ISBN: 978-3-95450-212-7 ISSN: 2673-5482 doi:10.18429/JACoW-CYCLOTRONS2022-THPO006

DESIGN AND IMPLEMENTATION OF ROBOT ADAPTER IN THERAPY CONTROL SYSTEM

Shangmeng Jiang[1,†], Zhiguo Yin[1], Yang Wang[1], Tianjue Zhang[1], Qiqi Song[1],
Qingzhen Zhu[2], Cheng Qi[3], Qiyong Ran[2]
[1]China Institute of Atomic Energy, Beijing, China
[2]Konica Minolta Zaiqi Medical Products (Shanghai) Co., Ltd., Shanghai, China
[3]Leoni Cable (China) Co., Ltd., Jiangsu, China

Abstract

The China Institute of Atomic Energy (CIAE) in Beijing has designed and established a proton therapy facility based on a superconducting cyclotron CYCIAE-230, which can provide proton beams with energy from 70 MeV to 230 MeV for cancer treatment. As the most critical and core part of the proton therapy system, therapy control system (TCS) consists of various components, each of which has corresponding processing services. Motion control of external hardware systems is one of the essential parts of TCS development, and adapters figure prominently in the interaction between services and these external hardware systems. One of the adapters, called robot adapter, is specially developed for the external robotic couch system, which is a vital equipment that directly contacts patients in the whole process of proton therapy. This adapter serves as the connection between TCS and robotic couch for communication and corresponding movement. In this paper, we introduced the communication protocols, design, and characteristics of robot adapter as well as the actual test contents and results with the robotic couch. The test results indicated that the robot adapter can satisfy the needs of couch motion control and status monitoring.

INTRODUCTION

Protons have been successfully utilized in the treatment of cancer in recent years, and proton therapy is superior to the conventional photon radiation therapy due to its physical properties, making it one of the world's preferred choice for cancer particle radiotherapy methods [1]. From 1954 to 2021, more than 324,000 patients worldwide underwent particle therapy, 86% of whom received proton therapy. According to Made in China 2025, high-performance medical equipment including proton heavy ion therapy system is explicitly listed as one of the top ten key industries [2]. CIAE has established a superconducting cyclotron that generates 230 MeV proton beam to promote the development of proton therapy in China [3].

Accelerator control system (ACS) is a complete automatic system for medical accelerator equipment, which realizes the automatic start-up, real-time monitoring, control, and protection of 230 MeV superconducting cyclotron related equipment. The system has complete status monitoring and fault diagnosis functions, including automation, operation status monitoring, equipment safety interlocking, automatic recording of operation data, etc. in each accelerator subsystem equipment.

Beam control system (BCS) is a distributed control system with a standard control model structure. It uses an energy selection system that adjusts the energy of the extracted proton beam according to the different depths and thicknesses of the tumor. Energy degrader, the core component of the proton energy selection system, is mainly used to adjust the energy between 230 MeV and 70 MeV.

As the central system of proton radiotherapy, therapy control system (TCS) not only integrates all the execution systems involved in the treatment, but also is responsible for the management of the whole proton radiotherapy process. The treatment process includes patient setup, setup verification, equipment movement, dose delivery, treatment report, etc. It commands and controls the proton beam hardware in each link of the treatment process.

Scan dose diagnostic (SDD) is a software program of the Scan Dose system that enables a complete dose delivery nozzle by running maps and generating records, even though it is not designed for clinical dose administration. SDD can compute the threshold used and monitor the beam characteristics to ensure that the treatment is performed according to preset limits. In addition, SDD can record all parameters relevant to the treatment and provide room-centric and facility-centric interlock chains, so as to achieve fast beam shutdown.

In the whole proton therapy system, ACS can ensure the normal operation of the accelerator and the proton beam at 230 MeV. BCS can adjust the proton energy between 230 MeV and 70 MeV to meet the requirements of the clinical treatment regimen. It receives and processes the beam request of TCS, and arranges the beam supply to the designated treatment room. TCS uses the adapter to provide treatment prescription data to SDD. SDD distributes a predetermined dose of beam by controlling the extraction and monitoring the ionization chamber. If SDD is not directly connected to ACS, TCS can provide a channel between them.

ROBOT ADAPTER

Adapters support each specific subsystem independently. Each adapter is responsible for monitoring the status of its corresponding subsystem, and receiving and processing the operation information issued by services in TCS.

