International Journal of Robotics and Automation
Vol. 1: Issue 1
www.journalspub.com

Guidance for Robot Teleoperation using Augmented Reality

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Abstract

In Nuclear power plants, Tele-operated Robots are generally employed for handling tasks in the harsh radiation environments. Maneuvering of the Tele-operated Robotic Arm in such critical workspace faces challenges such as time-delay in communication and Interaction constraints. Augmented Reality (AR) based predictive display offers potential solution to these problems. In this paper, the proposed work aims at using Augmented Reality concept of superimposing virtual objects onto the real video image. The graphical model of the Robot arm is created using OpenGL and it can be augmented onto the real image using accurate camera calibration and registration methods in OpenCV. Image processing technique such as Feature based tracking algorithm is used to obtain the required information such as position and orientation of the real Robotic Arm from the real video. With this information, virtual robotic arm model could be drawn and superimposed over the real-time video captured from the camera. Algorithm has been developed for activating motion in the virtual model through the user interface and incorporating the same in the real Robotic Arm.

Keywords: *Augmented realities, robot teleoperation, OpenCV, virtual model.*

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INTRODUCTION

With the various advances in the field of Tele robotics, exploration and access to extremely dangerous environments like aerospace, seafloor or high-radiation area[1] have become feasible by the support of teleoperation. The teleoperation system enables the human operator to control the remote robot without facing the harsh working environment directly[2], which guarantees the safety of human beings, but meanwhile inevitably introduces time delay and interaction constraints. Using Augmented Reality (AR) is a good way to deal with these two problems as AR has three important properties: combining real and virtual objects in a real environment, running interactively and in real time, registering real and virtual objects with each other[3]. Integrating AR can allow operators to observe real working condition and virtual simulation result simultaneously; therefore the operators can timely rectify the errors instead of awaiting time-delayed feedback, which greatly compensates the confusion caused by time delay. Additionally, AR can provide guidance to operators by adding virtual words or animations to the registered display video, making AR even more appropriate for teleoperation applications.

AUGMENTED REALITY AIDED TELEROBOTIC SYSTEM

Related Work

Bejczy A.K, *et al.* (1990) introduced augmented reality into teleoperation, in NASA JPL, as they proposed “Phantom Robot” to add computer-generated predictive simulation results into usual display[4]. In the domain of robotics and telerobotics, it has been experimented and proved that an augmented display can assist the user of the system[5,6]. In the framework of Xie T, *et al.* (2013) Augmented Reality Aided Teleoperation Guidance (ARATG), AR is not only an important way to handle time delay, but also proved to be a good helper in providing in-time operation guidance[7]. In a general telerobotic system, the operator uses a visual image of the remote workspace to guide the robot. Augmentation of the view with the virtual object would provide an opportunity for the operator who is attempting a motion with the remote robot; to practice it on a virtual robot and visualize the result in the real scene.

The operator can then decide to proceed with the motion based on the results. The robot executes the motion pattern directly thereby avoiding the oscillations often present due to long communication delays to the remote site.

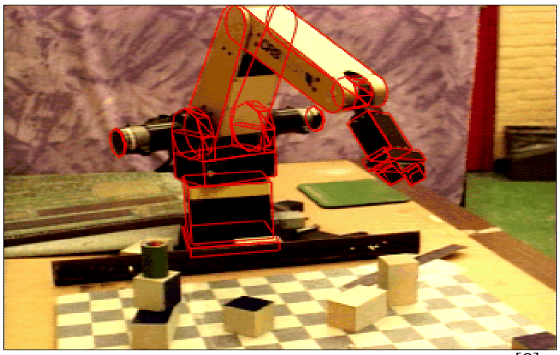

Fig. 1: *Augmented Reality in Robotics.*[8]

Proposed Work

The proposed system aims to develop an Augmented Reality aided tele-robotic system for guiding Robots in Nuclear Power Plants. The Figure 2 depicts the AR Aided Tele Robotic System.

