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Original Article

The Fan and Plate Angular Position Control Techniques and Applications

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Abstract *- This paper presents the application of fan and plate used for the control experiment. Some control algorithms are tested on it. Practical testes for analysis and design of the controllers are investigated to illustrate the aerodynamic behaviour of this system. The main objective is to show that this equipment can be used to educate students, illustrate and reinforce stability and controller design knowledge. The fan and plate is excellent tool for investigating nonlinear effects, which influence the sensitivity of the control algorithms, and set-point changes. The fan and plate is another challenged problem for control system design because it has non-linearity characteristic, non-minimum phase and highly sensitivity for ambient disturbance.*

Keywords - *PID-SMC, MPC, Laboratory education, Fan and Plate, Non-minimum phase.*

I. INTRODUCTION

Nowadays digital technologies are increasingly present in the process control area. As processes to be controlled are becoming more complex, they demand a higher flexibility in the variation of parameter specifications while trying to attain a cheap benefit. It is essential to ensure practical knowledge with real-time control while conventional lectures and Matlab-Simulink simulation show limitation in evaluating practical aspects of dynamic systems. Thus, fan and plate is one of the plants that students may use to test out the different regulator types, as are currently employed in industrial processes, and the tests can be performed in highly realistic conditions, as the system is entirely made of industrial quality components. Here, PID, MPC and SMC controllers are tested in the system because they have increasingly used becoming a popular in industry processes.

The rest of this paper is organized as follows: Section 2 provides the brief descriptions of the mechanism and experiment identification of process. In section 3, a survey of the design of the control algorithms and Section 4, algorithms of the controllers for stabilizing fan and plate are presented. The simulation and experimental results are shown in section 5 and 6 respectively. Finally, the conclusions are discussed in section 7.

II. PRELIMINARIES

A. *Describe the experimental Fan-and-Plate*

The fan and plate, represented in Fig.2, is composed of a fan driven by a 24 volts DC motor. The angular orientation of the hinged plate which is able to swing with low friction is controlled by blowing an air stream from the fan. The angular deflection of the plate is measured by a low-friction potentiometer, which employed electrical signal via voltage divider circuit in order to be the feed-back signal to the control loop. The control problem is to regulate the angular deflection of the plate by actuating the input voltage of the DC motor.

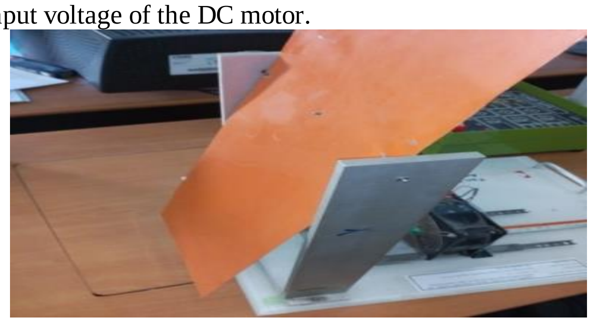

Fig. 1 Physical setup of the fan and plate

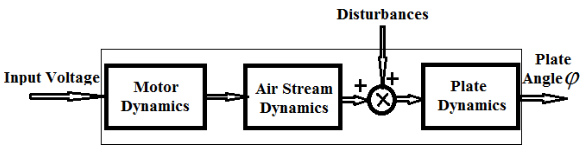

Fig. 2 Block diagram of fan and plate control apparatus.

Where, Fan and plate model comprises 3 main parts: motor dynamics, air stream dynamic block and plate block. Important dynamic elements include the fan motor time constant, air transport lag, resonant poles, disturbances from air turbulence or an external torque applied to the plate and a non-minimum phase response. Loading the plate allows a change in the dominant time constant while moving the position of the fan allows a change in dead time. Therefore the fan and plate can serve as tangible evidence of the usefulness of many other control techniques and be also a versatile plant for evaluating controller robustness.

B. Parameter identification of the system

As analysed in section A, It is very difficult to determine the parameters in the model of fan and plate because they change according to the working mode and are always affected by disturbances, so, for simplicity, we use the "ident" software in Matlab.

This system is known to be well-behaved from an identification point of view and can be well approximated by an ARX model. The input *u(t)* is the voltage driving the fan and the output $\varphi(t)$ is the angle of the plate. Data has been collected using a random binary telegraph signal as input, switching between 1.5 V and 4.5 V with the sampling time was set to *Ts*= 0.1 second. In total, 2000 data points have been collected and illustrated in Fig.5.

