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# Augmented Reality Interface for Taping Robot*

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***Abstract* - Applying masking tape to a particular area is a very important step for protecting an uninvolved surface in processes like mechanical part repairing or surface protection. In the past, the task was very time-consuming and required a lot of manual works. In recent years, with some advances in the fields of automatic robotic system and computer vision, the task now can be completed with the help of an automatic taping system containing a 3D scanner, a manipulator and a rotating platform. This implementation has been proved to provide better quality and be at least twice as fast as comparing to the work done by a human operator. However, there are still some limitations of this setup. First, it is difficult for the user to monitor the taping process since the system uses the 3D scanner to reconstruct the surface model and there is no calibrated projector to overlay the manipulator's trajectory over the real surface. Second, the main user is supposed to use a computer with keyboard and mouse to identify the area for masking which requires some expert knowledge and might not be appropriate in an industrial context where people wear protective equipment such as gloves or helmet. This paper introduces the use of spatial augmented reality technology and wearable device in the semi-automatic taping robotic system and the related calibration algorithms to enhance the user experience. The framework and its components are presented, with a case study and some results.**

***Index Terms - Human-Robot Interaction, Laser Writer, Taping System.***

## I. Introduction

Taping System had been deployed in various industrial scenarios such as surface protection or plasma spraying to cover the uninvolved or undamaged surface area. With the recent development of sensor technology and advanced algorithms, the system now can automatically perform the entire masking process without seeking the help from the main user.

The automatic taping system, which has the potential to increase the productivity of many industrial processes, poses some limitations in term of human-robot interface. Firstly, since the robot can only identify the area of the work-piece using a 3D scanned model stored in the computer software system, there is no opportunity for the user to directly view the trajectory or the taping area the robot is going to cover on the real object. The information overlaying process is very important in a human-computer interface because it allows the user to intuitively monitor the intention of the robot and intervene if there is some misunderstanding during the masking process. This problem can be solved using the technology called "Spatial Augmented Reality" [1]. The main idea of this technology is to use a calibrated projector to overlay the computer-generated information over the real scene or real object. This approach has been proved to provide significant impact on how human and robot behave when sharing the same working environment. Some typical applications of this technology are in shipping industry [2], navigation of autonomous mobile robot [3], guiding robot in a museum [4] or material transportation in an industrial site [5]. Secondly, although the main taping process is automatic, the system still needs some initial inputs from the main operator, this lead to another limitation of the current interface. In some industrial scenario such as shipping industry or material transportation, the operator is supposed to wear protective equipment including gloves or helmet which are very inconvenient to control the taping system using traditional devices such as mouse and keyboard. As a result, a new handheld device will be introduced to the interface that can be an alternative to the current input devices. Furthermore, using mouse and keyboard to define the input parameters for the system might require the user to have some expert knowledge of the operation of the system which is unnatural and difficult for the new user. On the other hand, defining the taping area directly on the real surface is easy and very natural for all users. With the help of our new handheld device which contains a lot of sensors such as a laser pointer, haptic buttons or gyroscope, the user can define the initial input directly on the real workpiece which is a simple and intuitive task.

In short, with the help of our proposed interface, the operator now can define the trajectory to be taped by the manipulator directly on the real surface. Supported by knowledge of its position and calibration, the robot identifies suitable paths and presents the various taping information to the real surface using a laser projector while executing the task. This is a natural and intuitive interaction, and is similar to a human-to-human interaction.

## II. Related work

### A. Augmented Reality and Spatial Augmented Reality

Augmented Reality (AR) is the technology that allows computer-generated information to be overlaid over the real environment. Spatial augmented reality (SAR) is a category of AR which projects this type of information on the real scene or real objects. This technology normally requires a projector to be included to the system setup. This source of information has become an important channel of communication between human and robot in many industrial scenarios. In shipping construction field, some SAR systems are deployed to perform

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several automatic processes such as stud welding or hull painting. In navigation field, there is some research involving using mobile robot with SAR system for guiding people by projecting instructions on the floor or on the wall. AR and SAR also turn out to be extremely useful for building interfaces that provide instructive information [6][7] since they allow users to focus on their task while following the instructions from the overlaying graphics.

### *B. Multimodal Human-Robot Interaction (HRI) Interface*

In the past, HRI is normally designed for controlling robots using graphical user interface elements in computer platform [8]. Then, with the development of mobile system, movable systems such as tech-pendant [9] or tablet [10] are specially designed to facilitate the control of a robotic platform. However, in current industrial context, there are some constrains that make it inconvenience or even impossible for people to interact with these input devices. As a result, there are some researches concerning about creating a new interface for the interaction between human and robot in industrial contexts. One typical trend is to use hand gesture and vision system to control the system [11]. Another trend involves deploying a handheld device with attached sensors for capturing human command [12].

