Increasing Stability of Mark Projections on Real World with Angular Velocity Sensor

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***Abstract*— There are varieties of methods for realizing the augmented reality. For example, there is a method to display augmented information and video information on a single display using augmented reality markers. However, this method needs the users to look at the display. In order to share same information among multiple persons, everyone should look at the displays that show the same image. Projection type augmented reality solves this problem. Projection type augmented reality is the method projecting augmented information on the surfaces in the real world using projectors. A projection type augmented reality proposes augmented information to the real world. Every person can share the experience at the environment. However, the method needs many preparation works and enormous energy for freely projecting images. It can work on only limited conditions, such as indoors or at night. Our research solves these problems. We propose a method that works in a head-worn type equipment using the method of projection type augmented reality. It recognizes an object from the camera images. It projects a mark that carries a little information onto a recognized object. There is an error of the position where the mark projected when the equipment moves. We decrease this error using an angular velocity sensor. We propose the method, the implementation and the experiments for evaluating the performance.**

Keywords—augmented reality; projection; angular velocity sensor;

I. INTRODUCTION

Augmented reality (AR) is the technology to create a “next generation, reality-based interface” and is moving from laboratories around the world into various industries and consumer markets [1]. In cooperative works, all members must carry devices that show the same information. The device may be a head-worn type or a hand-held type. However, in many cases, it is difficult to carry the devices that communicate among them. In the cases, the projective AR works well. All members may share a single device. This enables to make a very simple system comparing the system based on the personal device.

Many projective ARs work in many environments [2]-[5]. In the environments, all related devices share the proper places and have proper calibrations. This enables to make beautiful projection mappings. In cooperative working environments, we cannot control objects’ surfaces. We cannot place the devices at the proper places. The relation between the projector and the surface projected changes time by time. For instance, in connecting works, the connecting terminals must have their surfaces’ materials. On pure shining surfaces, we have no way to project proper images on the surfaces. However, almost all surfaces are the mixture of pure shining and pure matt. If there is a matt feature, we can project some kinds of images that our eyes can catch.

Our proposed system will not project beautiful images on a surface. The system will project a mark that catches a human attention. With the system, users may say ‘We move that one.’ This is the expansion of our pointing ability. This helps many kinds of cooperative work.

In many kinds of cooperative works, there is no proper place to set up the related devices about implementing a projective AR system. They are cameras and projectors. In many cooperative works, workers move in their working environments. In the case, the spatial projective type of AR system has many problems about the occlusions with the workers and related materials. A head-worn type of AR system eases this problem. Our proposed system selects a head-worn type.

Head-worn types of AR systems decrease the problems about the occlusions. However, there are problems about the delay between the image acquisition and the projection. Most of the projective AR systems presume no movement about related devices and objects. At non-projective types of AR systems, there is a little problem about the delay between the image acquisition and the image display. The created images are good with the delay. At projected types of AR systems, the delay between image acquisition and the projection influences the complex both of a projected image and a surface. The complex may be dirty to look. In some cases, the complex carries false information. For instance, in connecting works, the delay may cause the false terminal connection. In the non-projective types of AR systems, there is no chance of these errors. The displayed image may have some direction errors. However, the displayed image shows the proper terminal for connecting.

This paper proposes the stabilization of the marks projected on real objects with a head-worn type projective AR system. First, we discuss about the effects on the projected mark quality with translation and rotation of the proposed head-worn projective AR system. Then, we propose the compensation method about the rotation using the angler velocity sensor. Next, we show our implementation of the

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proposed projective AR system. Then, we show our experiments. And last, we conclude our work.

II. TRANSLATIONS AND ROTATIONS

The motion of a solid object is a combination of translations and rotations. Fig. 1 shows the three elements of rotations. Our head-worn projective AR system must include a projector and a camera. The system must include the projector that projects the proper image on an objective surface. It must include the camera that understands the environments around the projective AR system. The camera may be a normal color camera, a depth camera or some other types of sensors that understand the environments. The projector may be a normal image projector or some types of pointers that can show the understandable images on the environments.

