Mark Projection on Real World with Precise Measurement of Angular Velocity for Helping Picking Works

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Abstract. There are varieties of methods for realizing augmented reality. A projection type augmented reality proposes augmented information in the real world. Every person can share the experience within 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 outdoors 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 camera images. It projects a mark that carries a little information onto a recognized object. There is an error on the position where the mark projected when the equipment moves. We decrease this error using precise measurements of angular velocity. We propose the method, the implementation and the experiments for evaluating the performance in vitro and in vivo.

Keywords: Augmented reality · Projection · Angular velocity sensor

1 Introduction

In the future, we may have a pure cyber-world that includes no flesh human. However, now, our cyber-world includes a flesh human. We and a cyber-world need to interact each other. Our flesh human cannot interact with a cyber-world directly. We can interact with only real world directly. Many applications in a cyber-world need to interact with a human. So, they need to operate real world around human.

A video image is one method to connect a cyber-world to a real world. The video images can carry a huge amount of information about a real world into a cyber-world. So, it is important. A video image is a method to connect a flesh human to a cyber-world also. Connecting a cyber-world and a real world seamlessly, we need to keep the consistency between the video images of a real world and the video images in a cyber-world. This is not difficult in a static environment. However, we must move and the real world around us must move and change. In the dynamic environment, the delay from capturing an image to recognizing the image breaks the consistency between the real world and the cyber-world. For instance, in the case that we use a head-worn type display, the delay from our move to the displayed image makes us to have a motion sickness. In the case, there is no error in the displayed image. However, our motion sensation of the three

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semicircular canals and the motion sensation of the vision based on the displayed image differ. As a result, we have a motion sickness.

When we use video images to exchange information between a real-world and a cyber-world, we must have some delay from capturing an image to displaying an image. There is a precise heading reference system that includes gyro sensors. Using a heading reference system, we can compensate the delay from capturing to displaying an image. However, a heading reference system is expensive [1].

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 works.

In many kinds of works, there is no proper place to set up the related devices about implementing a projective AR system. The main components are a camera and a projector. 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 real 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.

Previous work proposes the mark projection system with angular velocity sensors [6]. The system enabled the stable projection of a mark on a real surface. However, the performance is not good enough.

This paper discusses the performance of the pseud picking works in a no argument reality (AR) real environment, in the real environments with displayed AR, and in the real environments with the proposed projective AR. This paper proposes the stabilization of the marks projected on real objects with a head-worn type projective AR system with precise observation of angular velocity. First, we discuss the relation between cyber-world and real-world. Next, we discuss about the effects on the projected mark quality with translation and rotation of a 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 proposed projective AR system. Then, we show our experiments about the stability of mark projection. Next, we discuss the effectiveness of the proposed head-worn type projective AR system with precise angular velocity measurements. And last, we conclude our work.

2 Relation Between Cyber-World and Real-World

Cyber-world is the network of computers in simple definition. The cyber-world that has no relation with a known real world is virtual reality. However, we cannot interact with pure cyber-world directly. We must have some help of real devices. In many cases, the real devices are displays. Looking from our human, the seamless complex of a cyber-world and a real-world is augmented reality. Figure 1 shows the relations between cyber-world and real-world. From a human, virtual reality is a cyber-world that has no relation with the real world around the human. Augmented reality is a cyber-world that has close interaction with the real world around the human.

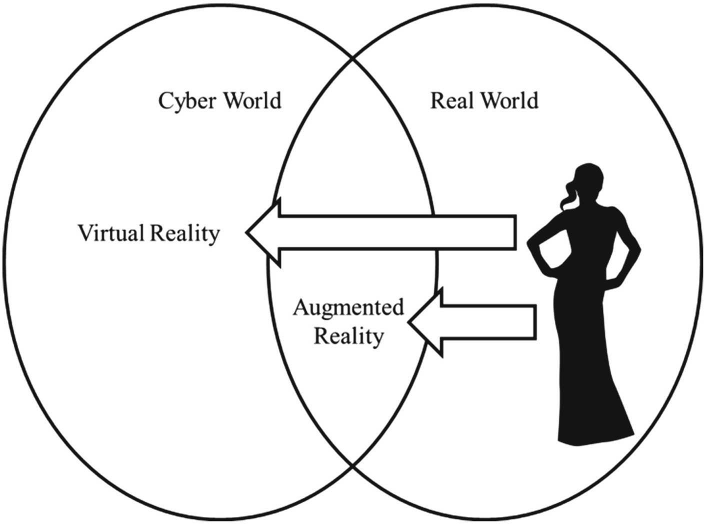

Fig. 1. Relation between cyber-world and real-world.

