A Mixed Reality Telepresence System with Limited DOF Motion Base and Immersive Display

Maiya Hori
Nara Institute of Science and Technology
8916-5, Takayama
Ikoma, Nara, Japan
maiya-h@is.naist.jp

Masayuki Kanbara
Nara Institute of Science and Technology
8916-5, Takayama
Ikoma, Nara, Japan
kanbara@is.naist.jp

Naokazu Yokoya
Nara Institute of Science and Technology
8916-5, Takayama
Ikoma, Nara, Japan
yokoya@is.naist.jp

ABSTRACT

This paper describes a mixed reality (MR) telepresence system for a ride to provide users with a highly realistic sensation. To make a realistic scene in a virtual environment, it is necessary to combine visual information with a reproduction of the forces which a user experiences in the real environment. This paper proposes an MR telepresence system that presents a realistic image and an inertial force sensation using an immersive display and a motion base with limited degrees of freedom. In our approach, the realistic image is acquired with an omnidirectional camera and the inertial force is generated virtually by a combination of the acceleration of gravity and a video effect. In experiments, a prototype system has been proven to produce a highly realistic sensation in various environments.

Categories and Subject Descriptors

H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; H.5.2 [Information Interfaces and Presentation]: User Interfaces—Prototyping

General Terms

Mixed reality, Telepresence, Motion base, Roller coaster

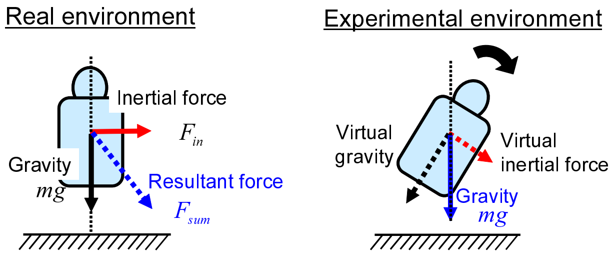
1. INTRODUCTION

The physical sensations experienced in a real environment, including acceleration and inclination, are achieved by a motion base. Speers [5] proposed a method of analyzing a roller coaster track and the generated force on a roller coaster when running. These physical sensations are communicated to a user using a motion base that has six degrees of freedom (DOF) - the DOF refers to the ability to move forward/backward, up/down, left/right (translation in three perpendicular axes), combined with rotation about three perpendicular axes (roll, yaw, and pitch). The motion base plays an important role in motion simulation and requires many DOF to represent the motion of a real ride [1]. As an example of a motion base with many DOF, the Stewart platform, which features six DOF, is applied to drive and flight simulators etc. This motion base, which was proposed by Stewart [6], has sufficient mechanical efficiency as an actuator connection. A transitional inertial force is generated from translational movement and a continuous inertial force is generated virtually through gravity acceleration from inclining the motion base. However, the Stewart platform has problems such that its control is complicated and the device is expensive. Motion simulation using a motion base with limited DOF, which is comparatively cheap [4], has been developed in recent years. In this system, only the axes of rotation are movable, and the motion base can achieve ride inclination. The implementation of inertial force is difficult due to movement limitation of the motion base. On the other hand, a method of generating inertial force using gravity [2], which is used in the six DOF motion base, needs to avoid generating of the rotation acceleration by inclining a motion base. Thus, implementing transitional inertial force generated from a translational movement in the six DOF motion base is difficult.

This paper proposes a new telepresence system that can give a user a realistic image and an inertial force sensation when a running ride is accelerating, decelerating, or turning. To construct a highly realistic telepresence system, we use an immersive display and a motion base with limited DOF (movable axes of rotation). Inertial force sensation is generated from the acceleration of gravity by inclining the motion base. An immersive display prevents the user from noticing the inclination. Presenting the user with a real scene image with an inclination different from the real world allows the proposed method to give the user an inertial force generated from the acceleration of gravity. The implementation of transitional inertial force is difficult due to a restriction - the motion base must be leaned so that the user does not perceive the rotational acceleration. Our approach presents a virtual inertial force by temporarily rotating the image shown to the user in the direction in which the inertial force operates.