If there is no change about the environment and there is a well description of the environment, the projective AR system excludes the camera for understanding the environment. However, our proposed head-worn projective AR system itself the part of the environment. If there is no object that moves or changes, the proposed head-worn projective AR system must move.

The motion of a solid object is a construction of the 3-dimensional translation and 3-dimensional rotation. When the size of an interesting object is much smaller than the size of our human, it makes the projected mark to move onto another object that is a little translation in the plane that is vertical with the line directed to the object.

The proposed head-worn projective AR system works well in the environments where the sizes of interesting objects are similar to the size of a human. In the environments, translation motions of a proposed projective AR system is not larger than the scale of the interesting objects. As a result, the effect about the translation motion is not important about the combination both of the projected image and the surface projected.

Rotation affects the combination of a projected image and a surface projected. The scale of the distance between the surface and the projector is similar to the scale both of an interesting object and a human. The direction of the projector affects the position of the projected image. For easing this problem, we propose the rotation compensation method using an angler velocity sensor.

III. PROPOSED ROTATION COMPENSATION METHOD

A. Understanding an environment and Making a projection.

Projective AR systems need to know and understand the environment. For cooperative works, the interesting objects must be known and found. Our application offers no clear image projected. However, the places of the interesting objects are important. With the images captured by a camera, our proposed system knows the relative positions of the interesting objects to the projector.

There is some delay from taking an image to understand the position of the interesting objects. We need some processing time for finding the interesting objects in the captured image. There is a delay from deciding the position of the interesting objects to making the projection of the proper image. We can decrease the delays with the help of expensive very high speed camera, expensive processors and special designed projectors. The total cost of a high speed system easily exceeds the benefit from the usage of the proposed projective AR system.

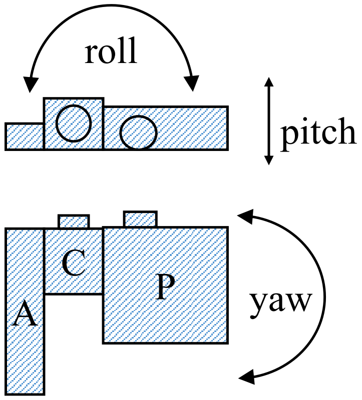

Figure 1. Rotations.

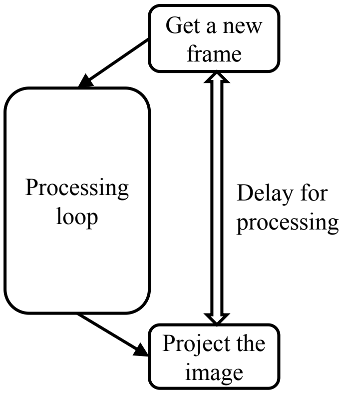

Figure 2. Delay and Processing

B. Processing loop of our proposed projective AR system

Without the rotation compensation, a processing loop of a normal AR system has three stages. They are capturing an image, processing the image and displaying a projection image. Using normal cameras, we can have an image at every 33 mS. We can create and display a simple mark at every 33 mS interval. However, for finding an interesting object, we need 100 mS at least in our PC. The PC has Intel Core i3 processor and 8 GB of RAM. Our object finder is based on the object finder included in the OpevCV distribution [2].

The object finder has some stages. They are a pre-processing, a feature description and a feature matching. At each processing stage, we need some processing time. We insert a processing for compensating the rotations. The size of the processing code is small. It is constructed from three function calls. They are a call for getting an elapsed time, one getting the measurement of an angler velocity sensor and one calculating the compensation amount of the rotations. Fig. 2 shows the overall relation between the processing and the delay about projections.

C. *Compensation of rotations*

We have the angular velocity using the angular velocity sensor. Fig. 1 shows the experimental device setup. In Fig. 1, 'A' stands for an angular velocity sensor. 'C' does for a camera. 'P' does for a projector. The light axes both of the camera and the projector are parallel. We call the rotation around the light axis as 'roll'. Fig. 1 shows the definitions of 'pitch', 'roll' and 'yaw' in our experimental system.