Augmented reality 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 [7]. When we control an avatar in a cyber-world not relate our real environment, the cyber-world is virtual reality. The avatar may be a robot in a real-world in some cases. However, the real-world is not the environment around us.

When we use the help of inter-connected computers for our construction works, the cyber-world and the real-world around us must have close relation. In the case, the cyber-world looked from us is augmented reality. There are many types of construction works. Watch assembling and house construction are examples. In construction works, there are many parts. The parts are important. AR helps us in the construction works. In many cases, there are multiple workers in construction works. For using AR in cooperative works, all members must carry the devices that show information. The device may be a head-worn type or a hand-held type. However, in many cases, it is difficult that all of the related peoples carry the devices that span between a cyber-world and a real-world.

In the cases, the projective AR works well. Projective ARs do not disturb our interaction with our environment. Projective AR enables to make a very simple working environment comparing with displayed AR.

When we use AR in dynamic environment, it is difficult to keep the consistency in AR. In static environment, it is not difficult to keep the consistency in AR. However, a human must move and our environment must change. In dynamic environment, the delay from the change in real-world to the change in AR breaks the consistency in AR. We have proposed a method to compensate the delay from the head-worn camera image to the displayed image using an angular velocity sensor [7]. The proposed system can project a mark on a real surface. It is difficult to project a clear beautiful image on a real surface as projection mapping.

3 Movements of Head-Worn Type System

3.1 Movements of Human's Head

Our human's head has connection to our trunk as Fig. 2. The translational motion is restricted with the connection. Our neck has three dimensional freedoms in rotations. However, the rotation in the horizontal plane is larger than other two planes. The rotation

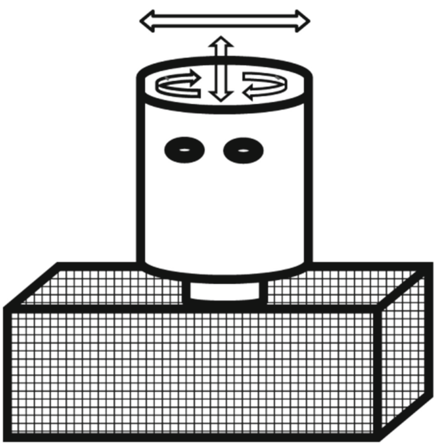

Fig. 2. Head rotations.

in right-left vertical plane is restricted with our shoulders. We tend to keep our eyes to be in horizontal plane. The rotation in front-rear vertical plane is not restricted as the rotation in right-left vertical plane. As a result, the rotation around our eyes' light axis is restricted.

Our mark projection system will project a mark for our eyes. Therefore, the light axis of the projection system is nearly parallel with the light axis of our eyes. In the case, the roll is the rotation in the left-right vertical plane. The pitch and the yaw are larger than the roll.

3.2 Translations and Rotations

Figure 3 shows our proposed head-worn components. The motion of a solid object is a combination of translations and rotations. In Fig. 3, 'A' stands for an angular velocity sensor. 'C' does for a camera. 'P' does for a projector. Our head-worn projective AR system must include a projector and a camera. A camera and a projector must share a same field of view for projecting a mark and finding an interesting object. 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. Figure 3 shows the three elements of rotations.

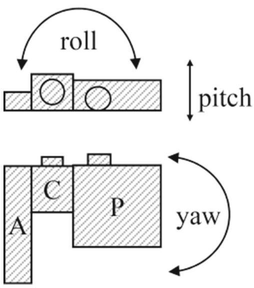

Fig. 3. Components and rotations.

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 is 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 translation in the plane orthogonally intersecting 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 are not larger than the scale of the interesting objects. As a result, the effect about the translational motion is not important about the combination both of the projected image and the surface projected.

Rotations affect the combination of a projected image and the 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.

4 Proposed Rotation Compensation Method

4.1 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 an interesting object on the projector.

There is some delay from taking an image to estimate the position of an interesting object a shown in Fig. 4. We need some processing time for finding an interesting object in the captured image. In our experiments, we need about 300 mS to find an interesting object in a captured image. There is a delay from deciding the position of the interesting objects to a projection of the proper image. We can decrease the delays with the help of

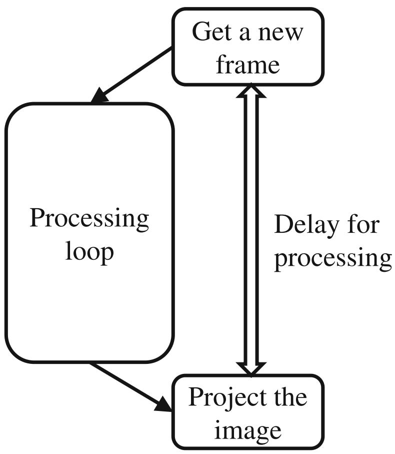

Fig. 4. Delay and processing.