As robot is becoming more popular and sharing the same working environment with people, the human-robot interface also needs to be improved more not only to reduce the programming effort but also to enhance the role of the robot in the interaction with human. In particular, robot is no longer behaves as a “slave” but as a “partner” in the robot – human relationship

### *C. Automatic Taping System*

Masking a surface is an important step in many industrial processes. The main idea is to isolate and protect the covered area from the main task. Normally, a 3D scanning model of the taping object is investigated and reconstructed using a depth camera. This kind of model has been used in other surface treatment tasks such as laser coating removal or spray painting. A rotating platform is manipulated to hold the taping work piece. Finally, a robotic platform is configured and calibrated so that its end-effector is able to handle taping task for objects with different shapes and orientations.

## III. METHODS

### *A. Laser System with Multimodal Handheld Device*

To make the interface become user-friendly for non-expert users, the important idea is to provide as much instructive information as possible while concealing the complex configuration and programming parameters. For the robot taping scenario, our proposed method relies on a powerful and bright laser writer to create spatial augmented reality on the real object and a multimodal handheld device to provide commands from the main operator the taping system.

*1) Laser Writer*: To create laser graphics, two tiny computer-controlled mirrors aim a beam at a suitable surface. The beam bounces first off of one mirror moving horizontally, then off another at right angles, moving vertically. Such system consists of an electromagnet and a constant magnet mounted on the same axis with a mirror. When the current in the coil changes, a constant magnet interacts with the magnetic field of the coil, and turns the shaft with the mirror to an angle proportional to a coil current. Combining two galvanometer scanners, in orthogonal planes, allows the control of a laser beam positioning onto a surface, as shown in Fig.1.

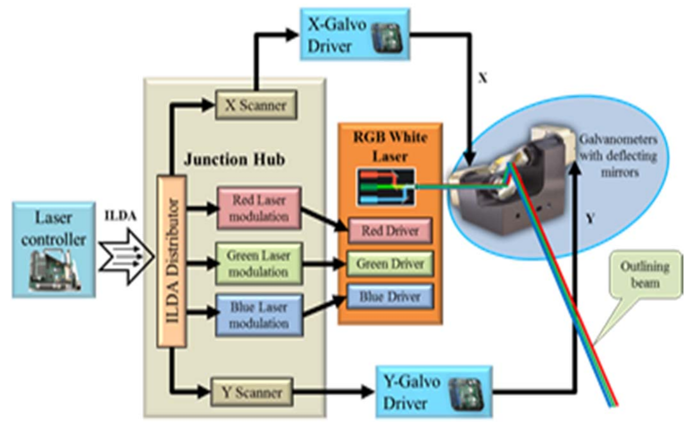


Fig. 1 Laser writer functional block diagram.

The computer “connects the dots” by aiming the mirrors from one place to another, sufficiently fast that the viewer sees only a single outline drawing. This process is called “scanning” and computer-controlled mirrors are galvanometer “scanners”. The scanners move from point to point, at a rate of approximately 30 to 40 kbps. To add more detail to a scene, additional sets of scanners can be used to overcome the limitations in scanning speeds. Figure 4 provides a schematic of the implemented system. A white RGB laser consists of red, green and blue lasers each with an individual driver. These three laser diodes are able to compose a powerful white beam. The drivers control the intensity of each laser. Red, green and blue laser beams are mixed in the transparent mirror system and subsequently projected to the mirrors of the galvanometers.

An ILDA (International Laser Display Association) interface allows the import of custom graphics, text, and effects into laser animation. Files containing vectorial pictures or videos are loaded to the graphic controller in a special format. The control software converts these files into the flow of points, each of which is characterized by the angular deflections of galvanometers in the vertical and horizontal planes. The intensity of lasers radiation is also controlled. The ILDA laser control standard produces a sequence of digital-to-analog converter (DAC) outputs on differential wire pairs. When the galvanometers receive new values, for mirror deflections, it drives the mirrors to the desired angular position. The following images show some results of projecting rectangle images on the taping object using the laser writer running the embedded image generation software.

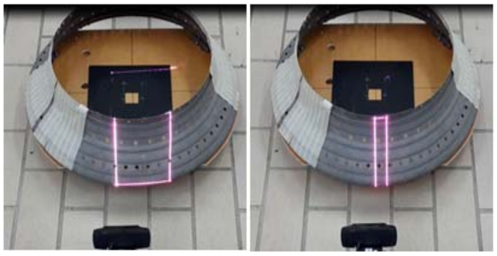

Fig. 2 Projecting rectangle images using laser writer.

