Neural Network Based Smith Predictor for Teleoperation of Quadrotor with Force Feedback

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Abstract— In this research neural network based smith predictor is used to achieve stability in time delayed control system like teleoperation of quadrotors. The objective is to control Quad rotors and to establish telepresence to teleoperators over the Internet in a robust fashion with good performance characteristics. Teleoperation is the ability to remotely control a robot, where contact or environment information (force feedback) is communicated from the quadrotor to the master joystick. The stability of this system is interlinked with the amount of telepresense provided to the operator. In this research we tried to extend existing techniques to establish Internet based tele operation for quadcopter.

Keywords: Teleoperators, Neural Network, Smith Predictor

I. Introduction

Tele-operation[i] of quad rotor can replace human to work in the inaccessible or hazardous or remote environments, and create more social value. A typical tele-operation system is mainly composed of the human operator, the haptic joystick, the remote quad rotor, the communication channel and the work environment. The special work mode is that human operator sends control instruction through a transmission medium to remote quad rotor. Remote quad rotor work according to the received instruction, and state of the remote system is returned to control stick, operator make a decision according to the feedback information.

II. Force Feedback

The force feedback improves the performance of the teleoperated system. The force feedback is essential in teleoperated underwater robots and for space teleoperation, it improves the quality of work. It is used even in robotic surgery. In robotic surgery if visual feedback is blocked then surgeon can work with force feedback for an moment, in that way force feedback improves the performance of operator and the time to finish the job reduces.

III. Smith Predictor

The ordinary compensation method (Lag, Lead compensators) don't give the satisfactory output for the time delayed control system. The smith predictor is a type of compensator used when the model of the system and time delay can be predicted up to a satisfactory level. Smith predictor uses the model of the remote system in the operator side to compensate for delay present in the network. The entire arrangement and the process explained in the further sections.[4]

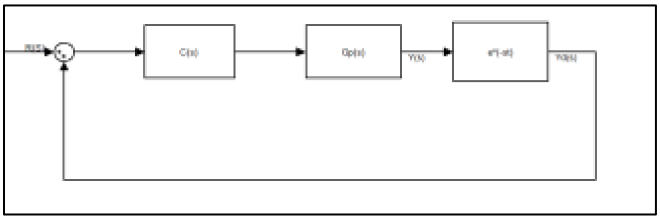

Fig. 1: Feedback Control with Delay

Smith predictor algorithm can be described as an attempt to cancel out the transmission delay in the control. The method is an effective algorithm to compensate for transmission delay given an accurate model of the remote system is provided.

To better understand the function of the Smith predictor, we will first show a block diagram of a simple feedback control where the transmission delay is represented by a separate block from the rest of the plant, as shown in Fig. 1 Here C(s) is the control block, $G_p(s)$ the plant block without the delay, and T the transmission delay. We can clearly see that the output delay $Y_d(s)$ is used for the negative feedback, and the pure delay term is clearly in the characteristic equation to potentially destabilize the closed-loop system. If we could use the fictitious un-delayed output Y(s) for the feedback, then we can remove the pure delay term from the control loop and significantly improve performance. T his is not physically feasible because it is usually not possible to isolate the pure delay from the rest of the plant.

