ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-TUPHA056

CONCEPTUAL DESIGN OF TREATMENT CONTROL SYSTEM FOR A PROTON THERAPY FACILITY AT HUST*

Wei Li, Dong Li†, Ping Tan,
State Key Laboratory of Advanced Electromagnetic Engineering and Technology,
Huazhong University of Science and Technology, Wuhan 430074, Hubei, China

Abstract

A proton therapy facility based on a superconducting cyclotron is to be built by Huagong Tech Company Limeted, Wuhan, China. This facility is aimed at providing proton beams with continuously tuneable energy from 70 MeV to 250 MeV, for kinds of cancer treatments. Our team is responsible for the development of the treatment control system, which consists a number of functional modules and connects to many subsystems. In this paper, we will report our conceptual design of the treatment control system.

INTRODUCTION

With the development of science and technology, proton therapy has made significant advances in the last ten years. While not yet considered as the main method of therapy, proton therapy is becoming widely available in cancer therapy centers, a number of proton therapy facilities are being built and planned all around the world [1].

Due to the great number of cancer patient in China, the demand for proton therapy is growing very fast. The development of proton therapy facility (PTF) directed by the Huagong Tech Company Limeted (HGTECH) is one of the projects supported by the Ministry of Science and Technology of China in the thirteenth five-year plan for science and technology.

The PTF mainly consists of a superconducting proton cyclotron, beamline system, gantries, scanning system, patient positioning system, Image Acquisition and Registration system (IAR), Safety Interlock System (SIS) and Treatment Control System (TCS). With degrader in the beamline, the proton beam with an energy ranging from 70 MeV to 250 MeV is delivered to the treatment room for cancer therapy. The TCS propagates the treatment information from the Oncology Information System (OIS) to other subsystems, coordinating the operation of all the subsystems based on the defined workflow. It provides the Graphical User Interface (GUI) to the clinical and other users for operation, and enables the users to execute the clinical and quality assurance workflow. In this paper, we will present the architecture design and functionalities of the TCS for this PTF.

TREATMENT CONTROL SYSTEM

The treatment control system is internally divided into a number of independent modules for specific functionalities, including the interface modules to subsystems. All the modules are designed to be standalone applications, each of them runs as a separate process, so that one will not affect another. The overview of the TCS is shown in Figure 1.

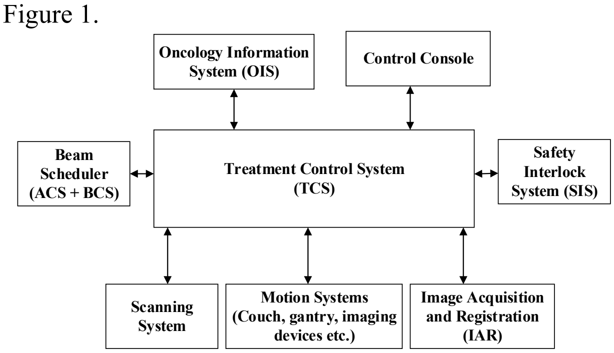

Figure 1: Overview of the treatment control system.

Data Distributed Service

The Data Distributed Service (DDS) is used for the internal communication among the TCS modules. It is an objective management group (OMG) machine-to-machine middleware standard [2]. It enables scalable, real-time, dependable, high-performance and interoperable data exchanges by using different strategies of QoS (quality of service) between the publisher and the subscriber, i.e. the modules of TCS. Thus, the TCS modules can exchange information in multiple modes: one-to-one, one-to-many and many-to-one. The nature of the DDS publish-subscribe pattern allows the individual modules to run over different hosts, which are connected through internet, thus the modules are transparent to each other. A central broker is not necessary for communication among modules in the TCS, therefore, this design prevents the effect of a single module failure to the whole systems, providing high reliability.

Functionalities

The TCS is basically a software used to guide and help the users to deliver the treatment according to the prescribed plan. Therefore, the TCS should have the following major functionalities from the users' point view:

- Allow the users to verify the patient information and prepare specific equipment;
- Allow the users to position the movable devices, e.g. couch;
- Allow image guidance, i.e. the image acquisition of X-ray or CBCT, thus allow automatic correction of the patient position using the registration information;
- Guide the users to perform required steps for a treatment session, inform the users about problems and safety issues when needed;
- Allow the users to execute the irradiation and moni-

* Supported by national key R&D program, 2016YFC0105308
† email address: lidonghust@hust.edu.cn

ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-TUPHA056

tor the progress, record the status of a stopped treatment;

- Display the relevant status information of all connected systems (e.g. accelerator system, safety interlock system, etc.).

