.2015.7169860.

[7] Z. Zhu et al., "AR-Weapon: Live Augmented Reality Based First-Person Shooting System," 2015 IEEE Winter Conference on Applications of Computer Vision, Waikoloa, HI, 2015, pp. 618-625, doi:10.1109/WACV.2015.88.

[8] Y. Lee, K. Masai, K. Kunze, M. Sugimoto and M. Billinghurst, "A Remote Collaboration System with Empathy Glasses," 2016 IEEE International Symposium on Mixed and Augmented Reality (ISMAR-Adjunct), Merida, Yucatan, Mexico, 2016, pp. 342-343, doi:10.1109/ISMAR-Adjunct.2016.0112.

[9] R. S. Andersen, S. Bøgh, T. B. Moeslund and O. Madsen, "Intuitive task programming of stud welding robots for ship construction," 2015 IEEE International Conference on Industrial Technology (ICIT), Seville, 2015, pp. 3302-3307, doi:10.1109/ICIT.2015.7125587.

[10] T. Matsumaru, "Mobile Robot with Preliminary-announcement and Display Function of Forthcoming Motion using Projection Equipment," ROMAN 2006 - The 15th IEEE International Symposium on Robot and Human Interactive Communication, Hatfield, 2006, pp. 443-450, doi:10.1109/ROMAN.2006.314368.

[11] Wee Ching Pang, Gerald Seet, and Xiling Yao. 2013. A multimodal person-following system for telepresence applications. In Proceedings of the 19th ACM Symposium on Virtual Reality Software and Technology (VRST '13). ACM, New York, NY, USA, pp. 157-164. doi:10.1145/2503713.2503722

[12] S. P. Osorio, L. M. Aristizábal and C. A. Zuluaga, "Development of a command interface based on handheld devices for remotely operated vehicles," 2016 IEEE Colombian Conference on Robotics and Automation (CCRA), Bogota, 2016, pp. 1-5. doi: 10.1109/CCRA.2016.7811422

[13] A. Agarwal and M. K. Thakur, "Sign language recognition using Microsoft Kinect," 2013 Sixth International Conference on Contemporary Computing (IC3), Noida, 2013, pp. 181-185. doi: 10.1109/IC3.2013.6612186

[14] M. Mohandes, S. Aliyu and M. Deriche, "Prototype Arabic Sign language recognition using multi-sensor data fusion of two leap motion controllers," 2015 IEEE 12th International Multi-Conference on Systems, Signals & Devices (SSD15), Mahdia, 2015, pp. 1-6. doi: 10.1109/SSD.2015.7348113

[15] C. A. Grimaldos-Trillos, S. N. Moreno-Lizarazo and S. A. Salinas, "Electronic glove for rehabilitation exercises controlling a mobile robot," 2013 Pan American Health Care Exchanges (PAHCE), Medellin, 2013, pp. 1-4. doi: 10.1109/PAHCE.2013.6568263

[16] P. Rouanet, J. Bechu and P. Y. Oudeyer, "A comparison of three interfaces using handheld devices to intuitively drive and show objects to a social robot: the impact of underlying metaphors," RO-MAN 2009 - The 18th IEEE International Symposium on Robot and Human Interactive Communication, Toyama, 2009, pp. 1066-1072. doi: 10.1109/ROMAN.2009.5326260