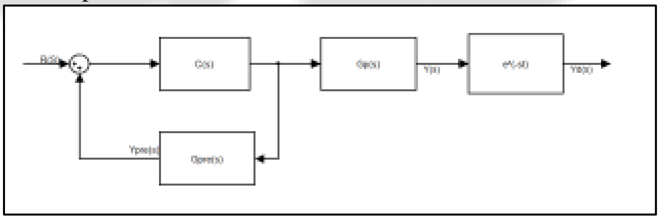

Fig. 2: Preliminary Smith Predictor

The delay may be distributed not lumped, and in case of teleoperation any information flow between the user and remote site will need to undergo pure transmission delay. Furthermore even if it is possible to isolate the pure delay term, there is no reason that it will be placed after the rest of the plant. Although we can not use the un-delayed output of the actual plant, if we have a model of the plant we can use its un-delayed output instead. Consider a modified block diagram as shown in Fig.2. The hat sign above the variables indicates estimated value. In this setup only the un-delayed modeled output is used to close the feedback loop. The controller would be very good at controlling the model, but not necessarily the actual plant because the actual plant dynamic is in an open-loop. To solve this problem an outer loop is added to the block diagram in Fig. 2 to create an algorithm represented by Fig.3. Now the control block C(s) can be designed with higher gains more suitable to control an un-delayed plant since the effect of pure delay is minimized by the inner loop. This is the complete Smith predictor algorithm. [5]. The block diagram in Fig.4 . is almost mathematically identical to that in Fig. 1 except for the addition of a disturbance at the plant input. But now we can see the Smith predictor control is lumped into a single inner loop as outlined by the dashed box.

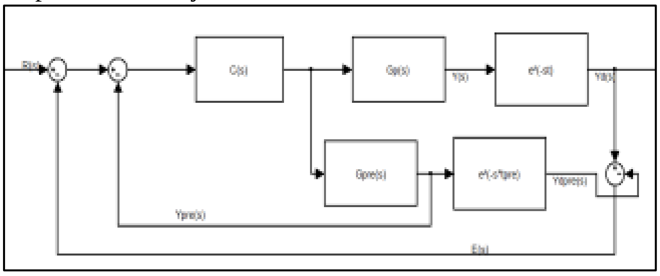

Fig. 3: Complete Smith Predictor

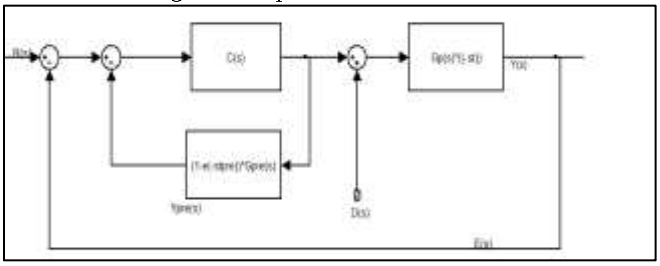

Fig. 4: Complete Smith Predictor New Arrangement

The effectiveness of the Smith predictor algorithm can be seen by observing the closed-loop transfer function with R(s) as input. Assume for now that there is no disturbance. Notice that the pure delay terms have been completely eliminated from the characteristic equation, although the term still remains in the closed-loop transfer function numerator. While this will not produce a stability problem, it does imply that tracking at the output will be delayed by the amount indicated by the system dead time. With perfect modeling, the block diagram in Fig.5 can be reduced to the Fig.6.

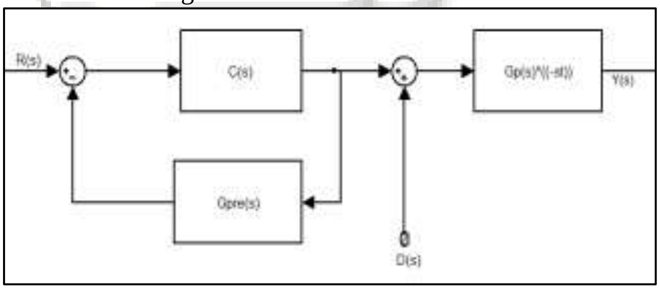

Fig. 5: Smith Predictor Reduction by Assuming Perfect Modeling

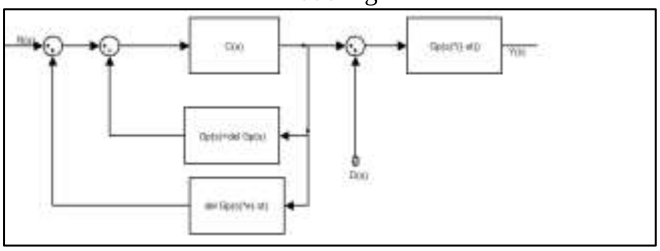

Fig. 6: Smith Predictor with Inaccurate Gp(s)

IV. NEURAL NETWORK BASED SYSTEM IDENTIFICATION

There are various method to do system identification and model prediction, for example LMS filter and other adaptive filters. In this work, neural based approach for system identification is chosen, since the prediction error should be as minimum as possible to implement the smith predictor. Nonlinear system identification with less effort is possible using neural network. The system is trained with set of vectors and using the test vector set the neural model is verified. The number of hidden layers are optimally chosen to get minimum error and lesser computation time.

