NEURAL NETWORK BASED GENERALIZED PREDICTIVE CONTROL FOR RFT-30 CYCLOTRON SYSTEM

Young Bae Kong, Eun Je Lee, Min Goo Hur†, Jeong Hoon Park, Yong Dae Park, Seung Dae Yang
Radiation Instrument Research Division, Korea Atomic Energy Research Institute,
Jeollabuk-do, Republic of Korea 580-185

Abstract

Beamline tuning is time consuming and difficult work in accelerator system. In this work, we propose a neural generalized predictive control (NGPC) approach for the RFT-30 cyclotron beamline. The proposed approach performs system identification with the NN model and finds the control parameters for the beamline. Performance results show that the proposed approach helps to predict optimal parameters without real experiments with the accelerator.

INTRODUCTION

Beamline tuning is an important and critical issue in the accelerator control. The control is to manipulate the devices of the system in order to make the accelerator be the desired state. The operators should control the accelerator system to obtain the desired output. Especially, beam tuning is a difficult task for the accelerator. Beamline tuning is to manipulate the control parameters of beamline to obtain the desired beam shape. For the beam tuning, the operators should manipulate the parameters based on the measured information during the operation. Beamline tuning requires human resources and is time consuming works since the accelerator is very non-linear and highly complex.

Researches using the neural network have been proposed for the beam tuning. In SLAC, artificial intelligence (AI) technique has been proposed for accelerator control [1]. The approach utilizes the feedback control approach based on the neural network. The approach trains the neural network with the beamline emulator and then controls the steering magnets of the beamline. Another approach has been proposed for the control of the ion source of the RFT-30 cyclotron [2]. The approach trains the ion source model using the neural network and then finds the optimal parameters to obtain the desired ion source current.

In this work, we propose a neural network based generalized predictive control (NGPC) approach for the RFT-30 cyclotron beamline. First, the proposed approach constructs the beamline model by using the NN based system identification procedure. Next, the model predictive control (MPC) approach is used for finding the optimal parameters for the beamline tuning. The proposed approach can reduce the beam tuning time and enables effective beamline tuing. Moreover, combined with other control approach, it enables beam auto-tuning and control automation.

CONTROL PROBLEM OF RFT-30 CYCLOTRON BEAMLINE

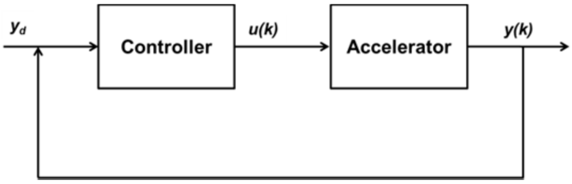


Figure 1: Overview of the accelerator feedback control.

Control means to manipulate the input signals to obtain the desired output signals. Figure 1 shows the accelerator feedback control system. Assume that $y(k) \in R^m$ is m-dimensional plant (i.e., accelerator) output and $u(k) \in R^n$ is n-dimensional control input, and reference target y_d is a control objective. The controller receives the error $e(k) = y_d - y(k)$ and then decides the control input $u(k)$. Control problem is defined as minimizing the error $e(k)$ between the reference target y_d and the plant output $y(k)$.

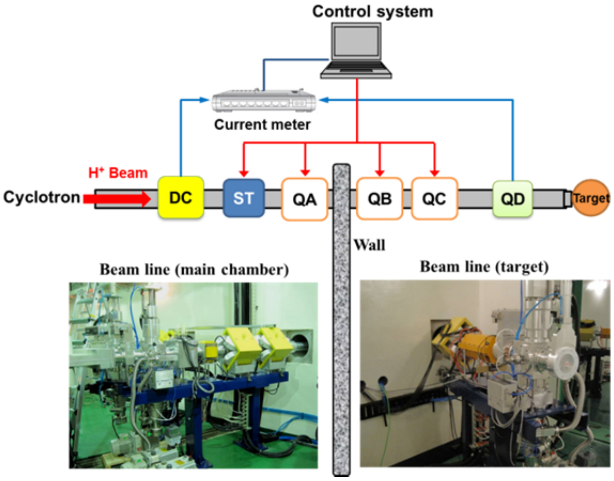


Figure 2: Overview of the RFT-30 cyclotron beamline.

Figure 2 shows the beamline system of the RFT-30 cyclotron. The RFT-30 cyclotron is a 30 MeV proton accelerator for radioisotope (RI) production and research. The RFT-30 is composed of four beamlines which are used for transmitting the proton beam to a target system. As shown in Fig.2, each beamline is composed of drum collimator (DC), steering magnet (ST), quadrupole magnet (QA, QB, QC), quadrant (QD), and vault/target faradaycup (FC). Steering magnet controls the center position of the proton

---

† hur09@kaeri.re.kr

beam and quadrupole magnet changes the shape of the proton beam. Beamline quadrant is used for measuring the current and the distribution of the beam, and it is composed of top, bottom, left, right parts. The cyclotron operator measures the current data from the beamline and then performs beamline tuning by adjusting the steering magnet and the quadrupole magnet to modify the beam.