2. GENERATION OF INERTIAL FORCE USING A MOTION BASE AND AN IMMERSIVE DISPLAY

In this research, a commercially available motion base with rotational axes of roll and pitch is used to produce the iner-



(a) Forces in a real environment

(b) Forces in a telepresence environment

Figure 1: Generating inertial force by using gravity.

tial force sensation that is felt when the ride is accelerating. Generally, since a motion base has limitations on its movable axes and a movable range, it is difficult to perform the same motions as found in a real environment. In our work, an inertial force sensation is achieved from the acceleration of gravity by inclining the motion base, as shown in Figure 1. In a real environment, the user feels an inertial force and gravity when the ride accelerates, as shown in Figure 1(a). In a telepresence system, these forces are generated virtually from the acceleration of gravity, as shown in Figure 1(b). Although the direction and the magnitude of inertial force change depending on acceleration, the acceleration of gravity does not change in a telepresence environment. Inclining the motion base makes it possible for the user to experience virtual inertial force and virtual gravity. Although the inclination of the telepresence system differs from that of the real ride, the user does not recognize the inclination in the experimental environment because the user looks at a scene with an immersive display. As a result, the user experiences a virtual inertial force generated from the acceleration of gravity.

To give the user the sense of inertial force, it is necessary to prevent the user from perceiving the rotational acceleration of the motion base. In this study, a deficiency of inertial force due to the restriction on the rotational acceleration of the motion base is compensated by a video effect. An example of compensation for a deficiency of inertial force is shown in Figure 2. A target inertial force is irreproducible only using gravity due to the restriction of the rotational acceleration of the motion base when the inertial force occurs transitionally. The problem is handled by compensating for the deficiency in inertial force with the video effect. The direction and the magnitude of inertial force felt in a real environment are estimated from an image sequence captured when the ride is moving. Details of each technique are given in the following sections.

2.1 Estimation of inertial force using omnidirectional image sequence

In this section, we describe a method for estimating the direction and the magnitude of inertial force to give a user the same inertial force sensation as in a real environment. The inertial force is a pseudo force, which operates in the direction opposite to the acceleration vector and is generally represented by the following expression.

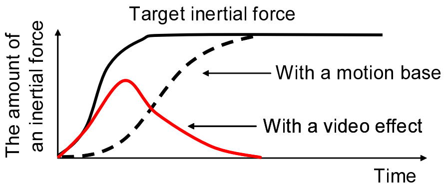


Figure 2: Example of attaining transitional inertial force.

$$\boldsymbol{F_{in}} = -m\boldsymbol{a}, \tag{1}$$

where $\boldsymbol{F_{in}}$ is the inertial force vector felt by a user, m is the mass of a user, and $\boldsymbol{a}$ is the ride acceleration vector. In our research, the acceleration vector $\boldsymbol{a}$ is estimated from extrinsic camera parameters which are estimated from an omnidirectional image sequence captured on the ride. We use the existing method [3] for estimating extrinsic camera parameters from multiple image sequences obtained with an omnidirectional multi-camera system. This method uses the structure-from-motion technique which is based on tracking natural features. The camera parameters are estimated by tracking natural features automatically and using a robust approach, called RANSAC. The vector of inertial force is estimated from the extrinsic camera parameters. First, the ride velocity is estimated from the 3D camera position in each frame. The velocity vector is computed from the velocities that operate along each base vector in the world coordinate system. The 3D camera positions may contain high frequency noises, which consist of estimation error and camera vibration. It is unnecessary to remove these influences for generating a long term inertial force. To remove the influences, the estimated velocity values are smoothed with a simple moving average technique. We assume that the ride velocity changes smoothly if the velocity has little influence on high frequency noises consisting of an estimated error and camera vibration. The acceleration vector is calculated by differentiating the velocity vector with respect to time. The vector of inertial force is calculated from the estimated acceleration vector as mentioned above, according to Eq.(1). The vector computed here requires conversion from the world coordinate system to the user coordinate system because the inertial force vector in the user coordinate system in each frame is needed to generate a sensation of inertial force. The inertial force vector is converted to the user coordinate system using a coordinate transform matrix determined from estimated extrinsic camera parameters.