*2) Multimodal Handheld Device*: The difficulty of designing the interacting device for people working in an industrial environment is that the handheld tools must allow users to send command signal to robot naturally and intuitively while still wearing protective equipment. With this idea in mind, the below one-handed wearable device below is implemented and used for industrial applications. This device contains a lot of sensors that support many interaction modalities such as a laser pointer for pointing, an IMU (Inertial Measurement Unit) for gesture recognition, haptic buttons for pressing or giving command and a laser ranging sensor for measuring distances. Our idea is to include as many sensors as possible so that users can choose to interact with industrial system the way that is the most convenient for their tasks. Figure 3 shows our first prototype of the wearable device with some descriptions of the sensor's functions. Figure 4 describes the device in details with all the hardware components used. A cover is also specially designed that can fit nicely to the human hand to make the user feel comfortable while using it.

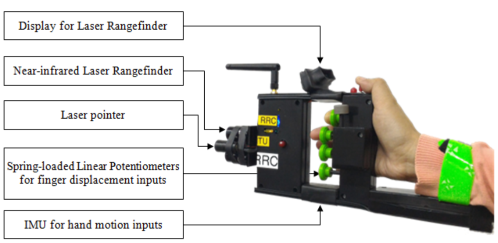


Fig. 3 The first prototype of the handheld device.

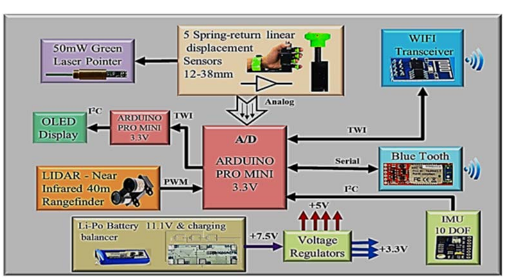


Fig. 4 Handheld device hardware block diagram.

In this section, a novel multimodal wireless single-handheld device is presented that incorporates 5 spring loaded finger paddles, a 9-axis inertial measurement unit, haptic force-returning finger-displacement pedals inputs, a laser pointer and a laser ranging LIDAR. The IMU forms the basis for hand motion gesture input and the pointer allows the user to identify target for the robot. The rangefinder assists in user localization. The device was conceptualized to solve the problem of human interface device (HID) in an industrial scenario where the hands of human operators are gloved and the use of double-handed HIDs viewed as undesirable from safety considerations.

### B. *Wearable Transparent Display*

The Epson Moverio BT-200 is a wearable device with a binocular ultra-high resolution full color display. It incorporates a front facing camera and motion sensors. The motion sensors capture head motion and the camera supports target tracking in the observer's field of view. The device is depicted on the human operator, in figure 5. Wearing the device allows the user to view his environment as well as any augmented data that may be generated, over the real-world scene. Through the display, the robot system can provide status information and selection menus for the operator to select.

### C. *Automatic Taping System*

The system includes a 3D scanner for the 3D model reconstruction, a part fixing platform, a taping robot and the robot taping tool. A part fixing platform is used to mount the parts for taping. This platform can either be a simple fixed base or a rotating platform. The special design of the end-effector is required to meet the proper taping requirement. Meanwhile, the mechanism for cutting and holding the tape is also needed to accomplish the taping process. This detailed implementation of this system is mentioned in this paper [13]. This work will focus more on improving user interface as well as user experience for this taping system. The figure below shows the detailed setup the current taping system.

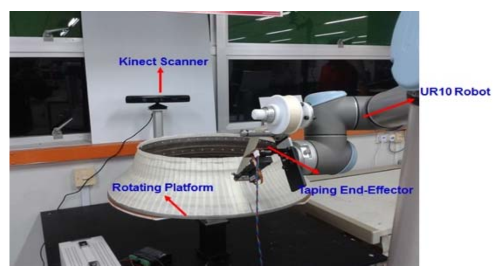


Fig. 5 Automatic Taping System.

### D. *Taping Path Programming using See-through and Spatial Augmented Reality*

This section describes the interactions between human and robot using the mentioned human-robot interaction interface, for the task of guiding the robot taping process. Robot taping is to cover the work-pieces' surfaces using masking tapes. In such work, the 3D models of the work-pieces are scanned so that path planning for the masking process with proper taping tools is possible. While, since the only certain area of the work-piece needs to be taped, indicating the area selection efficiently is very useful. The laser writer and handheld device system are directly useful for such application. The interfacing device, the taping system and a 3D vision measurement setup need to be well arranged in a workspace in such implementation. The interfacing device can project different patterns with variation of sizes, different colors and different animation patterns to indicate different robot strategies. The taping robot is able to locate the vision system (a Kinect Camera for 3D measurement) and calibrate the camera coordinate with respect to the work-piece platform coordinate. This vision system is used to detect the projected image and input the 3D information into the computer. The following steps describe the whole process.