We represent the fan-plate system as a "black box" system where the input is *u(t)* and output $\varphi(t)$.

Fig. 3 Black box system

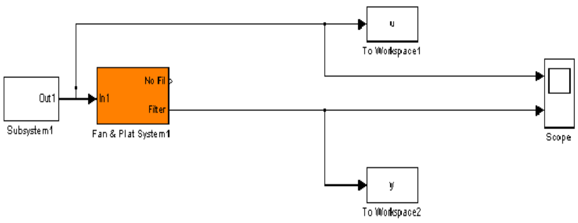

Fig. 4 Parts of the data collected

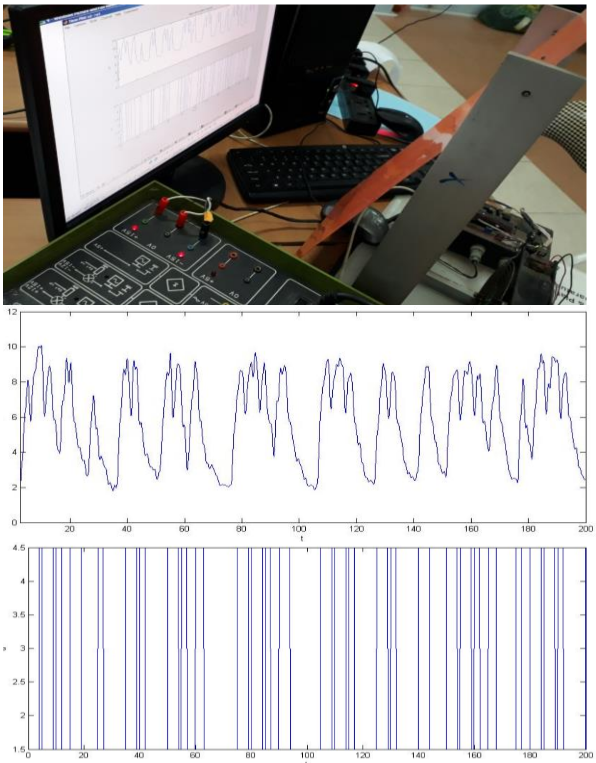

Fig. 5 Parts of the data collected from the fan and plate process

In Fig.5, the lower plot shows the input signal and the upper plot the corresponding output, response of the system in the range of 2º-10º.

We use System Identification Toolbox in Matlab, the process model is obtained as follows [7], [9]:

$$G(s) = \frac{\varphi}{u} = \frac{K(-\eta s+1)}{(T_1 s+1)(T_2 s+1)} = \frac{2,774(-0,51s+1)}{(1,992s+1)(0,758s+1)} \quad (5)$$

The tests showed that the best fit was given by this ARX model with 85.25%.

Where K is the static transfer coefficient, T_1 is principal time constant (s), T_2 is the secondary time constant (s).

The constrained condition of the control function is:

$0 \le u \le 24V$

III. SURVEY OF ANGULAR POSITION CONTROL ALGORITHMS

Due to the nature of the fan and plate dynamics, several control algorithms have been applied. Each control method has its advantages and disadvantages. In this section, the prominent controllers applied to the fan-plate object are presented.

PID controller: The classic PID control is a simple structure, which can use to control the fan and plate. Main controlling tasks are stabilizing good performance, and robustness [2].

Sliding mode controller: This is an easily applicable nonlinear control method that implements by applying a discontinuous control signal to the system to command it to slide along a prescribed trajectory [13], [17]. Its advantages are low sensitivity to external disturbances, rapid response, and good tracking ability.

Predictive control:

One strategy for enhancing closed loop performance is to use predictive control. A well-known predictive controller is the Smith Predictor controller. This is now available as a standard block in many commercial digital controllers.

Over the last decade, significant improvements have also been reported with the use of long range predictive controllers. Algorithms in this category include dynamic matrix control (DMC) and generalized predictive control (GPC) [8], [14], [15].

Fuzzy controller:

Fuzzy control has applied without any identification to process parameters. That means a simple fuzzy controller is used in feedback. Fuzzy control methodology can use to control non-minimal phase industrial processes. The proposed fuzzy control methodology has been applied to control a fan and plate process in real time environment [16].

Adaptive controller: This approach is aimed at adapting to parameter changes in the systems. In other words, this method is a robust and effective technique for systems having unmodeled dynamics and parametric uncertainties. It can handle the trajectory tracking problem of the fan and plate under fault conditions and produces better results as compared to other controllers [7], [9], [12].