2.2 Calculation of motion base inclination

The inclination of motion base is calculated from the inertial force and the acceleration of gravity in a real environment. The gravity of the user in an experimental environment is substituted for a resultant force consisting of the inertial force and the gravity of the user, as shown in Figure 1. The vector of resultant force $\boldsymbol{F_{sum}}$ is given as follows:

$$\boldsymbol{F_{sum}} = \boldsymbol{F_{in}} + m\boldsymbol{g}, \tag{2}$$

where $\boldsymbol{g}$ represents the vector of the acceleration of gravity. A user can experience virtual inertial force sensations by adjusting the directional vector of the acceleration of gravity in an experimental environment to the directional vector of the resultant force in a real environment. The direction of force can be changed by inclining the motion base so that the directional vector of resultant force in a real environment agrees with that in the experimental environment.

To generate the inertial force with gravity, it is necessary to incline the motion base such that the user cannot perceive rotational acceleration. The magnitude of rotational acceleration perceived by the user must be determined by subjective evaluation beforehand because individuals sense rotational acceleration differently. As shown in Figure 2, the video effect generates a virtual inertial force and compensates for the deficiency in inertial force from the inclination of the motion base - if it does not reach a target value due to movement limitations. The inclination of the motion base does not depend on the mass of the user because the user mass parameter m is contained in the resultant force and the gravity of the user.

2.3 Generation of user's view image

The inertial force cannot be given only by inclining a motion base because there is an inconsistency between the visual perception and the inclination of the user. Because the inclination of the motion base is different from actual inclination, it is necessary to change the image shown to a user. The image is presented to the user so as to fix the relationship between the ride position and the user. The user's view of the scene can easily be created from omnidirectional images. If a user cannot determine the inclination of the motion base from visual information, then he or she experiences the sensation of inertial force. To achieve this effect, it is necessary to cover the user's field of view with an immersive display.

It should be noted that the target inertial force cannot be reproduced only by gravity due to the restriction on the rotational acceleration of the motion base when an inertial force occurs transitionally. This problem is resolved by compensating the deficiency in the inertial force with the video effect. In this research, a transitional inertial force is given to a user virtually by temporarily rotating the presented image. This technique is based on the human response to motion, which is felt in the direction opposite to the moving direction of a scene. The deficiency in inertial force generated by inclining the motion base is compensated for by rotating the image in the same direction as the axis of rotation of the motion base. The user's view image can be easily rotated by setting the projection center of the camera as the rotational center when generating user's view from the omnidirectional image. A rotation proportional to the deficiency angle of each axis of the motion base is given to a presentation image. The processing returned to the original position, which cannot be perceived by the user, is added in order to provide temporary rotation of the image. Since the magnitude of inertial force generated by the video effect changes with individuals and cannot be expressed quantitatively, the magnitude of inertial force to the rotation of image is determined beforehand for each user subjectively.

3. EXPERIMENTS

To verify the validity of the proposed method, we experimented with a prototype system using image sequences captured in an outdoor environment. Figure 3 shows a motion base (Kawada Industries, JoyChair) that has two rotational axes (roll and pitch), each with a range of motion of 15 degrees. In the system, a user looks at an image made from a panoramic image sequence with a head-mounted display (Daeyang, i-visor FX601). The panoramic image sequence is captured with a multi-camera system (Point Grey Research, Ladybug2). The multi-camera system has six cameras located radially and their positions and posture are fixed. Each camera can acquire 768 × 1024 resolution images at 20-30 fps. A panoramic image generated from six images is shown in Figure 4.

Figure 3: Motion base with two degrees of freedom.

Figure 4: Example of omnidirectional image.