The robot adapter is designed for the external robotic couch system amid various adapters. Figure 1 shows the overview of the interaction between the robot adapter and the robotic couch and internal components in TCS.

† shangmeng99@foxmail.com

ISBN: 978-3-95450-212-7 ISSN: 2673-5482 doi:10.18429/JACoW-CYCLOTRONS2022-THPO006

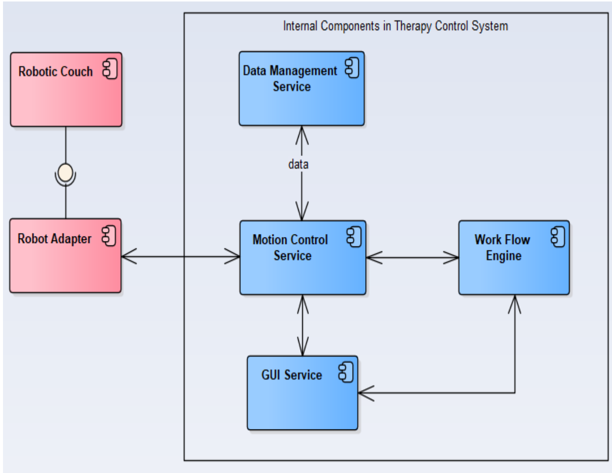

Figure 1: Interaction between the robot adapter and the robotic couch and internal components in TCS.

The motion control service in TCS is responsible for the motion control of the robotic couch, and feedback information such as couch status and coordinate position to the central workflow engine and TCS-GUI. The motion control service needs to send the motion requests of the robotic couch and modify the configuration parameters. Data management service stores patient setup information and verification results.

To invoke the interface of the robotic couch without altering the internal program of TCS, we extended TCS by developing a robot adapter. The interfaces implemented by the robotic couch are known as the provided interfaces, which denotes that the robotic couch offers robot adapter services. When the robot adapter requests services from the robotic couch, it should follow the required interfaces used by the robot adapter.

The robotic adapter controls and monitors the movement of the robotic couch system. It connects the data interaction between motion control service and robotic couch system. If there are specific requirements for the coordinate input of the robotic couch system, the robotic adapter is responsible for further converting the IEC coordinates transmitted by the motion control service.

Communication Protocols

TCS uses Data Distributed Service (DDS) to interact with the robot adapter to obtain high-performance real-time process data. DDS is a machine-to-machine middleware protocol and API standard of the Objective Management Group [4]. Interface Description Language (IDL) defines various data models (called topics in DDS terminology). By using DDS technology, TCS is completely decoupled from the external devices that need to be connected and controlled. The data flow interaction between TCS and robot adapter is only specified by the data model IDL.

The robot adapter uses Hyper Text Transfer Protocol (HTTP) to control the movement and status acquisition of the couch. The robotic couch can be remotely controlled on port 8081 by using HTTP/1.1 client.

Interface Information Summary

The robotic couch can be remotely controlled by using HTTP/1.1 client on port 8081. To use its API, JSON objects must be sent to the "/api" path on the ACU server. All commands should be HTTP POST. A method called "PromiseCommand" is compiled to implement requests for the robotic couch. Each request passes a command field, and the value is a specific operation instruction. The data structure requirements for command input parameters and response return values are shown in Tables 1 and 2, respectively.

Table 1: Command Input Parameters Type

Parameter	**Type**
command	string
param1_key	JSON
param2_key	JSON
…	
paramN_key	JSON

In Table 1, each command needs to enter a command name of string type. There can be multiple key-value pairs, and each value can be any JSON type.

Table 2: Response Return Value Type

Parameter	**Type**
command	string
returned_argument_1	JSON
returned_argument_2	JSON
…	
returned_argument_N	JSON
success	bool
error	string
masterId	string
result	object

In Table 2, a command is a confirmation of the received command name. It would be the same as the command parameters sent. There can be multiple return arguments, and each argument can also be any JSON type.

Success indicates whether the command is successfully received and executed. For motion commands, success means that the command is correctly interpreted and sent to the motion controller. If false, the "error" parameter should return the reason why this command failed. The command failure is described as the error if success is false. If there is no error, its value would be an empty string.

Functionalities

In the whole system, robot adapter act as a link between TCS and robotic couch. Therefore, the robot adapter should possess several principal functionalities as follows:

- Be able to establish a connection with the robotic couch and send commands to it in the format of HTTP POST.