Main Modules

As aforementioned, the TCS is internally divided into a number of modules, and the modules are connected using DDS for communication. These main modules are as following:

Workflow Execute Module (WEM): This module is mainly responsible for actually controlling and directing the flow of the entire TCS operations. It is internally designed with finite state machine to determine its behavior, so that the TCS operation will follow the required procedures defined by the workflow. This is one of the most important modules in the TCS, and it is complex due to its capability to handle various situations throughout the treatment session. The flow of this module (i.e. the sequence of operations during the therapy) should be designed according to the requirements of different users (the therapist, the engineer and medical physicist) for different operation modes.

Graphical Interface Module (GIM): It provides graphic interface to users, and serves as the main entry point into the TCS with respect to the patient verification, patient positioning, beam delivery and so on. It communicates with other modules using the DDS mechanism over a network connection. Since this module is used to visually assistant/guide users, e.g. to help position the patient, couch or gantry, it should display the relevant information both in the treatment room and the control room, but they are not necessary to be the same.

Motion Management Module (MMM): This module is designed to operate the movable devices of the system, including the coach, gantry and nozzle, hence it is in charge of the interfaces to the movable devices. The input of MMM is mainly from the handle pendant during preparation, the treatment plan for gantry and nozzle position, and the IAR interface for automatic position correction. This module is aware of the current position of the movable devices, thus, it also contains the collision prevention logic of the system.

Resource Management Module (RMM): It manages the access to the beam resources (accelerator and beamline). MMM receives the beam request and schedules the right of beam access to one treatment room in a mutually exclusive way. This mechanism prevents the beam to be used by two different treatment room in two conflicting operation modes or to perform conflicting actions. For example, during the beam delivery session, request of beamline parameter change from another treatment room is not allowed.

Besides, there are some other modules for different functionalities. For example, the Logger Module monitors and stores all messages internally exchanged between modules. There are also some interface modules to related systems for communication or exchanging data/file. For instance, the Treatment File interface (TFi) is connected to the OIS, it is used to receive the treatment plan in Dicom-RT format, interpret and distribute the data to the corresponding modules during preparation stage. This module is also responsible for receiving the treatment data from subsystems and uploading the result to the OIS.

Treatment Workflow

The treatment procedure is controlled and directed by the WEM of TCS. As it's shown in Figure 2, the conventional process of treatment can be roughly separated into three stages: treatment preparation (1 to 5), beam delivery (6) and ending treatment (7 to 9).

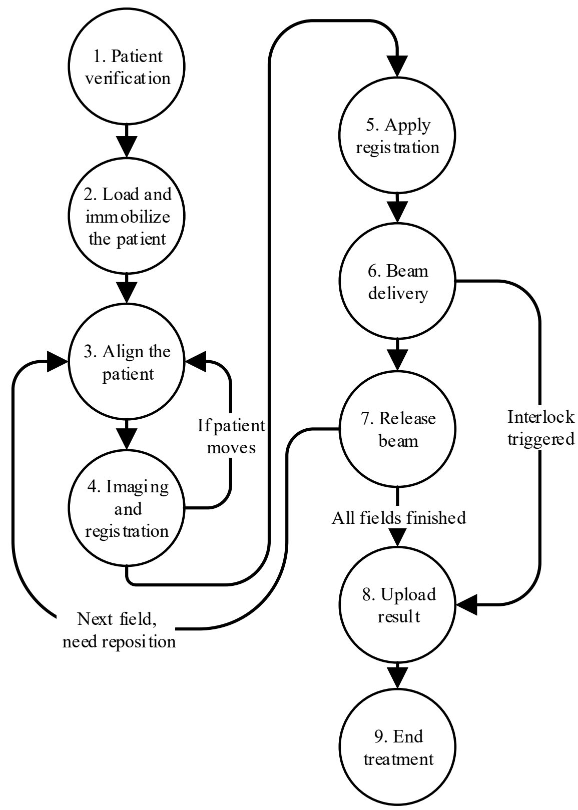

Figure 2: Conventional process of a treatment.