Our proposed device is a head-worn type. So, the motion of the device depends on the motion of a head. We can shake a head 10 times in 1S at most. In a normal movement, we shake a head one time in 1S. The processing loop needs about 0. 3S. If we have an angular velocity at each processing loop, we have three measurements of angular velocity in a second. In normal environments, these measurements may be enough for observing the head motions. In the processing loop, the projection position error depends on the movements from the image acquisition to the projection. In a single measurement of the pair of angular velocity and time, we cannot estimate the movement between the image capturing and the projection. At least, we need to have two pairs of measurements. With more measurements, the estimation of movements increases its precision. We try to measure the pair of time and angular velocity six times in processing loop. However, the measurements of angular velocity are discrete observation. We must interpolate the observations. There is no information between two successive measurements. We estimate the amount of rotations using the trapezoid interpolation that has no assumption about the measurements.

$$\mathrm{A} = \frac{1}{2}(t_1 - t_0)(a_0 + a_1) \tag{1}$$

In (1), A is the difference of the direction between the time t_0 and the time t_1. a_0 is the angular velocity obtained at the time t_0. a_1 is the angular velocity obtained at the time t_1.

With the movements of the projector and the surface projected, the complex of the projected image and the surface projected loses consistency. For keeping the consistency of the complex, we must compensate the movements of the projector and the surface projected. However, without the recognition of the surface projected from the captured image, we have no information about the movement of the surface projected. At least, we compensate the movement of the projector. In processing the captured image, we update the image projected with the movement of the projector that is measured with the angular velocity sensor.

With a captured image, we have the position of the object that we interest. We need to compensate the movement of the projector from the time when the image is captured to the time when the image is projected.

When we do not have the position of the object that we interest from the captured image, we must project the image with the recorded position of the object. In the case, the compensation of the movements of the projector is much important. With the measured angular velocity, we update the position of the image projected continuously.

IV. IMPLEMENTATIONS OF THE PROPOSED PROJECTIVE AR SYSTEM

A. *Component hardwares and softwares.*

The main components are a camera, a projector, an angular velocity sensor and a controlling computer. Fig. 3 shows the devices that construct the head-worn part. In Fig. 3, they are a projector, a camera and a Wii controller with Wii Remote Plus [7] as an angular velocity sensor, from left to right respectively. We use the camera that has a global-shutter. With motions, we cannot avoid motion blur. However, with a global shutter, we avoid the rotate distortions. The camera takes 1024x768 pixels images. In our experimental system, we use the small DLP projector for projecting a mark on the interesting object. The projector's angle of projection is 24 degrees in vertical and 38 degree in horizontal. The projected image is 1280x800 pixels. The weight is 0.8 Kg. For measuring the angular velocity, we use the Wii's controller. The controller has an acceleration sensor, an angular velocity sensor and a Bluetooth transceiver. The controlling computer is Windows PC with a Bluetooth transceiver. The processor is Intel core-i3. The PC has 8 GB memory.

We fix the camera, the projector and the sensor. The distance between the camera and the projector is smaller, the control of the projection is easier. We place the projector's lens and the camera side by side. There is no distortion on the angular velocity sensor with the distance from the projector.

Fig. 1 proposes the proposed experimental system. The experimental system needs the wired connections about the camera. It needs a power cable also. As a result, the experimental hardware is difficult to use in head-worn. The direction of the camera and the direction of the projector are same.

The main software component is an object finder included in OpenCV distribution. The object finder is 'find_obj_fern.' We add the generation of the mark projected, the angular velocity readout and the position calculation.

Figure 3. Devices constructing Head-worn part.