23rd Int. Conf. Cyclotrons Appl. CYCLOTRONS2022, Beijing, China JACoW Publishing
ISBN: 978-3-95450-212-7 ISSN: 2673-5482 doi:10.18429/JACoW-CYCLOTRONS2022-THPO006

- Be able to get position information (IEC coordinate system) and joint position information from the robotic couch and send them to TCS.
- Be able to acquire the status of the robotic couch system at a regular interval and keep TCS informed of current status, including Ready, Moving, Error and Collision.
- Under the requirement of the motion of the robotic couch based on path or target position, the robot adapter can receive respective the corresponding parameters from TCS, and then instruct the robotic couch to move properly.

THE ROBOTIC COUCH REFERENCE

The robotic couch system has five states: CONFIG, READY, BUSY, UNHEALTHY, and COLLISION. The state transition of the system follows the state transition structure diagram (Fig. 2).

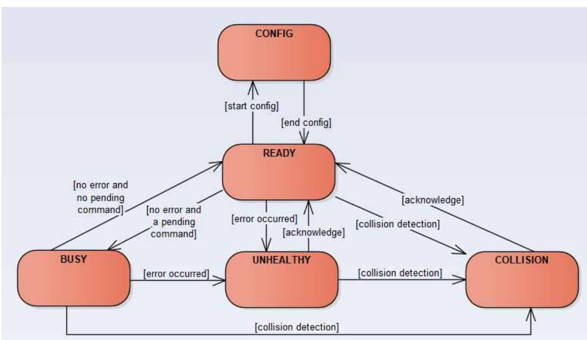

Figure 2: State transition structure diagram.

The robotic couch is involved in patient setup and setup verification, as shown in the following sequence diagrams (Figs. 3 and 4).

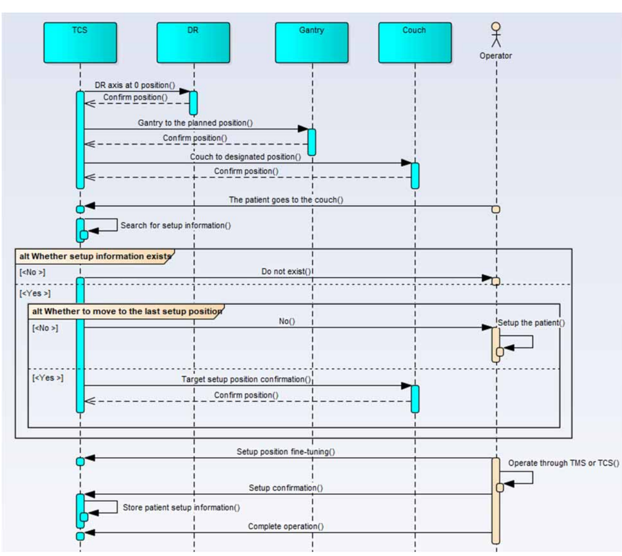

Figure 3: Setup sequence diagram.

Figure 3 shows the interaction during the patient setup process, which involves five objects: TCS, digital radiography (DR), gantry, couch, and operator. First, the DR axis is at position 0, and the gantry moves to the planned position. Then, the couch moves to the designated position, which facilitates the operator to help the patient move to the couch. Setup information can be searched using TCS in data management service. If the information does not exist or exists but the operator decides not to move to the last setup position, the manual setup will be performed. Otherwise, the couch will move to the target position. Afterward, the operator could fine-tune the setup position and confirm the position through TCS. Finally, the setup information of the patient can be stored in TCS.

