The Use of Industrial Robot Arms for High Precision Patient Positioning

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Abstract. The Indiana University Cyclotron Facility (IUCF) is in the process of designing and building the Midwest Proton Radiation Institute (MPRI) [1]. The design process includes the development of several patient treatment systems. This paper discusses the use of two such systems that provide for the high precision positioning of a patient. They are the Patient Positioner System and the X-ray system. The Patient Positioner System positions an immobilized patient on a support device to a treatment position based on a prescribed Treatment Plan. The X-ray system uses an industrial robot arm to position a Digital Radiography Panel to acquire an X-ray image to verify the location of the prescribed treatment volume in a patient by comparing the acquired images with reference images obtained from the patient’s Treatment plan.

INTRODUCTION

The unique design requirements presented by MPRI [1] for patient positioning has yielded the design of a general system called The Patient Handling System or PHS (see figure 1). This system is responsible for locating a patient in the proton beam isocenter with the correct orientation, as prescribed by the treatment planning process. This system provides feedback of the patient’s location to a Radiation Therapy Technologist (RTT) or Medical Physicist so that he or she can provide corrections to the patient’s position.

Figure 1. The Patient Handling System

Consequently, this system uses two robots, one for patient positioning, and another for acquiring X-rays that are used for patient position verification and correction. The use of a robot arm for patient positioning was previously proposed and are used clinically at the Centre de protonthérapie d'Orsay in Paris, France [2,3] and another system is under development at the Ithemba Labs in Cape Town, South Africa [4]. Both robot systems to be used at MPRI are managed by a control system that monitors the positions of the robots independently of the robot controllers. This is a unique feature of the MPRI PHS system. This control system also provides the interface between the PHS and the treatment room control system (TRCS), thereby providing a high level interface between the TRCS and the robot systems. An advantage of this configuration is that the PHS system is not specific to MPRI’s Proton Therapy System, but can be used in many treatment room applications.

SYSTEM OUTLINE

The PHS receives requests from one or more authorized external control systems to position a patient. Patient position for treatment can be verified or checked for corrections by reviewing X-rays acquired from the X-ray System.

The Robot Interface and Position Verification System (RIPVS)

The Robot Interface and Position Verification System (RIPVS) provides two features. The first is directly related to patient positioning, which is to provide an interface between an external control system, such as a room controller and the robotic systems used in the PHS. Such an interface will allow for the downloading of robot job files, manual jog commands, and the reporting of robot position data back to the user interface.
The second feature of RIPVS is a safety function that provides a verification of a robot’s position in the room as a redundant position check. This feature also includes a comparison of position requests with known collision points in the room.

It is important to note that RIPVS will only allow one robot at time to be enabled. Consequently, it is not possible to have the Patient Positioner and the X-ray system running simultaneously.

The Patient Positioner

The Patient Positioner is composed of a robot system, docking station, patient support device, and gurney. This system is responsible for moving the patient safely from a fixed docking station to the treatment position. This system can also be used to move other devices such as a Water Phantom.

The robot system uses a controller that can receive programs or jog commands over an Ethernet connection. The manufacturer has supplied a high-level communications library so that the RIPVS software can communicate with the controller.

The manufacturer of the robot has specified repetitive positioning accuracy of +/- 0.2mm at a maximum payload of 200 kg.

![Patient Positioner in Installation](image)

**Figure 2.** The patient positioner shown during installation with the bed attached to the robot arm.

Docking Station

The Docking Station provides a means of “docking” a gurney, which accurately and securely supports a patient support device in such a manner, that the Patient Positioner can pick up the support device. The patient is immobilized onto the patient support device. Both the support device and the Patient Positioner robot are outfitted with standard industrial automatic tool changer components that allow for quick coupling and decoupling of the support device.

Patient Support Device

This is either a carbon fiber bed shown in figure 2 or chair that is equipped with a tool changer component that matches the Patient Positioner’s tool changer. These devices also contain accelerometers, (for over acceleration and collision detection), and a tilt sensor. The output of these transducers are routed directly into a “safety circuit” that will activate an emergency stop if the signals are beyond set thresholds.

Gurney

The Gurney is a standard hospital gurney that has been modified to allow the Patient Positioner to reach under the support device, couple to the support device and lift and move the device into the treatment position. The gurney also is outfitted with locking mechanisms that secure the gurney precisely to the docking station.

The X-Ray System

The X-Ray System is responsible for acquiring X-ray images of a patient once he or she is positioned at the isocenter. Consequently, this system provides a RTT, or Medical Physicist the tools required to analyze images acquired from the X-ray system, and then iteratively modify the Patient Positioner’s current position if a correction is required.

The X-ray System is composed of a Panel Positioning Robot, Digital Radiography (DR) Panel, X-ray Source and Generators and a Image Acquisition and User Interface Computer.

DR Panel Positioning Robot

This robot is a small 20 kg payload robot that is mounted above the Patient Positioning System. This robot typically has one standing program that receives request to position the DR Panel in one of several predefined positions. Each predefined position is associated with a static X-ray source, permanently mounted in the treatment room that can be “fired” from the Image Acquisition and User Interface computer, once the DR panel is properly positioned.