B. Projection Position.

When we have the position of the interesting object on the image captured from the camera, we can calculate the position of the mark projected on a projector's frame. We need to use projective transformation for calculating the precise position on the image projected from the position on the image captured. However, there is a little distortion between two images. We use a simple liner transformation. The (2) is the expression that calculates the horizontal position on the projected frame. The (3) is the expression that calculates the vertical position on the projected frame. In (2) and (3), (x, y) is the position on the image projected. (X, Y) is the position on the image captured. c_x, c_y, $\mathrm{d}_x$and d_y are constants.

$$\mathrm{x} = \mathrm{c}_x\,\mathrm{X} + \mathrm{d}_x \tag{2}$$

$$\mathrm{y} = \mathrm{c}_y\,\mathrm{Y} + \mathrm{d}_y \tag{3}$$

In (2), X is the position of the interesting object in the frame captured by the camera. c_x and d_x are constants. In our experimental system, c_x is 1.5 and d_x is -700. In vertical position, c_y is 1.3 and d_y is -64.

C. Position compensation with angular velocity.

We have the position that the mark is projected. With the measured pair of an angular velocity and a time, we compensate the position for projecting the mark. We have the amount of the change of a position with (1). In the find_obj_fern, there are 5 operations in the main loop. At each operation, we measure the pair of the time and the angular velocity. After each operation, we compensate the rotations of the projector and update the projected image. Fig. 4 shows the motion compensation points in a processing loop.

The projector in our experimental system has the 38x24 degree in the projection angle. We compensate the pitch and yaw. We ignore the rotate. In a head-worn system, the rotation around the optical axis does not change the view. We do not slant our head between left and right. As a result, the rotation is small around the light axis both of the camera and the projector.

We compensate the horizontal position with dx in (4) and the vertical position dy in (5).

$$\mathrm{dx} = f_x \times A_p/38 \tag{4}$$

$$\mathrm{dy} = f_y \times A_y/24 \tag{5}$$

In (3), f_x is the horizontal frame size. A_p is the amount of pitch in degree. In (4), f_y is the vertical frame size. A_y is the amount of yaw in degree. In our experiment, f_x is 1280 and f_y is 800.

When we have the amount of an angular motion and the position of the interesting object on the image captured by a camera, we calculate the position in the image projected with (6) and (7).

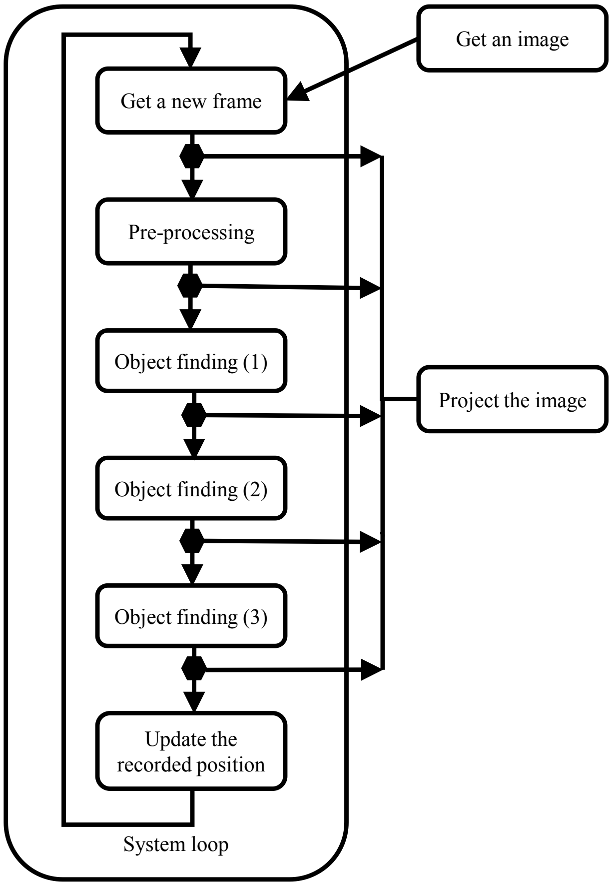

Figure 4. Motion compensation timings.

$$x_{cp} = \mathrm{c}_x\,\mathrm{X} + \mathrm{d}_x + f_x \times A_p/38 \tag{6}$$

$$y_{cp} = \mathrm{c}_y\,\mathrm{Y} + \mathrm{d}_y + f_y \times A_y/24 \tag{7}$$

In (6) and (7), (x_{cp}, y_{cp}) is the position on the image projected. (X, Y) is the position of the interesting object on the image captured by the camera.