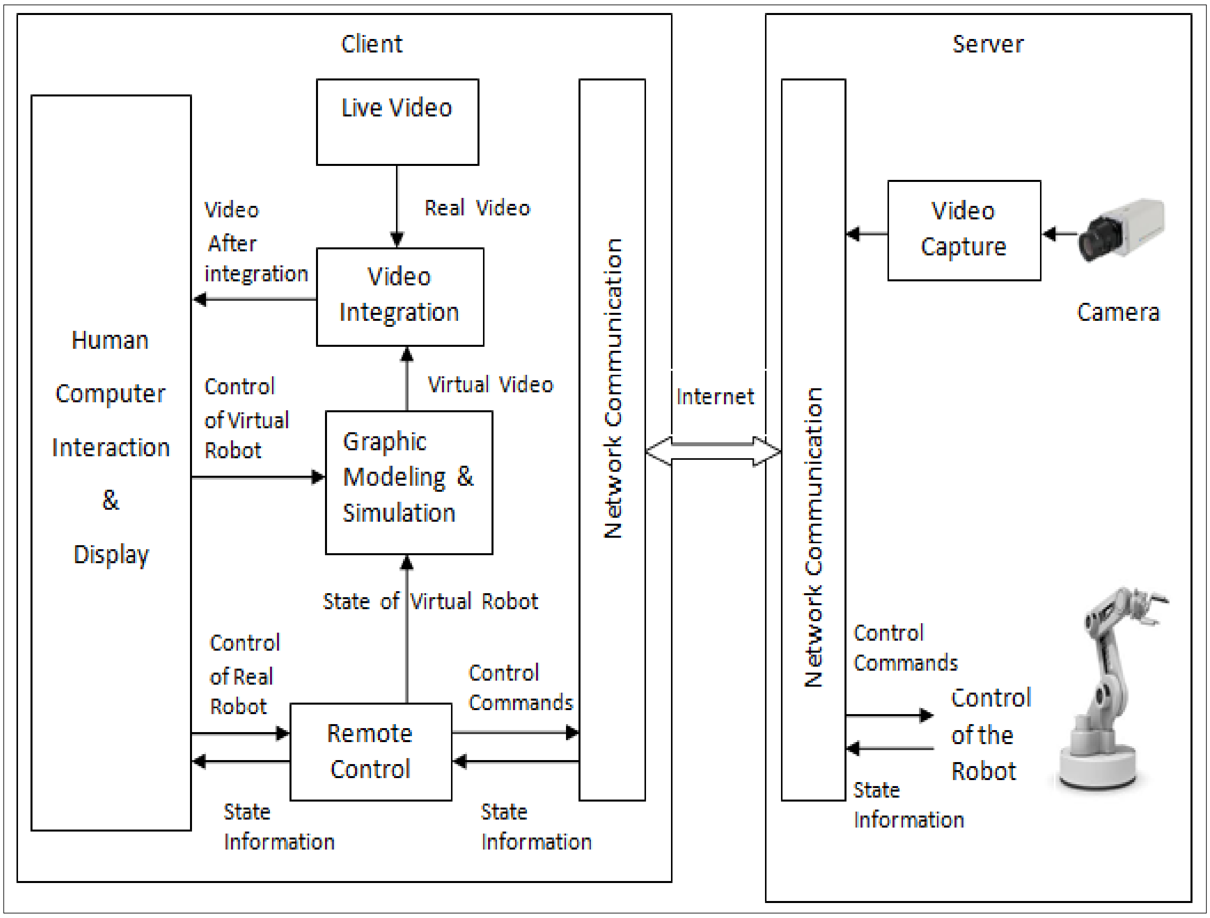

Fig. 2: *Augmented Reality Aided Tele Robotic System.*

The objective is to implement various modules of AR such as capturing module, tracking and registration module, virtual object generation and rendering, display module and user interface and verify the performance of the system. The real video is obtained through the capturing module (camera) and the tracking module uses feature detection algorithm to detect and track the real Robot arm.

The Virtual Object generation is done on the identified Robot arm. The operator controls the motion of virtual model through the user interface and the change in the shoulder and elbow angle of the virtual robot arm is carried over to the real Robot via serial communication.

The Display module takes care of the display of augmented video to the operator.