IV. DESIGN CONTROLLERS FOR STABILIZING FAN AND PLATE

A. PID Controller Design

We can use methods like Ziegler–Nichols and tuning of PID parameter performs by trial & error method [3].

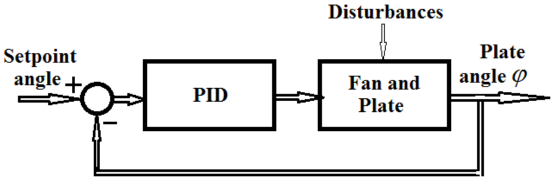

Fig. 6 Feedback with a PID Controller

B. SMC Controller Design

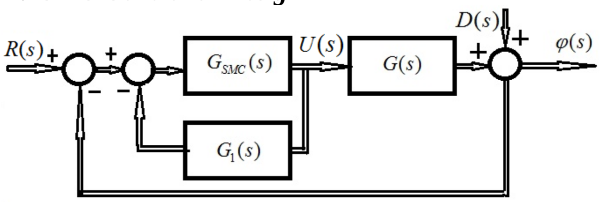

Fig. 7 The SMC Controller with compensator

The sliding mode controller is developed based on the system mathematic model:

$$G(s)=\frac{\varphi}{u}=\frac{K(-\eta s+1)}{(T_1 s+1)(T_2 s+1)}=\frac{2,774(-0,51s+1)}{(1,992s+1)(0,758s+1)}$$

$$G_1(s)-\frac{2K\eta}{(T_1 s+1)(T_2 s+1)}=\frac{2,83}{(1,992s+1)(0,758s+1)}$$

$$G^*(s)=G(s)+G_1(s)$$

$$G^*(s)=\frac{K(\eta s+1)}{(T_1 s+1)(T_2 s+1)}=\frac{2,774(0,51s+1)}{(1,992s+1)(0,758s+1)}$$

The new transfer function observed by controller is:

$$\frac{\varphi^*(s)}{u(s)}=\frac{K(\eta s+1)}{(T_1 s+1)(T_2 s+1)}$$

In differential equation form:

$$T_1T_2\frac{d^2\varphi^*(t)}{dt^2}+(T_1+T_2)\frac{d\varphi^*(t)}{dt}+\varphi^*(t)=K\eta\frac{du(t)}{dt}+Ku$$

There are many options to select the sliding surface, in our case *S(t)* was selected based on PID algorithm acting on the tracking error e

$$e(t)=r(t)-\varphi^*(t)$$

$$S(t)=\frac{de}{dt}+2\alpha e+\alpha^2\int_0^t edt \qquad (6)$$

Equivalent voltage u_{eq} needed to maintain the equilibrium:

$$\frac{du_{eq}(t)}{dt}=\frac{(T_1+T_2)^2}{4K\eta T_1T_2}e(t)+\frac{\varphi^*(t)}{K\eta}-\frac{u_{eq}(t)}{\eta}$$

Then, the complete SMC controller plus more term of the convergence voltage enforcing the convergence to the equilibrium and can be represented as follows:

$$u(t)=\int_0^t\frac{(T_1+T_2)^2}{4K\eta T_1T_2}e(t)+\frac{\varphi^*(t)}{K\eta}-\frac{u_{eq}(t)}{\eta}+\int_0^t Kd\ signS(t)dt \qquad (7)$$

Where: $\alpha=\frac{T_1+T_2}{2T_1T_2}$

In control law (7), the switch term *KdsignS(t)* is a robust term used to overcome disturbances. However, lager value of *Kd* may cause chattering of control input. Moreover, to reduce chattering we can also choose from several types of Lyapunov functions introduced in the documentation [17].

The stability analysis is performed with the Lyapunov candidate shown in the equation

$$V=\frac{1}{2}S^2(t)$$

We proceed for the analysis to derive the equation

$$\dot{V}=S\dot{S}=S\left[-\frac{K\eta}{T_1T_2}Kd.signS(t)\right]=-\frac{K\eta}{T_1T_2}Kd\left|S\right|<0 \qquad (8)$$