NEURAL NETWORK BASED PREDICTIVE CONTROL FOR RFT-30 BEAMLINE

In this work, we propose a neural network based predictive control approach for RFT-30 cyclotron beamline system. The proposed approach is composed of NN training procedure and model predictive control (MPC) procedure. Figure 3 shows the block diagram of the proposed approach for RFT-30 cyclotron beamline.

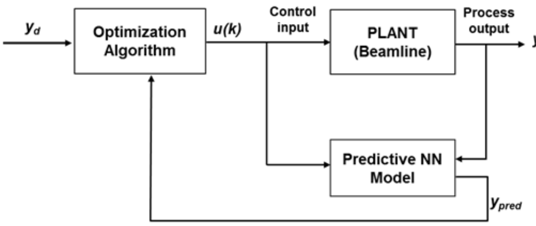


Figure 3: Block diagram of NN predictive control approach for RFT-30 cyclotron.

In the NN training procedure, the approach constructs the beamline prediction model based on the neural network. Based on the NN prediction model, the controller finds optimal control input by using the model predictive control approach.

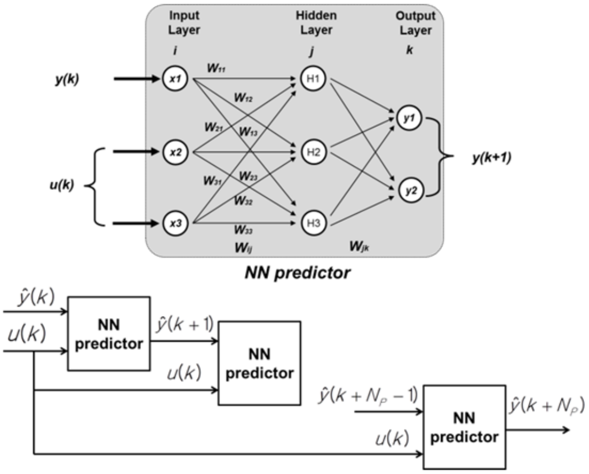


Figure 4: N-step ahead prediction model using neural network.

The NN prediction model is constructed through *N-step* ahead prediction approach. Figure 4 shows the *N-step* ahead NN prediction procedure using the neural network. The process output $y(k+1)$ at next time step is obtained by predicting the output with the NN predictor, and the prediction procedure is iterated to the future time step $k+N_p$.

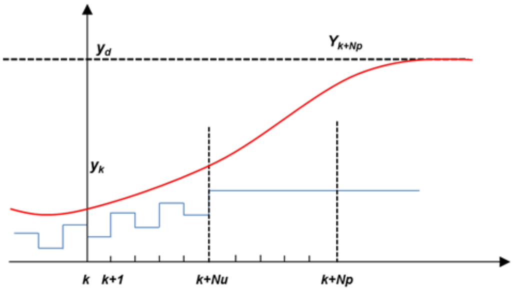


Figure 5: Generalized predictive control approach for RFT-30 cyclotron.

After the NN training procedure, the approach finds the optimal control input by using the model predictive control scheme [3]. Model predictive control approach is defined as minimizing cost function:

$$\text{Minimize} \quad \sum_{i=1}^{Np}\left[y_d - \hat{y}(k+i-1)\right]^2 + \lambda\sum_{i=1}^{Nu}\left[u(k) - u(k+i-1)\right]^2 , \quad (1)$$

where N_p is the prediction horizon, y_d is the reference trajectory, N_u is the control horizon, u is the control input, and λ is the weighting factor. As shown in Fig. 5, the basic principle of MPC is to maintain the reference trajectory y_d by predicting the value $y(k+1)$, $y(k+2)$, …, $y(k+N_p)$. Equation (1) is to find optimal $u(k)$ and it is nonlinear unconstrained minimization problem. We apply the quasi-newton algorithm to solve the optimization problem.

PERFORMANCE RESULTS

To analyze the performance of the NGPC approach, we evaluated simulations based on the RFT-30 cyclotron beamline. First, we performed NN training by using the accelerator simulation code SAMM [4]. Figure 6 shows the structure of the beamline simulation. The initial beam conditions of the beamline are set in the simulation. The input parameters of the steering magnet and the quadrupole magnet are randomly generated and then calculate the process output by using the beamline emulator. Based on the input and the output parameters, the beamline model is constructed using the neural network. Next, the reference trajectory is established and the optimal control inputs are calculated using the predictive controller. Control input is performed through one-step ahead prediction and Nu is set to 1. We calculate the second term of cost function by using $\Delta u(k)=u(k)-u(k-1)$. This procedure is iterated to the maximum time step. Simulation parameters are shown in Table 1.