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.

In a cheap system, there must be some amount of delay between an image acquisition and a mark projection. We need some compensation about the rotations in the delay. Translation of the system can affect the position of a mark. However, as discussed in the Sect. 3, in our supposed scale of environments, translations have less effect than rotations.

4.2 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 an AR 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 OpenCV distribution [8].

Our implementation includes two processing loops. One processing loop finds a target object. The processing loop takes an image with a camera, makes some processing and finds the target object. The other processing loop get the measurement of an angler velocity sensor, calculates the compensation amount of the rotations and projects a mark on the target object. Figure 5 shows the overall relation between the processing and the delay about projections.

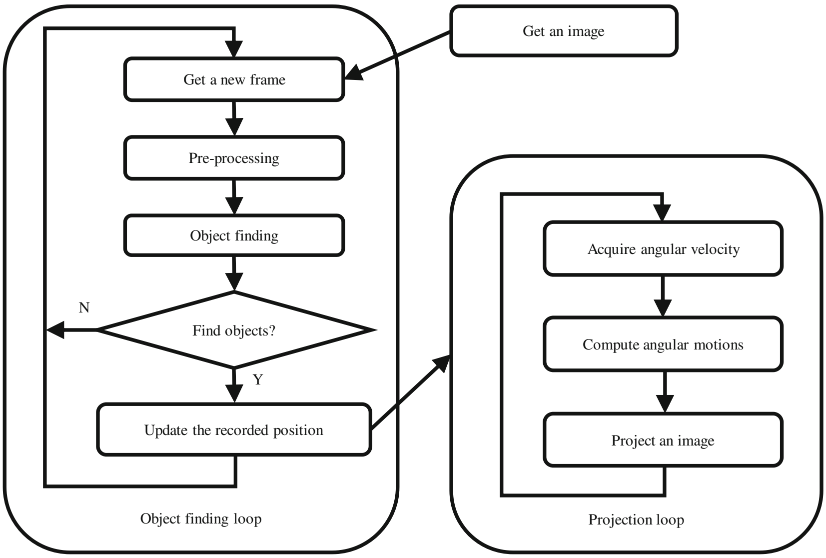

Fig. 5. Motion compensation timings.

The proposed system has two independent processing loops. The image processing loop is relatively slow in the two processing loops. However, the slowness of the image processing loop does not affect the mark projection loop. The mark projection loop gets the measurement of an angular velocity sensor, calculates the amount of rotations and projects a mark on the compensated position. This mark projection loop is relatively fast in the two processing loops. This mark projection loop enables 100 times measurements of angular velocity and projects a mark. With human movements, 10 mS is short enough for observing the motions.

4.3 Compensation of Rotations

We have the angular velocity using the angular velocity sensor. Figure 3 shows the experimental device setup. In Fig. 3, ‘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’. Figure 3 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 object finding 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 between two measurements of angular velocity using the trapezoid interpolation that has no assumption about the measurements as (1).

$$A_1 = \frac{1}{2}(t_1 - t_0)(a_0 + a_1) \tag{1}$$

In (1), A_1 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.

From the time when capturing an image, the total amount of rotations is defined as (2).

$$\mathrm{R} = \sum_{\{t \mid t > T_c, t \in S_m\}} a(t) \tag{2}$$

In (2), R is the amount of rotation from the time when the recent image is captured. T_c is the time when a recent image is captured. S_m is the set of the time when an angular velocity is measured. $a(t)$ is the angular velocity at time t.

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 at the image captured time 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.

5 Mark Projection System on Real World with Precise Measurement of Angular Velocity

This section proposes the outline of the proposed mark projection system on real world.

5.1 Component Hardware and Software

Hardware. The main hardware components are a camera, a projector, an angular velocity sensor and a controlling computer. Figure 6 shows the devices that construct the head-worn part. In Fig. 6, they are a projector, a camera and a Wii controller with Wii Remote Plus [9] 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 1024×768 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° in vertical and 38° in horizontal. The projected image is 854×480 pixels. 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.