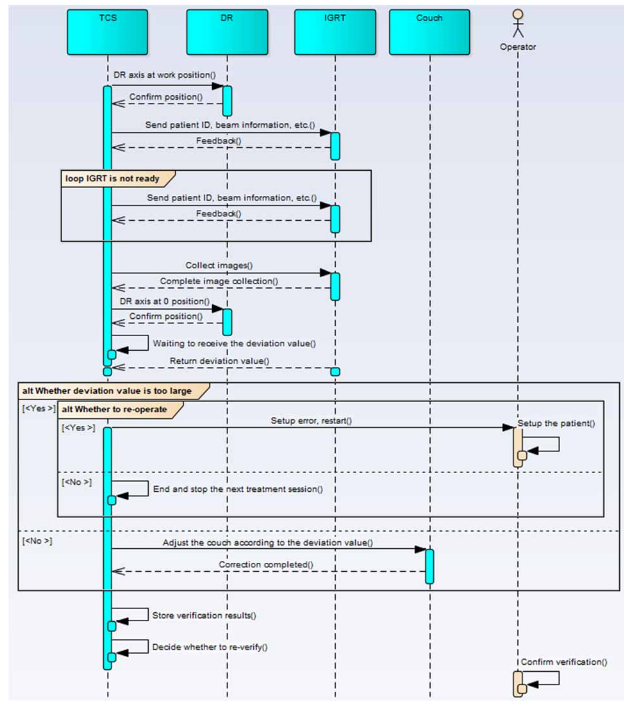

Figure 4: Setup verification sequence diagram.

Figure 4 shows the interaction during the setup verification process. This process involves five objects: TCS, DR, image-guided radiation therapy (IGRT), couch, and operator. First, the DR axis is at the work position, and TCS sends a message to IGRT. The sending operation will be repeated continuously if IGRT is not ready. Then, it is time for IGRT to collect images of the patient. The DR axis changes to position 0 and TCS waits to receive the deviation value computed by IGRT. If the deviation value is too large, the operator can decide to restart the patient setup process, or end and stop the next treatment session. If deviation value is not too large, the couch will be adjusted according to the deviation value. Then TCS stores the verification results and decides whether to verify again. Finally, the operator confirms the verification.

TEST WITH THE ROBOTIC COUCH

The network address was set to `http://192.168.0.2:8081` for testing. HTTP module of NodeJS was used to obtain the status of the robotic couch every 100 ms. In this way, the connection between robot adapter and robotic couch was established and maintained.

ISBN: 978-3-95450-212-7 ISSN: 2673-5482 doi:10.18429/JACoW-CYCLOTRONS2022-THPO006

Windows 10 64-bit Professional Edition was selected as the operating system and the unit test was performed using the robotic couch under the running environment of node 14.1.0 to verify the consistency between the functionality implemented in the interface and the interface design files.

With the help of the test tool, Postman, we simulated the following process: TCS sends requests to the robotic couch, the robotic couch receives and executes requests, then returns responses to TCS, and TCS receives the response.

Adding a new path needs the coordinates of several points. By moving the robotic couch to different locations and using the command `getStatus` at each location, the coordinates of a series of points will be obtained in the form of response, which can then be added to the new motion path as joints.

Adopting white box testing, unit test on relevant interface methods of the robotic couch is as follows (Table 3).

Table 3: Actual Tests

Interface	Description	Result
acquireMasterSession	Control right gaining	Successfully gain control right in clinical mode
getStatus	Status acquisition of the robotic couch	Successfully get current position, moving speed, etc.
jogJoint	Single-axis motion	Successfully jog along a single axis
gotoCartesian	Multi-axis motion	Successfully move to a certain point at specified speed and acceleration
gotoPath	Movement based on the preset path	Successfully move along the path that has been saved in advance in the robotic couch system
creatOrModifyPath	Setting a new motion path for the robotic couch	Successfully add a new path with several points

CONCLUSION

In our design, the robot adapter connected TCS with the robotic couch. DDS was selected to interact with high-performance real-time process data in TCS, and HTTP was selected to communicate with the robotic couch. The robotic couch is involved in patient setup and setup verification. Unit test on relevant interface methods of the robotic couch has been conducted, and the results illustrated the functions of status monitoring, motion control, and path management.

REFERENCES

[1] B. Qin *et al.*, "Design study of a 250 MeV superconducting isochronous cyclotron for proton therapy", in *Proc. 12th Symposium on Accelerator Physics* (*SAP'14)*, Lanzhou, China, Aug. 2014, paper WEPMH3, pp. 23-25.

[2] K. Tian, Z. Peng, and X. Han. "Current situation and development trend of proton heavy ion hospital construction", *Chinese Hospital Architecture & Equipment*, vol. 23, no. 08, pp. 20-24, 2022.

[3] T. Zhang, C. Wang, *et al.*, "Developments for 230 MeV superconducting cyclotrons for proton therapy and proton irradiation", *Nucl. Instrum. Methods Phys. Res. Sect. B*, vol. 406, pp. 224-249, 2017. doi:10.1016/j.nimb.2016.11.010

[4] DDS, http://portals.omg.org/dds