AUGMENTATION ENVIRONMENT

Telemanipulation Setup

The hardware setup of the tele-operated 2 DOF Planar Robot has been setup. This planar Robot could be placed horizontally without being affected by the gravitational field. There are three major components necessary to drive such a robot arm. One is the RC servo-motor built inside the joint. A power supply (5 V, 2 A) and a microcontroller (Atmega328) are used to drive the servomotor. The Figure 3 represents the schematic diagram of a Planar Robot Arm.

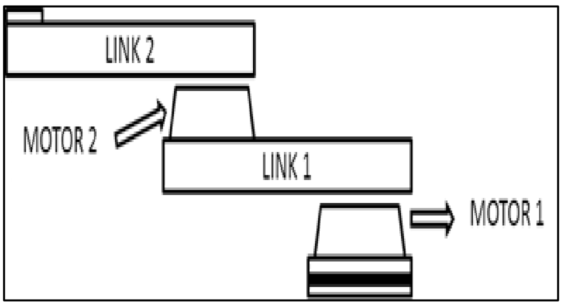

Fig. 3: *Two Link Planar Manipulator*.

Camera and display technology

The major components involved in augmented reality are camera, a computational unit and a display.

The image is captured by the camera, virtual objects are augmented on the top of the image by the system and the results are displayed. For combine the real world with virtual objects in real-time we must configure camera and display hardware. Monitor-based, Video See-through and Optical See-through are three most popular display configurations used now for augmented reality.

The monitor-based display is chosen for this work because of its simplicity and affordability, since a consumer-level PC and USB or FireWire video camera could be used. The video camera constantly captures individual frames of the real working surroundings and feeds each one into the augmentation system. Virtual objects are then fused into the frame, and this final merged image is showed to the operators on a typical desktop monitor.

The augmentation system then process each frame separately, and use vision-based methods to extract pose (position and orientation) information about the user for registration purposes (by tracking features or patterns).

However due to processing of captured frame, there is a potential delay from the time the image is captured to when the user actually sees the final augmented image. Finally, the quality of the imagery is limited by the resolution of the camera. Figure 4 depicts the monitor-based display.

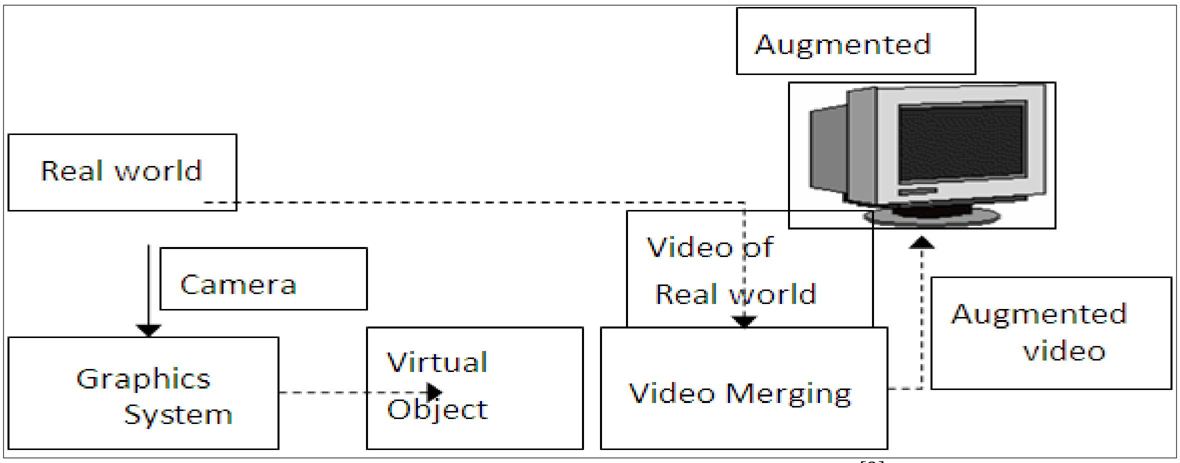

Fig. 4: *Monitor-Based Display Technology* [8]