*Step 1: The video cameras take images and calculate the positions of the projected shape.*

Assume the vision system's output is a set of the coordinates of the projected points (sequentially provided) $P_1$, $P_2$, … $P_n$. Given the coordinate transformation from the workpiece system to the camera system $T_{cw}$, the marked points $P_{w1}$, $P_{w2}$, … $P_{wn}$ on the workpiece can be calculated from the following equation,

$$[P_{wi};1] = T_{cw}[P_i;1].$$

The accuracy of the point estimation depends on the accuracy of the coordinate transformation, the vision measurement accuracy, and the width of the projected lines.

*Step 2: The estimated points should be matched with the work-piece model.*

The estimated points should be projected to be on the work-piece model using a numerical method (find the nearest mesh and interpolate a best estimation of it). Then, the marked area of the work-piece surface is known.

*Step 3: Provide initial Guess of the taping starting and ending points using the point function.*

Besides the area selection, the initial guess of the starting and ending position for each tape segment need to be provided in current surface covering method. The pointing functions of the device can be used for this purpose. The accuracy of the point estimation depends on the accuracy of the coordinate transformation, the vision measurement accuracy, and the size of the spot.

*Step 4: Execute the taping process.*

At this point, the system has enough information from the user to begin the masking task as usual. The diagram in figure 6 summarizes the entire process of a taping task.

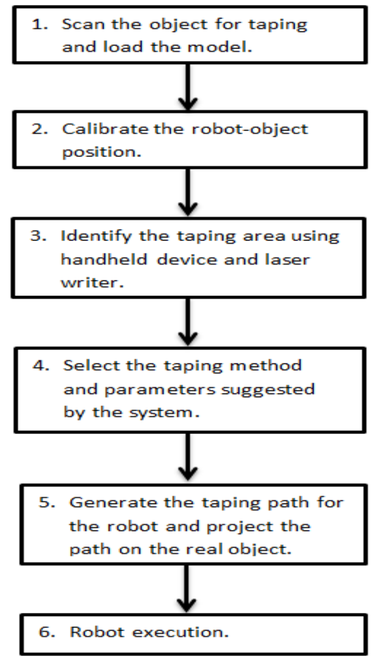


Fig. 6 The workflow of the taping task.

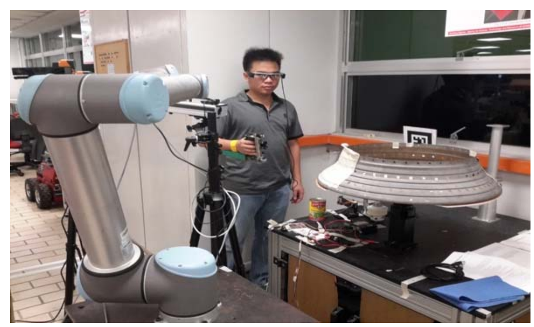

Fig. 7 The proposed system setup.

## IV. Results

The completed setup for this project is shown in the following figure 7. The main user is equipped with an Epson BT-200 see-through augmented reality glass and the hand-controller while the laser projection system is calibrated and added to the taping system. A marker is attached at the side of the taping platform for overlaying graphical information over the real environment. The main user will be able to control the whole system by looking at the instruction displayed at the marker using the see-through glass. The images in figure 8 illustrate the taping process in details. In 8(a), with the help of the see-through glass, the graphical instructions are displayed at the marker position. This approach will allow the system to provide the operator instructive information to complete the taping process

. In this figure, the user is asked to select the desired task for the robot to perform using the corresponding finger button in the handheld device. Here, the user pressed index finger to choose the taping task. In 8(b), the system suggests taping methods that is available to the robot. For demonstration purpose, we choose to tape a square area and pressed index finger button to confirm. Next, since the system normally requires a starting and an ending point to identify the square taping area, the system is asking the user to identify a starting point as shown in 8(c). Figure 8(d) shows the user selecting the starting point by using the laser pointer. In 8(e), the system confirms the user's starting point selection by projecting a small red circle laser dot at the user selected position using the laser writer. This provides intuitive and important feedbacks to the user to confirm his command. Similarly, the user can identify the endpoint for the taping process with the green laser pointer while the laser writer projects these points on the work-piece for confirmation as shown in figure 8(f) and 8(g).

