Development of immersive Augmented Reality Interface for Construction Robotic System

Jinki Moon1, Youngwan Son1, Shinsuk Park1, Jinwook Kim2

1 Dept. of Mechanical Engineering, Korea University, Anam-dong, Sungbuk-gu, Seoul, Korea
(Tel : +82-2-3290-3373; E-mail: drsspark@korea.ac.kr)
2 Imaging Media Research Center, Korea Institute of Science and Technology,
39-1, Hawolgok-dong, Sungbuk-gu, Seoul, Korea
(Tel : +82-2-958-6776; E-mail: jwkim@imrc.kist.re.kr)

Abstract: This paper presents a human-machine interface for tele-operated construction robot systems. By using augmented reality techniques, we developed an immersive interface for tele-operated construction robot system. Compared to the conventional tele-operated interface using only monitor view, the developed AR interface system allows the operator to see the invisible image out of camera view by using a virtual 3D model. Also, this AR system notifies the operator of a danger area and gives the operator a guide for completion of task by using the augmented reality. For these reasons, the operator can rapidly and accurately recognize depth information of structure in construction site. Therefore, the operator can easily and safely complete construction operation. Also, the efficiency of construction operation can be improved and the construction period can be decreased.

Keywords: Construction automation, Tele-operated robot, Augmented reality, Immersive interface.

1. INTRODUCTION

The Construction industry is infrastructure industry that importantly affect to almost industry field. However, it is thought as representative industry of manpower shortage because automation technology is insufficient [3]. Construction automation equipment and robot is actively developed to overcome these problems. Construction automation and robotics include software technology (informational system, integral management system etc.) and hardware technology (development of automatic or semi-automatic robot for substantiality of construction).

Fundamental purpose of construction automation and development of construction robot is solving a manpower shortage, securing economical efficiency, and enhancing safety through improvement of work environment [1, 4]. In the early stage of construction automation, it was difficult to satisfy safety of worker revealed in dangerous environment because focus was mainly set in increasing of economic efficiency through substituting of human power. For this reason, worker's manpower was decreased than traditional human power construction, but new safety accident happened due to inappropriate automation.

Comparing with automation of general manufacturing industry, repeated process consisting of equal pattern work is seldom in construction site, because construction process is not standardization. Therefore, following improvement items are needed: development of construction robot that can follow user's intention according to various work in complicated construction site, intuitive interface that can reflect dexterity of a skilled worker, mutual assistance of working force amplified by robot along with worker's force, and a construction robot that can share working space with worker. One of solution to satisfy these requirements is Human-Robot Cooperation (HRC) technology [2].

Research about Human-Robot Interface (HRI) had been achieved constantly until today. For efficient control of construction robot, development of HRI is very important in HRC system. The conventional interface of construction robot was only consisted of monitor view using a camera. The camera view can not represent various information of structure in complex and active construction site. Since the construction robot interface system using only camera view can cause to conflict invisible structures or people out of camera view and move dangerous area such as incomplete construction area. These problems can significantly cause to decrease efficiency of construction operation and increase construction period.

We may be able to solve these problems with conventional interface of construction robot through the use of augmented reality interface. Augmented reality, which merges real construction site image with virtual 3D model of construction site, can improve the limited visual feedback of a camera view. The structures and area out of camera view and invisible dangerous area such as incomplete construction area can be represented by using augmented reality system. This additional visual feedback can help the construction operator easily navigate and control robot. Since the augmented reality system can make robotic construction operation faster with higher accuracy and the enhanced depth perception in the real construction site.

In this paper, development of construction robot interface base on augmented reality (AR) was introduced. With manipulating mobile robot including video camera in remote place, many difficult and dangerous construction operations can be effectively solved. A user can easily control robot using information offered by AR system: depth information and structures outside visual field of video camera. As AR technology merges in the mobile robot systems, efficiency of construction operation can be improved and construction period can be decreased.
2. AR INTERFACE SYSTEM OVERVIEW

In construction interface using only camera view, it is difficult to realize skilful construction operation due to difficulty of depth recognition in complex construction site. For solving these problems, immersive augmented reality interface using virtual 3D model based on a constructional drawing (a blueprint) was proposed in this paper. Unlike typical AR system, virtual 3D model surround a camera view in our AR system. By merging a virtual 3D model based on a blueprint and camera view, AR technique could express invisible structure of construction site outside visual field of camera. By applying advantage of immersive AR system to construction automation interface, user can recognize easily depth information about structure of construction site and position information of construction robot without camera motion. For these reason, user can manipulate robot tool more exactly and rapidly. These advantages of immersive AR interface help to augment efficiency of construction operation as well as to reduce load of user.