AR IMPLEMENTATION MODULES

Generation of the Virtual Graphic Model

An articulated robot arm is generated with two segments using OpenGL library. The virtual model of the 2 DOF Planar Robot is drawn using OpenGL and controlled with keyboard inputs. The movement of the Robot Arm is varied by providing increment or decrement angle of 5 degree using Arrow keys to Shoulder angle and Elbow angle. The robot is controlled in the joint space, whereas most of the tasks are done in the Cartesian space. Transformation functions relate the location and orientation of the end effector coordinate system to the base coordinate system. When a command is received to move a link of the robot incrementally by $\Delta\theta$ in the joint space, new value of the angle is calculated by adding the increment to the current value ($\theta = \theta + \Delta\theta$). Then as represented in Figure 5, after checking whether the new value is within stated bound, new location and orientation of the joint point of the particular link and the links above that are calculated using the updated angle values sequentially. The computations are done using the direct geometric transformation equations based on base frame of reference. Once the location and orientation of the end points or skeleton points are calculated, the top and bottom apexes of the body shape (i.e. cube box) are re-calculated.

Then, the whole robot is rendered using the updated vertices. Thus, the robot is moved to a new location with expected position and orientation and the absolute values of joint space variables required i.e., θ (instead of incremental values) have been supplied to move to a specified position, then those angle values are directly used for subsequent computation and to re-draw the robot as previous.

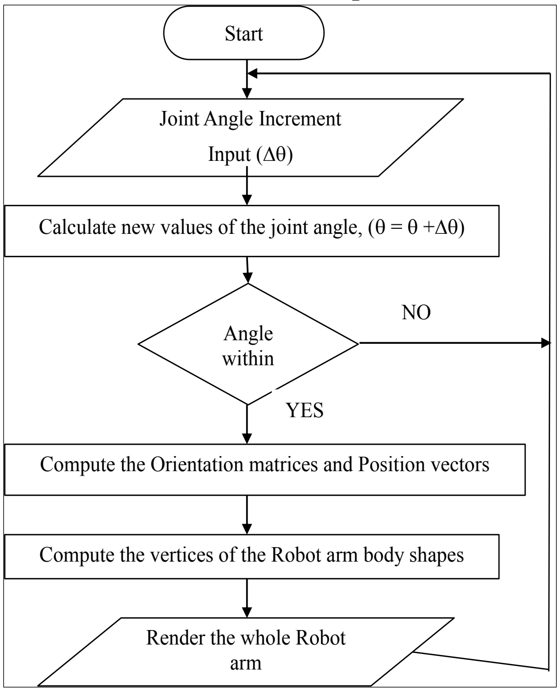

Fig. 5: *Movement of Graphical Robot in the Joint Space.*

Tracking and Registration Module

Augmented reality systems deal with two fundamental technical challenges: tracking the camera's position and orientation in the real world and registering virtual object geometry with images taken from the camera. The following sub sections analyses the various methods available for Tracking and Registration.

Tracking Methods

The tracking module is used to calculate the relative pose (location and orientation) of the Robot in real time of the camera. This module allows the system to add virtual objects into the real world. Many methods such as Sensor-based, vision-based and hybrid tracking are found in literature.

Vision-based tracking uses image processing methods to calculate the camera pose relative to real world objects. Since it has been developed from computer vision and doesn't need much prior knowledge about the scene, it is chosen as the optimum method to be applied in teleoperation. Also since the working environment in Nuclear Power Plant is an indoor AR system, visual tracking is chosen to be used.

Vision-based tracking method used could be either marker-based or feature based. Marker based tracking is widely used in Augmented Reality because of the ease of implementation and due to the availability of well-known marker based toolkits. The tracking method use a predefined easily detectable sign in the environment that can be detected in the video using computer vision technique, image processing and pattern recognition.

Once the marker is detected, both the scale and pose of the camera is defined. The Figure 6 shows a chess board marker upon which the virtual model of the Robot arm is superimposed using image processing and pattern recognition technique in OpenCV.