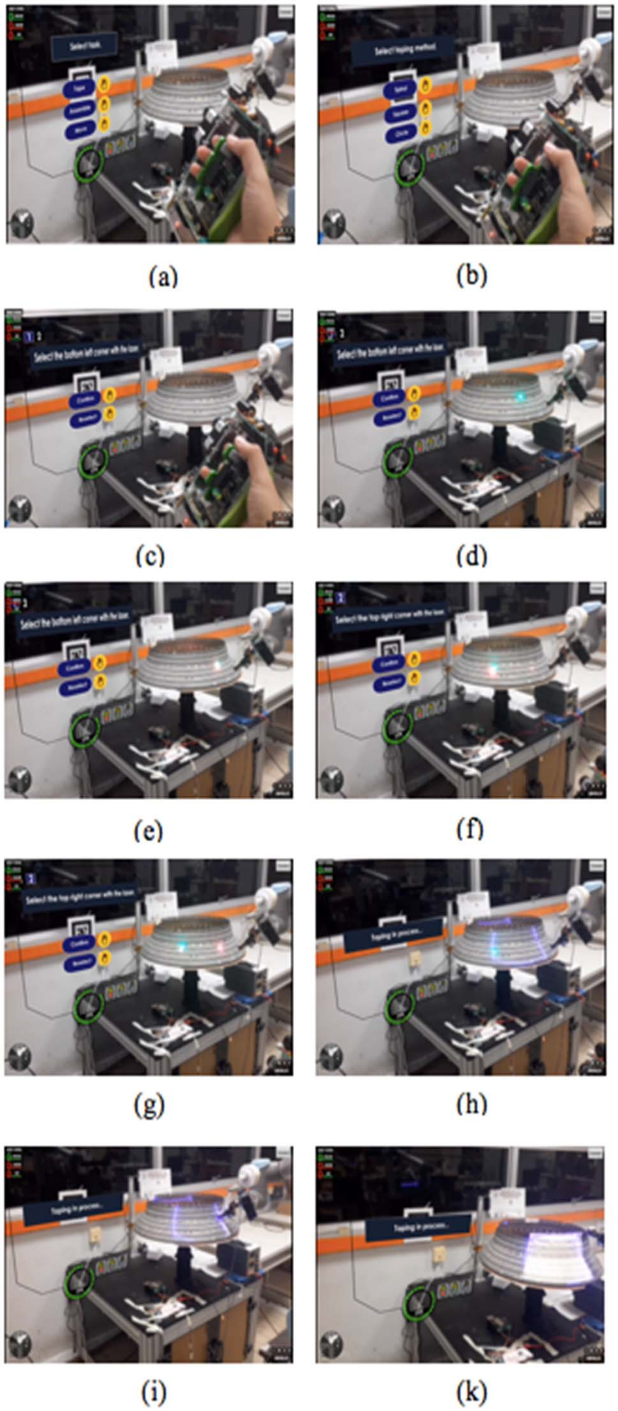


Fig. 8 The demonstration of taping a particular area using the proposed interface framework: (a) The system is displaying the task options available for the robot, the user selects the taping task using the index finger buttons. (b) Select the square taping method using the middle finger button. (c) The system asks for the taping starting point. (d) Identify the starting point with laser pointer. (e) The laser writer projects the starting point to the work-piece. (f), (g) Select the taping ending point. (h) Project the desired taping area to the work-piece using the laser writer. (i), (k) Robot performs the taping process.

Finally, in figure 8(h) the system projects a laser image showing the area of the work-piece which is going to be taped while the see-through glass says that the taping process is starting. Figure 8(i) and 8(k) show the robot arm taping the projected area of the object. This demonstration has shown the capability of our proposed interface to enhance the user experience with robot taping system by allowing instruction information to be overlaid over the real working scenario which can greatly improve the user-friendliness of this human-robot interface.

## V. CONCLUSIONS

A new paradigm was proposed, which promises to enhance the user experience in the automatic taping scenario. In the scenario, we envisage selecting different type of taping and identify the taping area directly using the real object, with the assistance of the robot system by providing instructions on taping area identification process. Options are presented to the human, and selections are made from the available options to complete the whole task. This is viewed as a more acceptable alternative to that of programming the entire taping task using a mouse and a keyboard.

Graphic menus and augmented reality information were deployed, in a non-immersive environment to better provide the human with options and information on the real working scenario. This allows the deployment away from the traditional constraints and promises a faster “training” cycle with its human centric approach. In an industrial setting, where the human operator may be wearing gloves and unable to use both hands to manipulate a Human-Interface-Device (HID), gestures via a multi-modal device would be an option of choice.

## ACKNOWLEDGMENT

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