Fig. 6. Devices constructing head-worn part for evaluating the stability of mark projection.

Fig. 7. Head-worn components in vivo experiments.

For the experiments of pseud picking works, we fix the camera, the projector and the sensor on a helmet. 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. The projector is replaced lighter one. The weight of the projector is only 0.22 kg.

Figure 6 shows the proposed experimental system for evaluating the stability of mark projection. There are a projector, a video camera, and a Wii controller from left to right respectively. We use only the angular velocity sensor in the Wii controller. The experimental system needs the wired connections about the camera. It needs a power cable also. The direction of the camera and the direction of the projector are same. All three components are placed side by side.

This testing device is too heavy for attaching on a helmet. The projector and the connecting rod are heavy.

Figure 7 shows a helmet based device for pseud picking works. Using the helmet itself for the base to connect all components. The heavy projector is replaced light one. As a result, we can ware this helmet based device with no difficulty. With this helmet based device, we make the experiments of pseud picking works.

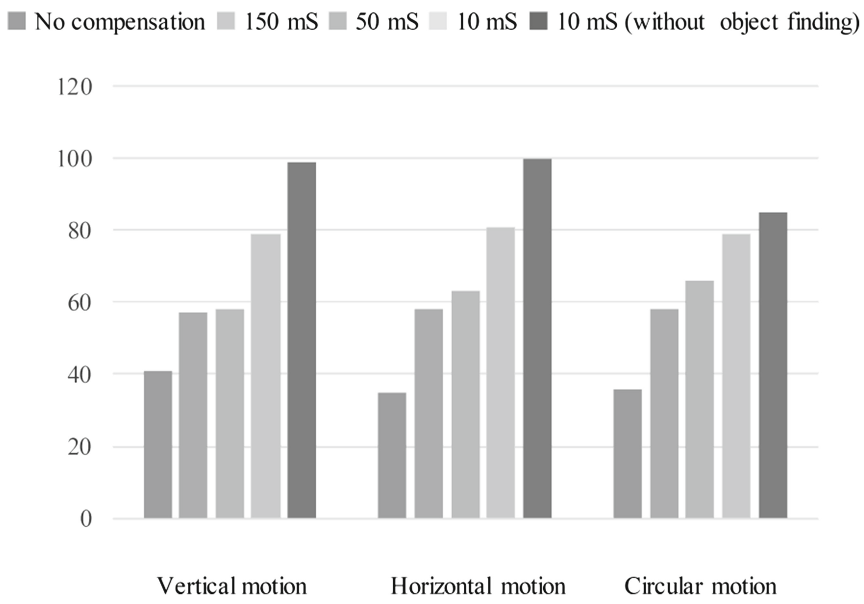

Fig. 8. Performances in experiments.

Software. 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. Our implementation has two processing loops. One processing loop finds an interesting object. Another processing loop projects a mark with compensating the rotations of the proposed system. Figure 5 shows the overview of the software structure. In Fig. 5, the left part is an object finding loop. The right one is a projection loop.

The object finding loop needs about 300 mS for completing one processing loop. This processing loop includes image capturing from a camera, pre-processing of a captured image, and an object finding.

The projection loop works independently from the object finding loop. The projection loop includes an acquisition of angular velocity, estimation of angular motion and projection of a mark. This processing loop completes each loop in about 10 mS. 10 mS is short enough for measuring the motion of a human body.

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 (3) is the expression that calculates the horizontal position on the projected frame. The (4) is the expression that calculates the vertical position on the projected frame. In (3) and (4), (x, y) is the position on the image projected. (X, Y) is the position on the image captured. c_x, c_y, d_x and d_y are constants.

$$x = c_x X + d_x \tag{3}$$

$$y = c_y Y + d_y \tag{4}$$

In (3), 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.

5.2 Rotation Compensation with Angular Velocity

We have the position where the mark is projected. In Fig. 5, at getting a new frame, the process records the time when the process work. We cannot record the time when an image is captured at the image sensor. However, the time when the process captures the frame is near at the time when the image is captured at the image sensor.

With the captured time of a frame and the measured pairs of an angular velocity and a measurement's time, we compensate the position for projecting the mark. We have the amount of the change of a position of the projection with (2). In the 'find_obj_fern', there are 5 operations in the main loop. At each operation, we record the time. Independently from the object finding process, we compensate the rotations of the projector and update the projected image in another processing loop as Fig. 5. Figure 5 shows the relations between two processing loops. The projection loop measures angular velocity at each 10 mS, and compensates the projecting position.