V. EXPERIMENTS AND DISCUSSIONS

A. Experiment method.

We use a picture of an interesting object for teaching to our proposed projective AR system in experiments. We make three types of experiments based on the projector's motions. They are vertical motion, horizontal motion and circular motion. Vertical motion is derived from the pitch. Horizontal motion is derived from the yaw. And, circular motion is derived from the combination of vertical motion and horizontal motion in the image. The speed of the motion spans from 10 degrees/S to 120 degree/S. We analyze the recorded

TABLE I. EXPERIMENTAL RESULT

Compensation method (the number of measurements)	**Type of Motions**		
	Vertical motion	*Horizontal motion*	*Circular motion*
No compensation	41	35	36
2 times	57	58	58
6 times	58	63	66

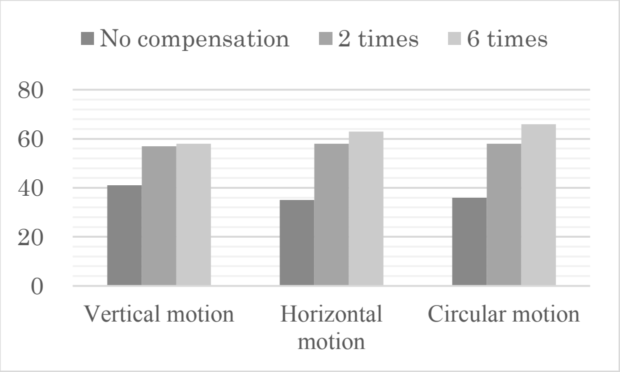

Figure 5. Performance improvements with the number of compensations in a loop.

images that representing the result of object recognitions. The recorded image shows the result of object recognition. In the recorded images, we can see the mark projected. In 100 recorded images, we check the position of the projected mark is good or not. In the case that the mark is on the object, we decide that the system keeps placing the mark. In other cases, we decide that the system cannot keep the mark on the object.

B. *Experimental results.*

Fig. 6 shows the four examples of the captured images in the circular motion experiments. In the images, at the left-upper corner, there is the interesting object. When the object is found, the rectangular is shown around the object found. The small circle is the projected mark that specifies the object. In the images (a) and (b) in Fig.6, the projected marks drop on the interesting object. In the images (c) and (d), the projected marks do not. In the image (d) in Fig. 6, the interesting object is found. In other images, the interesting object is not found. In those images, there is a motion blur.

We show the experimental results in Table I. Table I shows the number of frames that show good results in 100 recorded frames. Without the motion compensation, we have only less than 50% frames that show good results. With the motion compensation, every result shows more performance than the result without the motion compensation.

In the experiment of the vertical motion, there is a little difference between two measurements of angular velocity in a processing loop and six measurements. The horizontal experiments show more performance than the vertical experiment does. The circular motion experiments show the best performance in three types of experiments. At circular motion experiments, the amount of motions is less than the horizontal motion experiments. In 2 measurements, there is no difference between horizontal and circular experiments. In 6 measurements, horizontal and circular experiments show a difference. In circular motion experiments, the angular velocity has four peaks in one cycle motion. In horizontal and vertical motions, there are two peaks in one cycle motion. This difference affects the difference of the performances.

Fig. 5 shows the success rates expressed in percentage. In Fig.5, we easily confirm the differences between the performances of all experiments. With 6 times of angular velocity measurements, in every type of movement, the performance is improved.

VI. CONCLUSIONS

We show the motion compensation method in a projective AR system with an angular velocity sensor. We also confirm the performance of the proposed experimental system. With an angular velocity sensor, the projected mark stays much more periods at the proper place. In all cases of the experiments, there are over 50% of all frames that keep the proper marks' positions. In the experiments, the system moves in all frames. In real usages, the head-worn system has much stable time. If there are 90% stable frames, the total correct mark projections share 97% in all frames in circular movements. This enables to use the proposed stabilized projective AR system in real environments.