Neural network based system identification is scalable and can be reconfigured easily.For the nonlinear system it provide an acceptable performance. The synaptic weight of the neural network can be adjusted to an optimum value. The entire system is simulated in matlab simulink and the results are presented in the next section.

V. SIMULATION RESULTS

The neural network is used to identify the quad dynamics and hidden layer and number of epoch are mentioned and the input is given to the neural and the test data and evaluation lots are shown in the below figures.

The test vectors to validate the model is generated. By regression analysis the ouput is validated. When the model is made more accurate by reducing the error the stability is improved. The simulation results show that the stability is achieved using the neural based smith predictors.

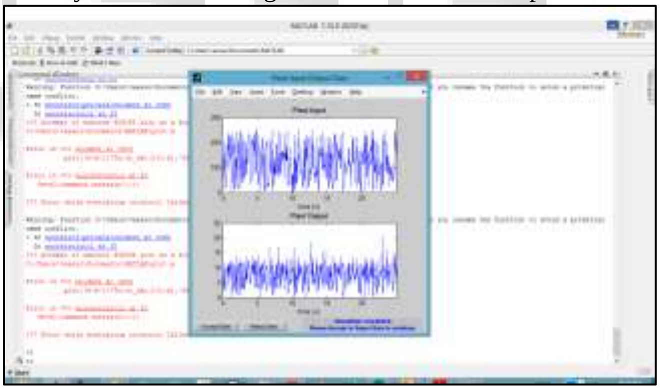

Fig. 7: Test data for Training

Fig. 8: Neural Network Training

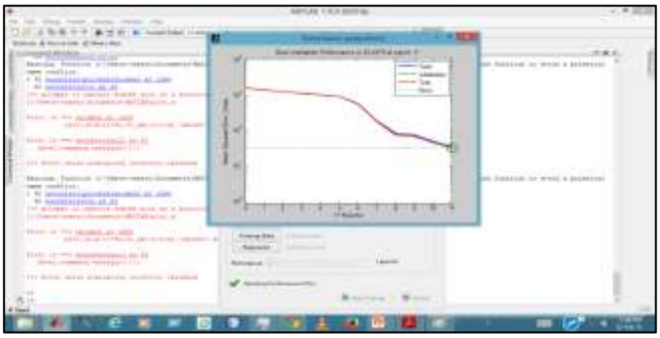