The robot system uses a controller that can receive programs or jog commands over an Ethernet connection. The manufacturer has supplied a high-level communications library so that the RIPVS software can communicate with the controller.
The manufacturer of the robot has specified repetitive positioning accuracy of +/- 0.06mm at a maximum payload of 20 kg.

**Digital Radiography Panel**

The X-Ray System uses a Digital Radiography (DR) Panel to acquire images directly in a digital format. This allows analysis of the images with a variety of image analysis tools available to the Medical Physicist. The Panel is mounted in a frame that has a tool changer component so that the system can select from different panels, depending on the application.

The panel assembly has accelerometers and distance sensors to monitor over acceleration and potential collisions. Such signals are monitored by a safety circuit similar to the one outlined in Section 2.2.2. The output of these transducers are routed directly into a safety circuit that will trip an emergency stop if the signals are beyond set thresholds.

**X-ray Source and Generators**

Each X-ray source is mounted in a fixed location in the treatment room. To save space, dual source generators are used. For a set of two orthogonal X-rays, each generator will fire only one source, thereby reducing total patient set-up time.

**Image Acquisition and User Interface Computer.**

The Image Acquisition and User Interface Computer provides a user interface to the X-Ray system so that a user can request an image, then store that image to a file for further analysis. This system also has the interface card to the DR Panel. This card provides a trigger signal to the X-ray generators. The computer system communicates with the X-ray generators using RS-232 communication, allowing the user to modify exposure settings on the generator.

Robot positions are selected from a user interface provided by the control software.

**SOFTWARE**

**The RIPVS software**

The PHS robot systems are primarily controlled through the RIPVS software. The RIPVS software performs the following functions,

- Download robot program files generated from external control systems.
- Record Events that occur during a transport.
- Monitor and verify the location of a robot load support during transport, using a vision system.
- Allow for user “jogging” of a robot.
- Validate a robot’s load position.
- Provides collision checking.

**Download Robot Program Files**

Robot program files, called job files, are generated in a treatment planning process where treatment planning parameters are used to calculate a robot trajectory. These job files contain the calculated robot trajectories and are tested in a robot simulation software package prior to execution on the PHS to verify the behavior and outcome of a robot when controlled via these job files. Such program files are then marked for acceptance and stored for use during patient treatment. At the time of patient treatment the job files are downloaded to RIPVS from an external control system, such as a room controller, and are executed.

**Record Events**

RIPVS, as stated earlier, communicates to the robot controllers using an Ethernet connection. Robot coordinate data and vision system coordinate data are logged for any given robot motion. The RIPVS controller also can monitor the Patient Positioner Safety Circuit for the occurrence of an over tilt or acceleration and log such events.

**Monitoring Robot Motion**

RIPVS can monitor the motion of a robot external to the robot’s controller by employing a vision system. This system monitors the location of three reflective markers located on the robot load device i.e. the patient support device or the DR panel. The vision system interprets the markers as coordinates and RIPVS uses the three coordinate sets to determine the location and orientation of the load device. RIPVS also uses the information to determine illegal tilts and rotations of the load device by calculating vectors orthogonal to the load device and the robot’s tool center (both are parallel to each other). In the event of an error RIPVS initiates an emergency stop.

**Jogging the Robot**

RIPVS will handle jogging requests that are submitted by external control systems or at the RIPVS console. Such requests are received through a TCP/IP socket. Upon receiving the position request RIPVS performs a
Validate a Robot Load Device

RIPVS treats the patient support devices and the DR panel as load devices. Such devices must have a serial number so that the correct support device or DR panel is being used for the given treatment. The serial number is a binary value that can be “sensed” through the tool changer mounted to the device.

Collision Prevention

RIPVS uses a “Safety Volume” concept to monitor the position of a robot. This can compensate for the delay in calculating the validity of a given position or potential collision by the system. Consequently, RIPVS always assumes that the robot is larger than it actually is, which allows for an intervention by RIPVS in the event of a position error before a collision.

Stated another way, collision prevention will be accomplished by comparing the magnitude of the distance vectors of the reflective markers to that of known collision points. Such points will be stored in a table in the RIPVS controller. If the magnitude of such a vector is within a predefined tolerance, then the RIPVS will initiate an emergency stop to the robot controller.

The Image Acquisition and User Interface Software

The software for the X-Ray system’s Image Acquisition and User Interface Computer is very basic. It provides the minimum user interface to allow a user to select a DR panel position and synchronizes it with the appropriate X-ray source and generator. It also controls the X-ray sources and generators. As stated above all robot movements are controlled through RIPVS.

Summary

Using industrial robot arms offers a cost effective and flexible solution to high precision patient positioning. The movements of such robot arms can be controlled through a system that monitors the positions of the robots independently of the robot controllers. This offers a redundant level of safety without compromising the flexibility of such systems. The PHS system a designed for the MPRI facility can easily be installed and utilized in a conventional radiotherapy facility.

References