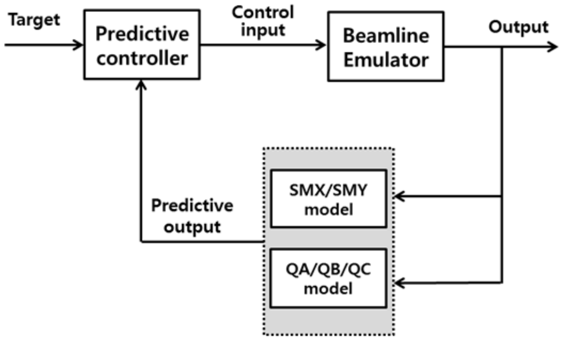
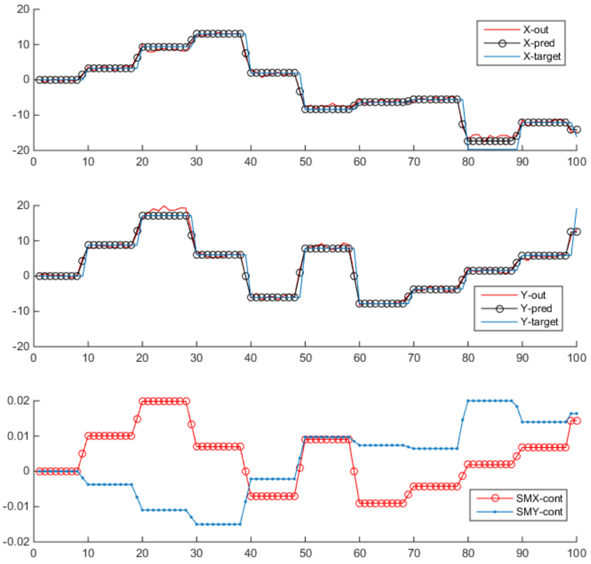


Figure 6: Generalized predictive control approach for RFT-30 cyclotron.

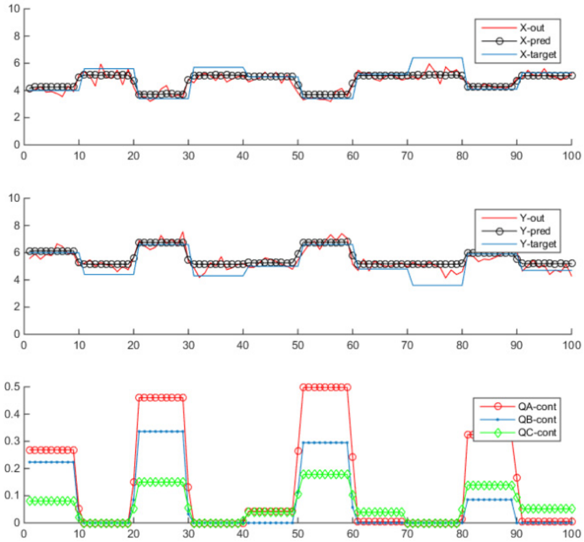
Table 1: Simulation Parameters

Parameter	Description	Value
Target	Reference target of proton beam	-
Yout	Output from beamline emulator	-
SMX/SMY	Steering magnet input	Max 0.02 T
QA/QB/QC	Quadrupole magnet input	Max (T/m) 3.54/3.15/1.89
Tmax	Maximum time step	100
Np	# of prediction horizon	2
Nu	# of control horizon	1
λ	Weighting factor	0.3

Figure 7 shows the performance results for the beamline simulation. We randomly change the center position and shape of the proton beam at every 10 step. As shown in Fig. 7, the process output of the beamline is close to the reference trajectory. Although the reference target is suddenly changed, the error between the target and the process output is small. The simulation results show that the proposed NGPC approach enables beamline tuning when the initial beam is constructed and the reference target is set up.



(a)



(b)

Figure 7: Performance results of the GNPC (a) Steering magnet control (b) Quadrupole magnet control.

CONCLUSIONS

In this work, we proposed a neural network based predictive control approach for the RFT-30 cyclotron beamline system. The beamline tuning is a difficult task and time consuming work for the human operators. The proposed approach enables the human operators to be easy beam tuning and provides the operators with reducing the time and cost required for the accelerator operation. We plan to implement the proposed approach into the RFT-30 cyclotron control system and conduct the real experiments using the real time beamline control system.

REFERENCES

[1] D. Nguyen *et al*., “Accelerator and Feedback Control Simulation Using Neural Networks”, in *Proc. PAC’91*, IEEE Particle Accelerator Conference, San Francisco, California, USA, May 1991, pp. 1437-1439.

[2] Y. B. Kong *et al*., “Predictive Ion Source Control Using Artificial Neural Network for RFT-30 Cyclotron”, *Nuclear Instruments and Methods in Physics Research A*, 806, 2016: 55-60.

[3] D. Soloway and P. J. Haley, “Neural Generalized Predictive Control,” *IEEE International Symposium on Intelligent Control*, (1996): 277-282.

[4] `http://pcwww.liv.ac.uk/~awolski/main_links_computercodes.htm`