The projector in our experimental system has the 38 × 24 degree in the projection angle. We compensate the pitch and the 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 axes both of the camera and the projector.

We compensate the horizontal position with dx in (5) and the vertical position dy in (6).

$$\mathrm{dx} = f_x \times A_p/38 \tag{5}$$

$$\mathrm{dy} = f_y \times A_y/24 \tag{6}$$

In (5), f_x is the horizontal frame size. A_p is the amount of pitch in degree. In (6), 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 (7) and (8).

$$x_{cp} = \mathrm{c}_x \mathrm{X} + \mathrm{d}_x + f_x \times A_p / 38 \tag{7}$$

$$y_{cp} = \mathrm{c}_y \mathrm{Y} + \mathrm{d}_y + f_y \times A_y / 24 \tag{8}$$

In (7) and (8), (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.

5.3 Projection Accuracy

The implemented system shows the performance in Table 1. If there is no object finding errors, the implemented system shows about 100 % accuracy about the mark projections.

Table 1. Experimental results

Compensation method (the interval of angular velocity measurements)	Object finding	Type of Motions (the ratio of correct mark projection) (%)		
		Vertical motion	Horizontal motion	Circular motion
10 mS	Yes	79	81	79
10 mS	No	99	100	85

Experiment Method. We use a picture of an interesting object for teaching to our proposed projective AR system in experiments. A projected mark is white circle. We make three types of experiments based on the projector's motions and two types of experiments based on the object finding. There are six types of combinations of motion types and object findings. In addition, there is an experiment without the compensation of angular motions.

For evaluating the performance, we recorded 100 images with the camera. With the recorded images, we evaluate the performance with inspections.

The motion types 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°/S to 120°/S.

The types of object finding are with and without object finding. Without object finding, stability of projected mark is measured. In the experiments, at first, we set that the mark drops at the center of the target object, then the system moves. In the experiments, object finding does not work.

We inspect the recorded 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.

Experimental Results. We show the experimental results in Table 1. Table 1 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 150 mS interval measurements of angular velocity in a processing loop and 50 mS interval measurements. The horizontal experiments show more performance than the vertical experiment does. The 10 mS interval measurement experiments show the best performance in three types of motions. At circular motion experiments, the amount of motions is less than the horizontal motion experiments. 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. In circular motion experiments, the error accumulation is larger than other experiments.

Figure 8 shows the success rates expressed in percentage. In Fig. 8, we easily confirm the differences between the performances of all experiments. With each 10 mS angular velocity measurement, in every type of movements, the performance is improved from the experiments with longer measurement intervals. Especially, without object finding, at the horizontal and vertical motion experiments, the success rate is over 99 %. This confirms that the 10 mS interval of angular velocity measurement is short enough for estimating the system rotations.

With the object finding, the performances are a little lower than ones without the object finding. The object finding process creates some error results in finding a target object. As a result, the projection of a mark must have some errors. Without object finding, at first, the object position is set correctly. Then, there is no object finding. As a result, there is no object finding error.

In a circular motion experiment without object findings, the performance is a little lower than other types of motions. In circular motions, errors derived from roll may accumulate. However, there is a little circular motions in our human head movements. The yaw and the pitch are dominant motions in our human head movements.

6 Performance Measurements in Pseudo Picking Works

6.1 Pseudo Picking Work

Picking work is a general work included in many construction works. For instance, there needs many parts to construct a mechanical watch. A watchmaker finds a part, picks a part, and then assembles it.

Our pseudo picking work is finding of a card and touching it. There is no assembling. We take the video of the experiments and confirm that the searched card is correctly touched. We use six cards in Fig. 9.

Fig. 9. Six testing cards.

Our experiments system shows a next card that is randomly selected at key-touch. A subject makes two motions. One motion is touching the searched card. The other is touching an enter-key. In the experiment, the system shows 20 cards.

6.2 Types of Experiments

Our experiment has three types. One type is only using real object without AR. One type uses display based AR. The last one does projection based AR implemented with our proposed mark projection system.

No AR Experiment. This experiment uses no AR. A subject searches and touches the paper card that is same as the displayed card. Figure 10 shows the process of experiments. Figure 11 shows the relations among a display, cards, and a subject with no AR. To complete this work, a subject must look at the display, and then look at paper cards. A subject must search the same card in six paper cards. Among three types of experiments, the parts enclosed dotted line box change in Fig. 10. As shown in Fig. 10, a subject changes the places to look. A subject must remember the card's texture, and search the same card in paper cards. Our experimental system records the time of key operations.