In the preparation stage of a treatment, the user (therapist) should verify the patient information to make sure that the right patient is treated. Patient is loaded to the couch and immobilized with specific devices. During patient alignment, the laser in the treatment room should be turned on, and the makers on the surface of patient/mask should be aligned to the crossing point of the lasers. To accurately position the patient, the IAR system is employed, the correction vector is built by comparing the newly acquired images and the planning images. After the correction vector is applied, the patient is well positioned. The subsystems like accelerator, beamline and scanning system should be well prepared for treatment. When all the systems are ready, it goes to beam delivery stage. In this stage, the WEM in treatment room applies for beam control and hands out the control right to the scanning system, only the GUI monitors the progress of beam delivery. The right of beam access is released when

ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-TUPHA056

a field of treatment is finished. If all fields are finished, the TCS will gather the treatment results and upload it to the OIS. Inside each of the states, there is a complex workflow, which includes the response to failure of modules and emergencies.

RELATED SYSTEM

Accelerator and Beamline Control System

Since the design of the superconducting cyclotron and beamline are undertaken by the China Institute of Atomic Energy (CIAE) and HUST team respectively, the control systems of the accelerator and beamline are separated. The control systems of these two constitute the machine control system. The main purpose of the accelerator control system is to produce stable fixed-energy proton beam. An electrical deflector is designed in the cyclotron central region for the beam intensity tuning by controlling the bias voltage between the plates. Beamline control system is used to deliver proton beam with proper energy and shape to the specified treatment room. The proton beam energy is changed by adjusting the thickness of graphite in the Energy Selection System (ESS) in the upstream of the beamline, and the beam shape is selected by choosing the proper combination of beam optics and collimators. The machine control system serves as a beam production unit for the connected treatment rooms, it is also connected to the scanning system to generate proton beam with specific parameters for delivery. Another important role of the machine control system is the executor of resource management, which has a mechanism to prevent conflicting beam operation among the treatment rooms.

Scanning System

This system is the main driver of the therapy in the facility, and it typically receives the treatment plan of a field from the TCS. To play it out, it uses the cyclotron and beamline to produce a beam with appropriate parameters (energy, size, intensity etc.) and the scanning magnets to transversely scan the beam over a layer of the tumor. The dose delivered into each spatial voxel, beam position and beam size are monitored using two ionization chambers in the nozzle. When beam parameter (e.g. the beam position) is detected to be incorrect, the scanning system should be able to terminate the beam and trigger the safety system simultaneously. Thus, the real-time control of this system is needed, and interlocks can be generated by the controllers for safety system. The scanning system is currently developed for pencil beam scanning technique, but it is capable of upgrading to intensity modulated scanning mode in the future.

Safety Interlock System

The Safety Interlock System is aimed at protecting the patient from radiation hazards by minimizing the risk from an uncontrolled irradiation [3]. Thus this system is designed with redundant sensors and final elements. Parameters of key devices need to be measured with at least two independent methods to ensure that the parameters are measured correctly. The final element devices are also designed to be redundant, when the SIS is triggered, they are activated simultaneously, each of them are able to terminate the beam. These final elements need to be designed in a "fail-safe" principle. The status of TCS in each treatment room is an important input to the SIS, because this is an important part of the interlock logics. The SIS should also inform the TCS about its status, so that the TCS can follow the right workflow, for example, if the SIS is triggered, a treatment should be stopped and patient should be removed

CONCLUSION

In our PTF project, the primary design of treatment control system consists of separated modules running as standalone applications, DDS is chosen for the communication among internal modules. Since the TCS is basically a medical software, its development should follow the procedures of international standards, such as IEC-62304, and this will take much of the development efforts.

In this paper, we also described several main modules, their functionalities and main treatment workflow. The accelerator and beamline control system, scanning system and a primarily design of safety interlock system is introduced.

ACKNOWLEDGEMENT

During the design of this treatment control system, we have got a lot of help from Cosylab d.d. in Slovenia, we would like to express our gratitude to the Cosylab, especially to Gregor, Dominik and Klemen for useful discussions and suggestions. The authors would also like to thank all colleagues at institute of applied electromagnetic engineering, HUST, for their useful discussions and technical supports. This work is supported by the national key R&D program, 2016YFC0105308.

REFERENCES

[1] https://www.ptcog.ch/index.php/facilities-in-operation

[2] http://portals.omg.org/dds/.

[3] M. Grossmann, "Therapy Control and Patient Safety for Proton Therapy", *Proceedings of the CAS-CERN Accelerator School on Accelerators for Medical Applications*, Vol 1 (2017), http://dx.doi.org/10.23730/CYRSP-2017-001