3.1 Evaluation of the proposed method

This section shows the results of generating inertial force when the vehicle makes simple movements, such as accelerating, decelerating, or turning, using omnidirectional image sequences captured on vehicles running on level ground. We demonstrate the validity of the proposed method by performing subjective evaluations of three methods: two conventional methods [4, 2] and the proposed method. Conventional method A [4] is to reproduce the inclination from the real environment using only the magnitude and direction of gravity in the real environment. Conventional method B [2] is to reproduce the inertial force with gravity, such as the motion base with six DOF. In method B, even if a transitional inertial force operates, the restriction on the rotational acceleration of the motion base is not given, while a required inclination is given to the appearance of inertial forces.

The inertial force was generated when a vehicle is accelerating, decelerating or turning left and subjects evaluated it with a questionnaire. In the experiments, methods A, B, and the proposed method were performed for 12 subjects in a random order. Five-level rating is performed concerning the realism of the sensation. Table 1 shows its results. Each score shows an average mark graded on this standard. The proposed method and the conventional methods were

Table 1: Evaluation of the realism of the sensation. (Evaluation values are underlined in case that a significant difference is observed by Dunnett's test between a pair of methods.)

	Method A [4]	Method B [2]	Proposed method
Accelerating	2.000	3.000	4.167
Decelerating	1.917	3.583	3.750
Turning left	2.167	3.833	4.583

Figure 5: Equipment of omnidirectional image capturing system.

compared by using the Dunnett's test with a 5% significance level. The significant differences were observed between these scores with only one exception of method B in case of decelerating. We have confirmed that the inertial force sensation was produced with the proposed system.

3.2 Applications

In this section, we describe a prototype system that allows users to experience the sensations of a roller coaster as an application of the proposed method. The omnidirectional image sequence is captured on a running roller coaster, as shown in Figure 4. The image capturing system is shown in Figure 5. Omnidirectional image sequences are captured with a head-mounted omnidirectional camera. The result of estimated extrinsic camera parameters when the roller coaster is running is illustrated in Figure 6. The motion base inclination necessary for the inertial force is shown in Figure 7. It can be seen that the motion base inclination for the inertial force exceeds the movable range in some frames. It means that, in some cases, the inertial force sensation cannot be achieved due to a limitation of the motion base inclination.

4. CONCLUSIONS

This paper described a telepresence system for a ride to provide a user with a highly realistic sensation. The contribution of this work is to construct an MR telepresence system that provides a user with a realistic image and an inertial force sensation using a motion base with limited degrees of freedom and an immersive display. In the present study, the realistic image is captured with an omnidirectional camera and the inertial force is generated by acceleration of gravity and the video effect. The inertial force in a real environment is estimated automatically by recovering extrinsic camera parameters from the omnidirectional image sequences. In experiments, we have confirmed that a user can experience entertainment applications with the prototype system. As future work, we should achieve the inertial force sensation when the necessary inclination of the motion base exceeds its movable range.

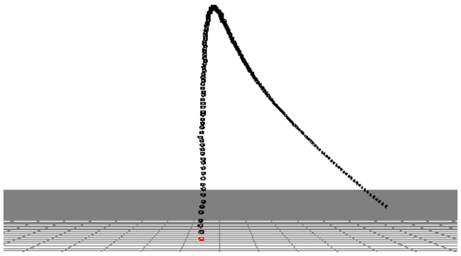


Figure 6: Estimated camera path (roller coaster).

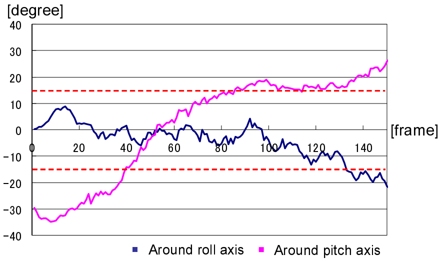


Figure 7: Inclination of motion base necessary to generate inertial force. (Red dashed line indicates limitation of motion base inclination.)

5. ACKNOWLEDGMENTS

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