Display Based AR Experiment. This experiment uses display based AR. On the display, cards' images are shown as placed, and the card searched is marked with a white circle as shown in Fig. 12. In this example, the lower center card is marked. A subject only need to remember the relative position of the marked card as shown in Fig. 13. There is no need to remember the texture of the card searched and to search the same card in six paper cards.

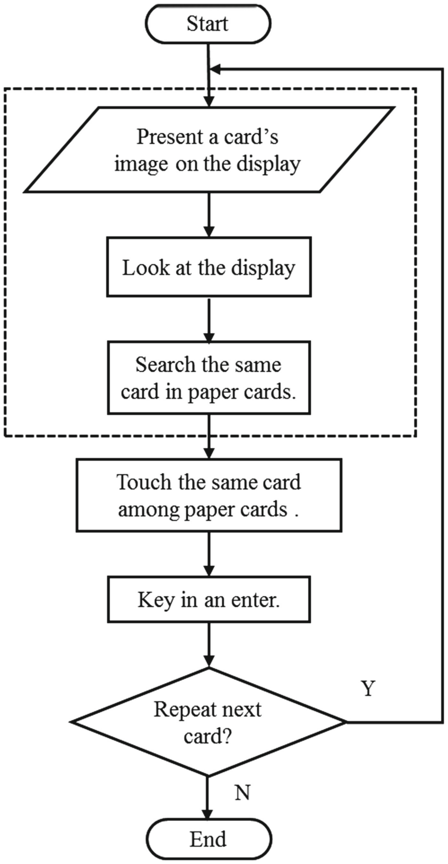

Fig. 10. Work flows of no AR experiment.

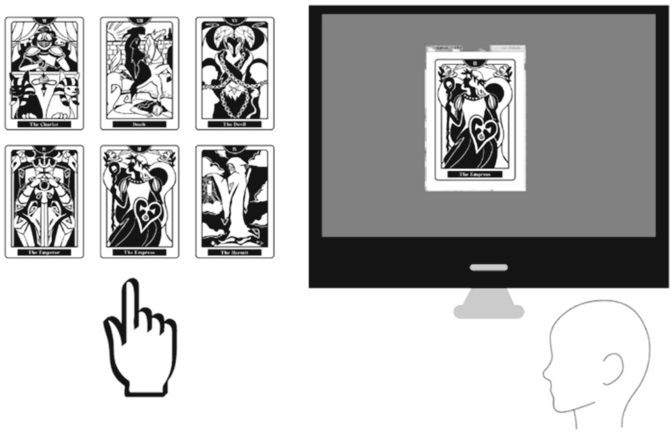

Fig. 11. Relations among a display, cards, and a subject with no AR.

Fig. 12. Relations among a display, cards, and a subject with displayed AR.

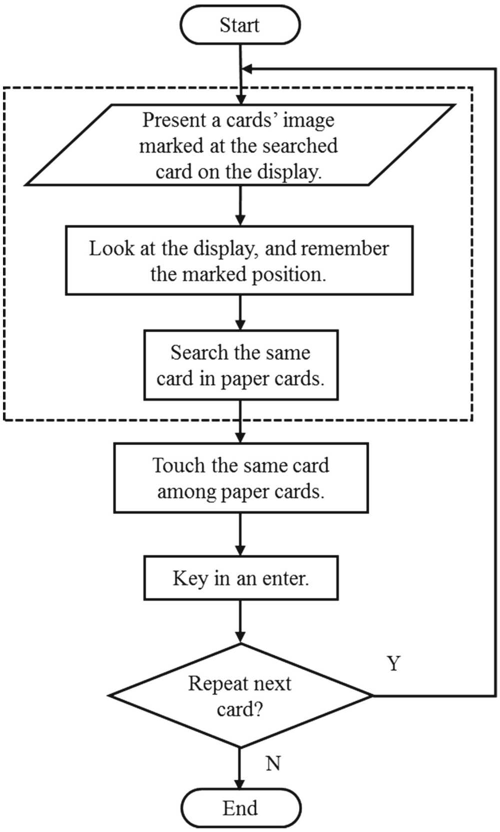

Fig. 13. Workflow of displayed AR experiments.