Fig. 9: NN Performance

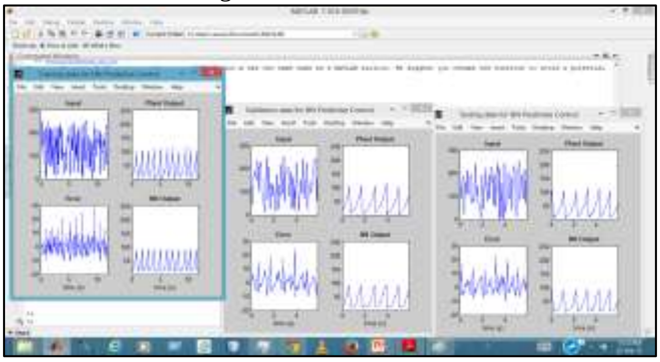

Fig. 10: Training Validation Testing Plots

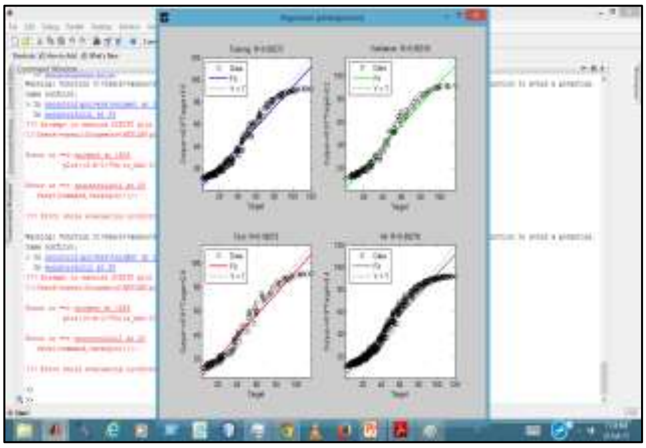

Fig. 11: Regression

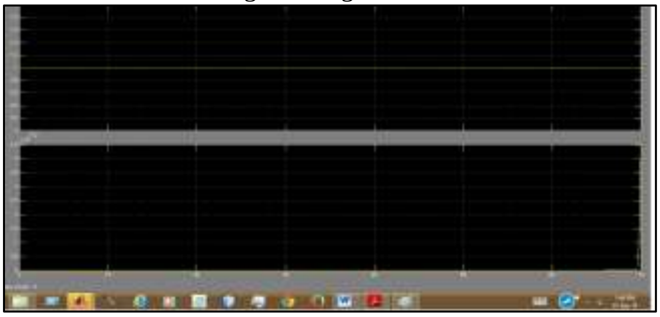

Fig. 12: Output for a unit step input(unstable)

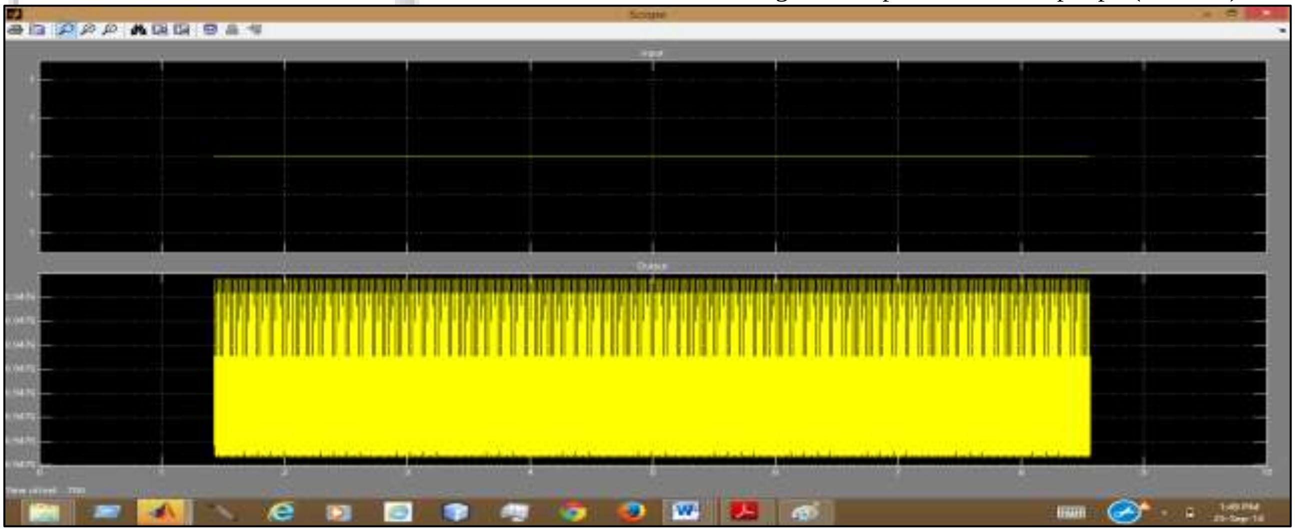

Fig. 13: Stable Output for a unit step input (after implementing Predictor)

VI. CONCLUSION

Fig 12 and Fig 13 shows the result of the proposed system. The time delay of 60 ms is introduced into the system and step input is applied the fig 12 shows how the system gone to an unstable state and output of the system goes unboundedly, when the neural networked based smith predictor placed in the operator side of the system the fig 13 shows how the system works for the same 60 ms delay and step input, the system doesn't go unstable and it tracks the input within 5% error. The performance of the system is satisfactory.

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