C. MPC controller design

This predictive control strategy generates a control law that may be considered as one of the most effective control algorithms to handle industrial complexities. Presently, predictive control schemes are amongst the most popular linear control methods for adaptive control. One of the most popular MPC methods is generalized predictive control (GPC). Generalized predictive controller has been widely used in adaptive context and it is an extremely flexible approach for control due to its performance and the large number of design and tuning parameters. GPC is a linear controller that can control non-minimum phase plants as fan and plate in this paper, open-loop unstable plants, and plants with variable or unknown delay time, and can systematically take into account real plant constraints in real-time. GPC is robust with respect to modelling errors, over and under-parametrization, and sensor noise. The controller computes the future incremental control vector by the minimization of the follow criterion of the form:

$$J_{GPC}(N_1,N_2,N_u)=\sum_{j=N_1}^{N_2}[\hat{\varphi}(t+j/t)-w(t+j)]^2+\sum_{j=1}^{N_u}\lambda\Delta u^2(t+j-1) \qquad (9)$$

The *GPC* is based on a model and optimizer. A model is used to predict the future plant outputs, based on past and current values and on the control signal calculated by the optimizer taking into account the cost function where the future tracking error and the constraints are considered. Where *φ(t+j/t)* is an optimum *j*-step ahead prediction of the system output on data up to time *t*, N_1 and N_2 are the minimum and maximum costing horizons, N_u is the control horizon, *λ* is the control weighting sequence, and *w(k+j)* is the future reference trajectory. Equation (9) can be obtained separating the predictive output vector into two terms as: one uses the future control increment vector ΔU to be optimized and the other Fx_k uses the available input/output data. The output prediction becomes [15]:

$$\varphi=Fx_{k_i}+\phi\Delta U$$

Where ϕ is the dynamic matrix and is computed with the step response elements for a controlled process. The minimization of the cost function, equation (9), leads to the following incremental control law:

$$\Delta U=(\phi^T\phi+R)^{-1}\phi^T R_S-Fx_k \qquad (10)$$

The predictive control is implemented using a receding-horizon approach: the first element of ΔU is $\Delta u(t)$ so that the current control $u(t)$ given by $u(t) = u(t\text{-}1) + \Delta u(t)$ is applied to the process.

To solve input constraints optimization problem we can use Toolbox optimization in Matlab for Quadratic programming method or use alternating directions of multipliers method for convex optimization problem to find out optimal value of ΔU [8], [14], [15].

GPC controller is designed for the fan and plate object similar in reference document [2], [14], [15].

V. SIMULATION RESULTS

In order to make the modeling diagram presented, in this part, we have modeled as follows. We use the Matlab software to simulate output response with controllers PID, SMC and MPC.

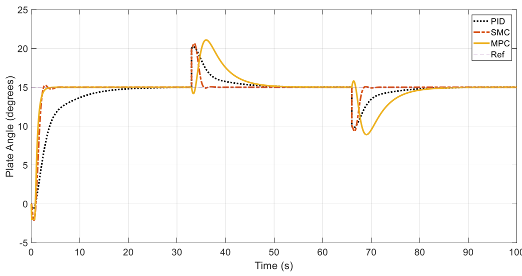

Fig. 8 Outlet response with step function

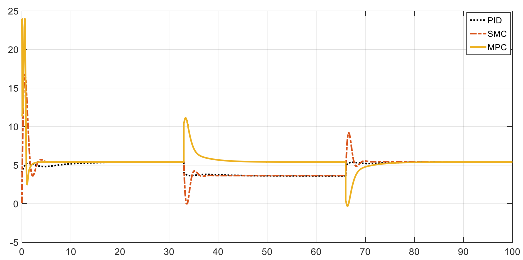

Fig. 9 The controller outlets with step function

The constraints on the control signals, voltage $u(t)$ Fig.9 and Fig.11 are all within the required range $0 \le u \le 24V$. The transient time of SMC controller is reduced to 3 seconds compared to nearly 20 seconds when doing PID controller. When affected by disturbance, the controller is still able to track the output reference Fig.8.

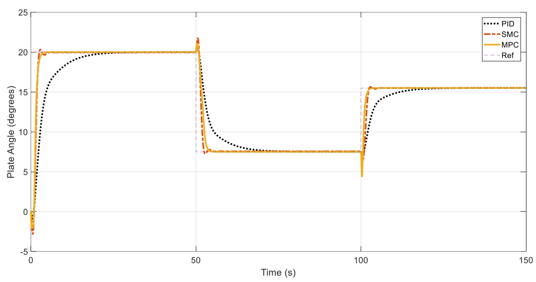

Fig. 10 Multi-step input responses

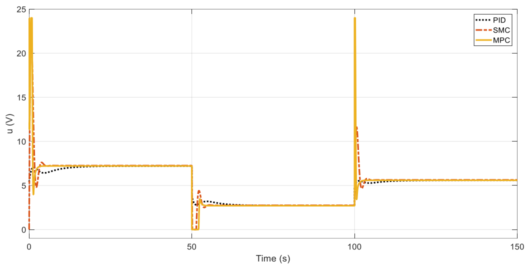

Fig. 11 The controller outlet with Multi-step input

The simulation results with Multi-step input are shown in Fig. 10, Fig. 11, respectively. The settling times of closed-loop systems produced by the PID, MPC, and SMC controllers are 20, 5 and 3 seconds, respectively. The overshoots in percentage made by these controllers are 0%, 0.1% and 1%, respectively.