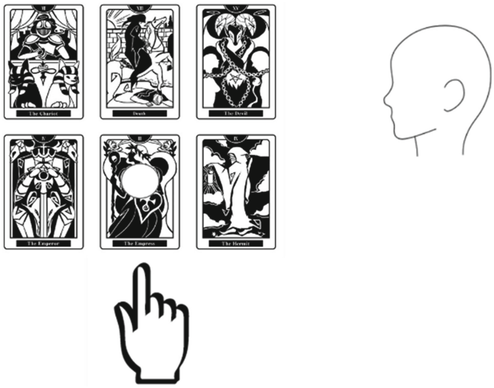

Fig. 14. Relations among cards, a subject, and a projected mark with projective AR.

Projection Based AR Experiment. This experiment uses no displayed images. The action of a subject is the simplest in the three types of pseud picking works as shown in Fig. 14. The system projects a mark on the paper card searched. A subject looks at the

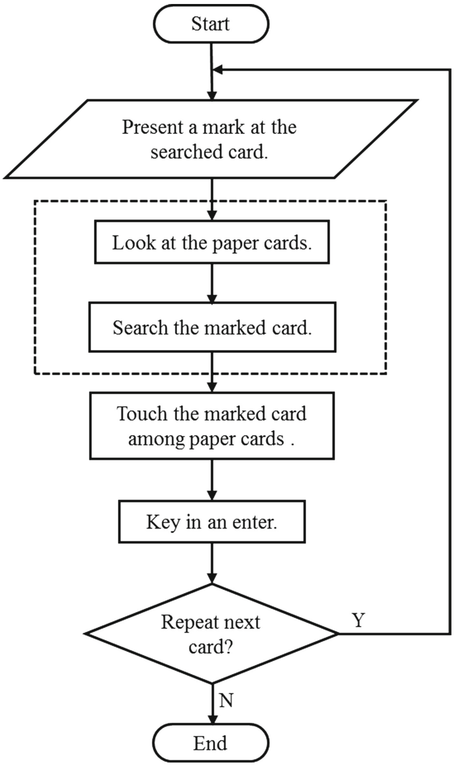

Fig. 15. Workflow of projective AR experiment.

cards, and touches the marked cards as shown in Fig. 15. In this experiment, a subject does not need to remember the texture of the card searched nor the relative place of the marked card in the six cards.

7 Experimental Results and Discussions

7.1 Experiments

We repeated the trials seven times. At each trial, we make three types of experiments. Each trial includes 20 pseud-picking processes. Figure 16 shows the environment of no AR type pseud picking experiment. A subject looks at the right-side display and remembers the displayed card, then looks at the paper cards on left-side and searches the displayed card.

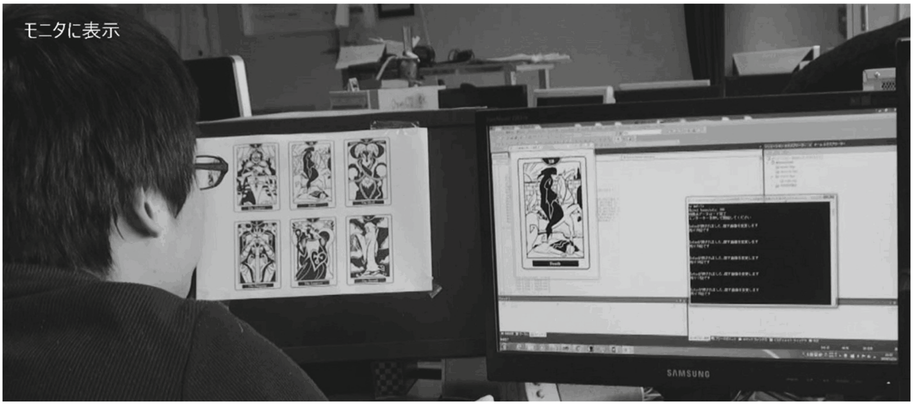

Fig. 16. Non-AR experiment.

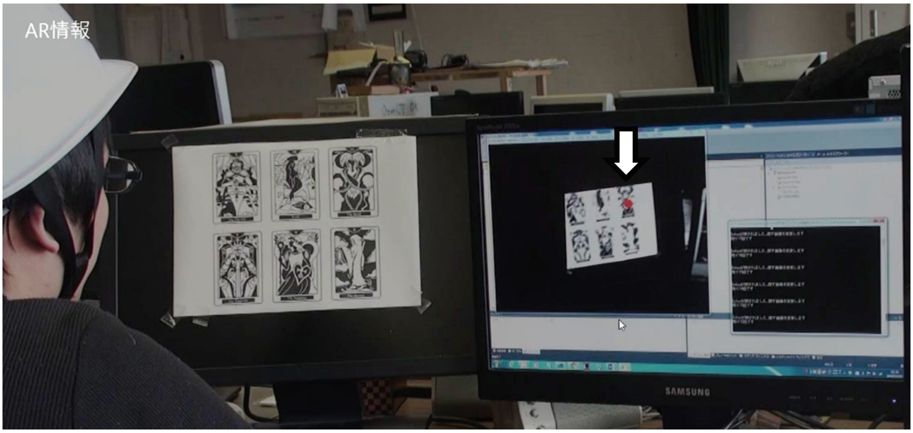

Fig. 17. Display AR experiment.