In this paper, the augmented reality system was developed by using a camera and a camera positioning module, DV converter, a joystick, a vision-station (Elumens, Inc.). In this AR system, the camera view is fixed at the center of the hemispherical screen and the virtual 3D model based on constructional drawing is displayed outside the camera view (Fig.1). The view direction of a camera and virtual 3D model can be changed according to the joystick input, so that the camera view and virtual 3D model view are changed concurrently. With AR system, user might be able to view the construction site from all angles merely by turning his head, without camera motion. These features are useful for the user to manipulate and navigate robot in construction site.

3. IMAGE PROCESSING AND COMMUNICATION

3.1 Virtual 3D model and camera video processing

For realizing augmented reality system, NAVERLib was used as the network environment. NAVERLib has several modules (nvLoader, nvmStreaming, nvmDeviceManager, etc.) that provide various libraries for interactions and interface of AR environment. Therefore each module of NAVERLib depends on various programs such as OpenGL Performer, Virtual Reality Peripheral Network (VRPN) and Digital Video Transport System (DVTS).

Virtual 3D model was displayed by using nvmLoader that constructs scene-graphs with nodes, just like pfvmLoader of OpenGL Performer. By using the libraries of DVTS, nvmStreaming module can receive and send the video streaming data of Digital Video (DV) format through the internet. The analog video signal obtained from the camera is converted to DV format by using the DV converter and then textured on the video board by nvmStreaming module. Since Real-time Transport Protocol (RTP) of DVTS is designed to achieve real-time stream transportation using the internet, our augmented reality system was operated at real-time rate.

3.2 Communication of master-slave system

In order to change the direction of camera view in the physical coordinate, our system uses a camera positioning module controlled by a joystick. Because the pitch and yaw motion of the camera is controlled by the joystick input, our AR system offer intuitive mapping between joystick and camera positioning module. For communication of master-slave system, VRPN was used, which consists of a set of classes within a library and a set of servers designed to implement network transparent interface between application programs.

nvmDeviceManager module employs VRPN to communicate with VRPN server of in which peripheral devices (joystick and camera positioning module) are connected. Whenever VRPN client periodically call for VRPN server, VRPN server send an encoder value of motor in camera positioning module to VRPN client. A forward kinematics of camera positioning module was calculated by using an encoder value of motors. nvmDeviceManager updates position and direction of view point in the image coordinate by using this forward kinematics. Fig.2 shows the schematic view of VRPN and DVTS system.
4. COORDINATE TRANSFORMATION BETWEEN PHYSICAL COORDINATE AND IMAGE COORDINATE

Augmented reality (AR) is a variation of Virtual Reality (VR) that completely immerses a user inside a synthetic environment. While the user in VR environment cannot see the real world, AR environment allows the user to see the virtual and real world concurrently. With virtual objects superimposed upon the real world, AR system can offer user more immersive environment than VR system [5, 6]. These AR technologies have the potential to improve the visual limitations of camera mounted on construction robot. By using a virtual 3D model, the AR system gives a user the depth information of complex construction site. For composing an AR system, virtual 3D model and real image was needed. Real image is obtained by video camera and virtual 3D model was created by using a blueprint of construction site (Fig.3).

For matching camera image and virtual 3D model image in AR system, coordinate transformation between physical coordinate and image coordinate was necessary [7]. For obtaining coordinated transformation matrix, first of all, relation between construction site model in physical coordinate and virtual 3D model in image coordinate was calculated. In order to register the 3D construction site model in the augmented reality system, several marker pins were placed on the real construction site model. The locations of the marker on the real construction site model were measured using a robotic manipulator. The locations of the marker on the virtual 3D model of construction site were measured using 3D edit program. The coordinate transformation between the marker in the physical world and those in the graphical world was, then, calculated.

The transformation between the coordinate systems requires rotation, translation, and scaling factor. The transformation matrix can be calculated by multiplying rotation, scale and translation matrices [8]. Rotation matrix $R$ can be calculated by using the unit vectors of the marker’s position vectors. In order to obtain scale matrix $S$, it is needed to calculate scale factors in $x$, $y$, and $z$-axes. Each scale factor is the ratio of the length of the position vector in the graphical coordinate to the length of the position vector in the physical coordinate. After rotation and scaling of the position vectors, translation matrix $T$ is calculated by subtracting the rotated and scaled position vectors from the position vector in the graphical coordinate. Translation matrix $T$ is then obtained from translation vector $t$. Using these $T$, $S$, $R$ matrices, transformation matrix was calculated. By using this transformation matrix, the real construction site model in the physical coordinate can be registered spatially to the 3D construction site model in the graphical coordinate.