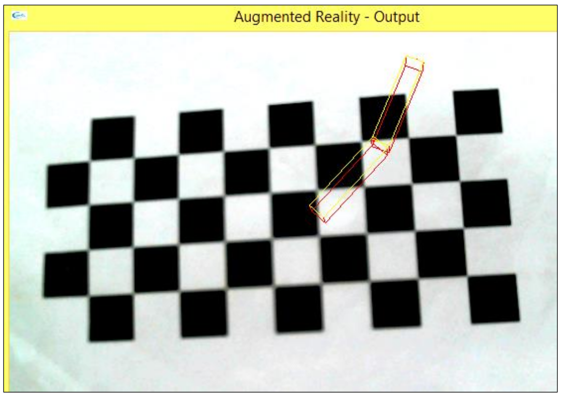

Fig. 6: *Marker Based Tracking and Augmentation of Virtual Robot Arm.*

Marker-based tracking performs precisely and quickly, but has a demand that fiducial marker's should be positioned in the observed scene before process starts. This has a conflict with some teleoperation applications like exploration. Feature based tracking[10] is alternative way which matches natural features, as an alternative of fiducial marker's unique features. Therefore tracking precision and efficiency are all limited when using markerless algorithms relatively. However the markerless method doesn't need to place any physical object into the working environment, which is suitable for our application. In future work instead of the chess board marker, the real robot arm would be used as the feature and the virtual Robot arm would be superimposed on the video. Feature selection, detection and matching or tracking are interlinked and tracking module combine these steps in the same process. These systems tracks real time features and matches it with backgrounds.

Registration Techniques

Registration is a key technology which performs the position registration of virtual scene and the real world. Relying heavily on computer vision technique for registration, results in a trade-off between precision and frame rate. Registration has two types, including technologies based on patterns and natural features. Since the AR technology grounded on natural features can be attained without placing man-made patterns in real scene, it has a wide range of applications. Among the various pattern recognition technique Speeded up Robust Features (SURF) feature detection algorithm is chosen based on the literature survey[11]. It has the same advantages as SIFT but with higher computing efficiency. Since detecting image features from every frame reduce registration efficiency, Lucas-Kanade (L-K) optical flow algorithm based on image pyramid could be used to trace the detected features. The Figure 7 shows the feature detection done using SURF in OpenCV[12].

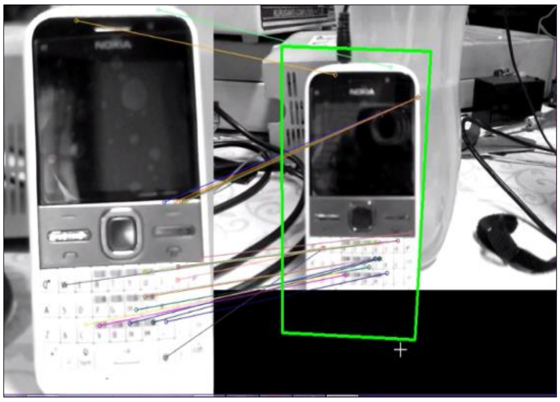

Fig. 7: *Feature Detection and Tracking Using SURF in OpenCV.*

CONCLUSION AND FUTURE WORK

Based on the literature survey and analysis, vision-based tracking with Speeded Up Robust Features (SURF) features detection algorithm is used as the Registration technique for superimposing real and virtual image. The telerobotic setup has been fabricated and interfacing with the microcontroller has been done. The 2DOF Planar Robot Arm Graphic model is developed based on OpenGL library.

The movement of the Robot Arm is varied by providing increment or decrement angle of 5 degree using Arrow keys to Shoulder angle and Elbow angle. Usage of mouse to move the Shoulder and Elbow by the user could be developed. In the future work, Tracking and Image Registration techniques would be applied with the real robot arm as the feature and virtual model would be superimposed onto the real image using OpenCV library. Performance analysis of the proposed system could be done by comparison with the conventional system.

ACKNOWLEDGMENT

Sincere thanks and gratitude to Mr. C. Rajagopalan, SO/F, Programme Lead, ISI Devices, RIRD,MMG, IGCAR, Kalpakkam-603102 and his project team members at RRHS/GRIP, IGCAR for their valuable guidance, motivation and encouragement to accomplish the work successfully.

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