Figure 17 shows the environment of experiments using display type AR. In the display, the searched card is marked with a red circle. The mark is difficult to see in Fig. 17. A down arrow points the mark in Fig. 17. A subject needs to look at the right-side display to confirm the position of the searched card.

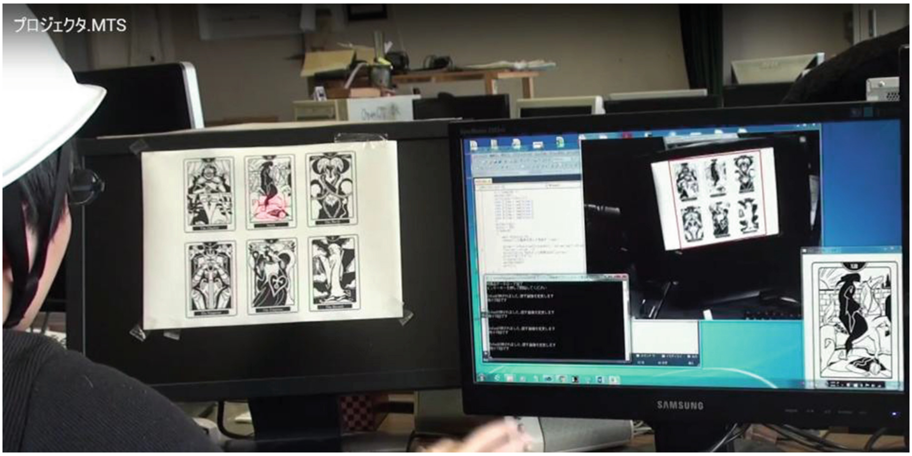

Fig. 18. Proposed projective AR experiment.

Figure 18 shows the environment of the experiment with our proposed projective AR system. In Fig. 18, on the paper cards, a red mark is projected. A subject needs to look only the left paper cards. On the right display, the processing status of the proposed system is displayed. A subject does not need to look the right side display.

7.2 Results and Discussions

We made seven trials in each three types of experiments. In each trial, there are 20 pseud picking works. Table 2 shows the results of seven trials. In Table 2, there are the average and the standard derivation. In Table 2, every value's unit is second. In average and in every trial, projective AR is the fastest in three types of experiments. The standard derivation of the projective AR is the smallest in three types of experiments. In the sequence of trials, every type of experiment decreases its time.

In every trial, the experiment with the proposed mark projection shows the best performance. At each pointing action, the pointing with the proposed mark projection system is 0.2 s faster than the pointing without AR.

The number of trials is not large. However, with Welch's t-test the proposed projective AR system is apparently better than the No AR. The probability is 0.0029. The proposed projective AR system is better than the displayed AR system. This is confirmed with the probability 0.025.

Table 2. Experimental results in three types of work environments.

Trial	Time (s)		
	No AR	Displayed AR	Projected AR
1	46.51	40.40	39.53
2	45.46	42.54	39.79
3	44.06	43.36	40.36
4	43.23	38.13	37.38
5	41.58	39.78	37.85
6	39.09	39.64	36.62
7	39.33	38.57	36.35
Average	42.75	40.35	38.27
Standard derivation	2.67	1.80	1.49

8 Conclusion

This paper proposes the mark projection system with precise measurements of angular velocity and confirms the performance of the proposed system in vitro and in vivo. in vitro, with the angular velocity measurements in every 10 mS interval, the proposed system enables to project a mark on a target object in a dynamic environment without expensive heading reference system. In number, there are over 79 % 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 98 % in all frames in circular movements. This enables to use the proposed stabilized projective AR system in real environments.

in vivo, we propose a pseud picking work. With the proposed mark projection system, a subject works more efficiently than other systems. With the proposed mark projection system, we can complete the pseud picking work in 10 % shorter time than the no-AR trials. The pseud picking works confirms the advantage of projective AR system. Next our step is the application of our proposed system in real assembling works and connecting works.

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