5. FIELD OF VIEW MATCHING CAMERA VIDEO AND VIRTUAL 3D MODEL

For obtaining real image, a small cylindrical camera (Vision high-tech, Inc.) with a charge couple device (CCD) sensor was used in this experiment. External images through the camera lens make a circular image on the plane where the CCD sensor is mounted. While the circular image is projected on the plane, the only image in effective CCD pixel was projected on the...
image circle is textured on the circular video board. Fig.6 shows a lens angle ($\alpha^\circ$), horizontal ($x^\circ$) and vertical ($y^\circ$) effective CCD angle.

The size of video board and the field of view (FOV) are determined, so that the camera video and virtual 3D model are matched at the boundary. The size of video board can be arbitrarily determined in the clipping window. Once the size of video board is determined, the FOV can be calculated from the effective CCD angle and the lens angle. Fig.7 shows a horizontal ($X^\circ$) and vertical ($Y^\circ$) FOV.

6. REAL-TIME CAMERA DISTORTION CORRECTION USING TEXTURE MAPPING

A camera offers a user a wide-angle view information of construction site. Wide angle lens mounted on camera permit large construction site to be visualized rapidly. A camera image suffers from a fundamental radial distortion due to the wide angle design of the camera’s objective lens [9]. The distortion causes image farther from the center to appear severely smaller than they really are. Therefore, radial distortion prevents accurate distance judgment and measurement of structures in construction site. Also, radial distortion causes difficulties in emerging a camera image and virtual 3D model of construction site.

Camera image requires distortion compensation for the accurate location, registration of construction robot and measurement of construction structure. Also, a real-time capability is desirable for interactive HRI systems. Therefore, distortion correction should be ideally performed with minimal Central Processing Unit (CPU) load. A texture-mapping accelerator can use along with the dynamic distorted image to render high quality distortion corrected images at image frame rates. The grid based approach is shown to have both more accuracy and greater speed than the traditional method using the CPU to transform each pixel individually [10].

Graphic Processing Unit (GPU) based on image processing can significantly free the CPU for other tasks. The rendering process needs to compute the displayed position of each vertex and to interpolate between the corresponding texture coordinate to determine the texture location to sample in order to fill the pixels in each grid (a local affine transformation with texture mapping method). The goal of texture mapping in a GPU is to spread distorted images.

The intuitive approach to utilizing the GPU is to tessellate the distorted input image into a set of rectangles in a uniform grid. The original grid intersection positions become the list of texture coordinates and the distortion corrected positions compose a list of rectangle vertex positions for rendering. A stream of distorted images is fed to the GPU as a sequence of replacement textures. The vertices are correctly located, but the image data of each rectangle interior experience an affine transformation. The trade off is accuracy for speed. The more vertices were used, the more accuracy image was corrected but the less rapid process is.

RESULT

1. Estimation of distortion correction accuracy

In this paper, distortion of camera image was solved by using texture mapping method. The accuracy of distortion correction using texture mapping method was estimated by using normalized distance error. As shown in fig.10, the distortion image further from image center accumulated more distortion error.
Comparing with distorted image, the image corrected by texture mapping method includes significantly small error. Unlike traditional method transforming each pixel individually, distortion correction image did not accumulate distortion error. Because reference points of texture mapping method are distributed over whole image, distortion error was not accumulated even if image is far from image center.

2. Immersive AR interface for Construction robot

We developed immersive AR interface for construction robot (Fig.11). By using a wide angle screen (Elumens, Inc.), the user can obtain a wide visual field about construction site. Therefore, the user can more easily control and navigate the construction robot without an accident.

The fig.12 represents screen image of the immersive AR interface for construction robot. The camera view is fixed on center of the wide angle screen, and the outside of the center view is the virtual 3D model. The user can concurrently change direction of camera and virtual 3D view by using joystick. Because of using a joystick, the user can more intuitively change the view direction in construction site.

CONCLUSION

By using immersive AR interface, a worker can feel like that he seem to be on construction site. For this reason, worker can easily recognize the depth information about structure of construction site. Also, worker can control construction robot more exactly and rapidly. The property of immersive AR interface reduce problem of traditional camera interface such as depth recognition, and narrow visual field. For these reasons, the immersive AR interface will lead to apply robot to many construction procedures and develop new construction robot. Applying immersive AR interface to construction robot, physical and environmental load of user might be reduced as well as a manpower shortage of construction industry might be improved.

ACKNOWLEDGEMENT

This work was supported by the Korean Institute of Construction & Transportation Technology Evaluation and Planning (KICTEP). (Program No: 06-Unified & Advanced Construction Technology Program-D01)
REFERENCES