VI. SOME EXPERIMENTAL RESULTS

Fig. 12 Fan-plate experiment system.

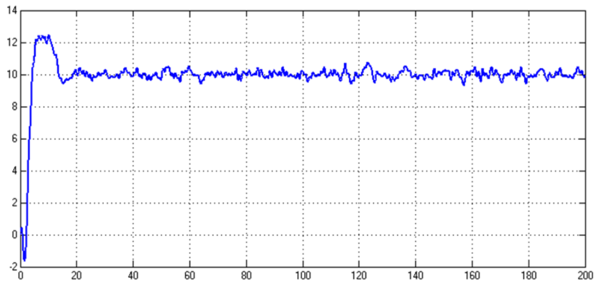

Fig. 13 Response of the system when input is 10°

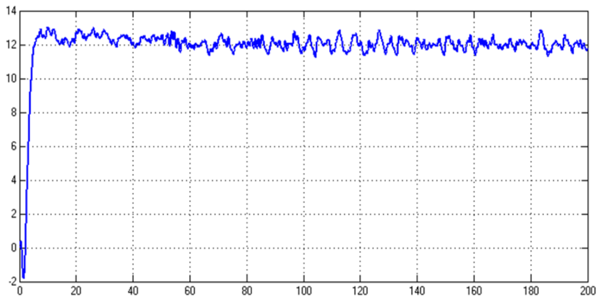

Fig. 14 Response of the system when input is 12°

We see that the output response (flat angle) clings to the set value. The characteristic curve has a delay of about 2s. For a setting angle of 10°, there is a large overshoot of about 20% and a transient time of 18s. For the setting angle of 12°, there is a smaller overshoot and a transient time of about 12s.

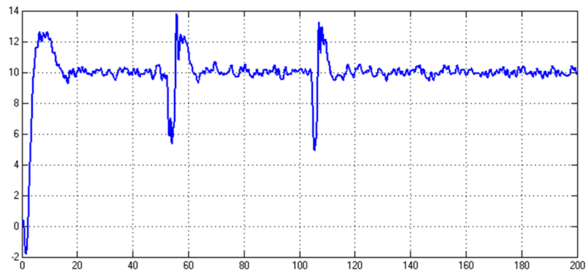

Fig. 15 Response of the system with disturbance when input is 10º

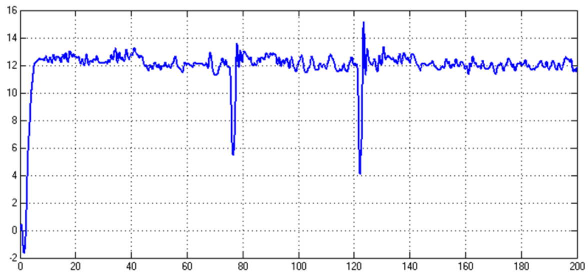

Fig. 16 Response of the system with disturbance when input is 12º

Disturbance effect on the fan or plate by impacting the plate, deflecting the plate from the angle position or obstructing the air flow from the fan to the plate we see that the fan and plate system when there is disturbance, the system has the ability to return to the steady state after the transition time: the angle of the plate blade tracks to the set-point value. The settling time is from 5s-15s, so the system has the ability to disturbance cancellation.

VII. CONCLUSION

This paper has shown the synthesis of the controllers based on the fan and plate experimental process. The simulation and experimental results show that the controllers provide very good performance in comparison with the conventional PID controller. The advantage of the SMC and MPC controllers is simple and practical to implement, ensure the stability of system and have relative lower requirements for precision of model of object. It would take into account the real constrained inputs of the control signal ($0 \le u \le 24$) for the controllers and exploit the advantages of both controllers. The results demonstrate that the performance of SMC controller is the most superior to that of PID and MPC controller in both set-point regulation and reference tracking control. For education and training purpose, it is necessary for student analyzing and performing experimental tasks such as system identification, controller design, and has experience of real-time control.

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