The experimental system needs some cables for connecting devices. In the next step, we will make a wireless experimental system.

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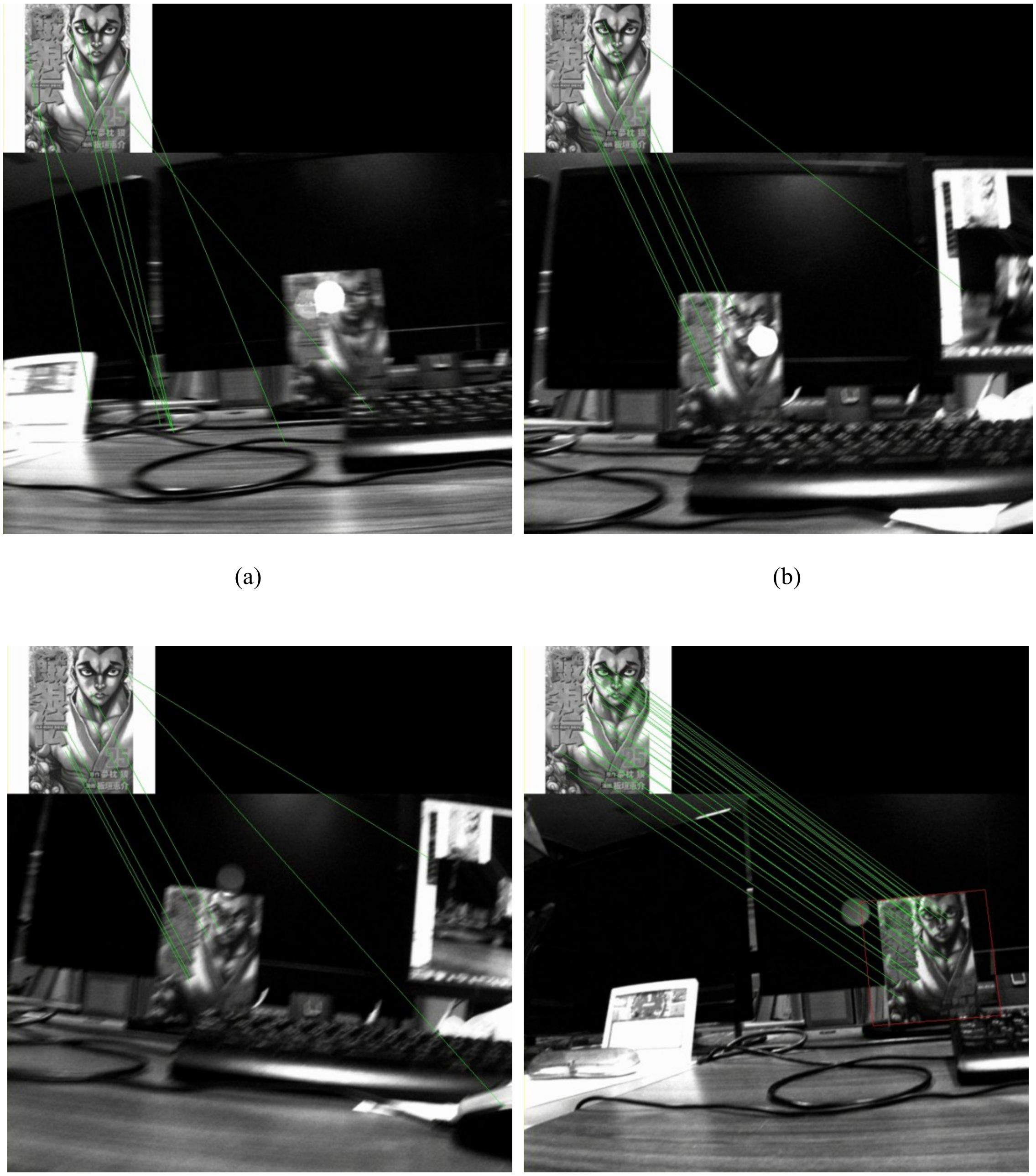

(a) (b)

(c) (d)

Figure 6. Examples of experiments.