A Method of Pilot Transfer Function Identification Suitable for Adaptive Control Using Analog / Hybrid Computer

A Method of Pilot Transfer Function Identification Suitable for Adaptive Control Using Analog/Hybrid Computer

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A new method is proposed that can quickly identify incrementally changing transfer function during operating a Link-trainer (an example of simple pilot trainer). As a form of human transfer function we considered a well known "Tustin Model" with rate feedback. Making use of this method of iddentification, iterative type differential analyzer with digital logic or analog-hybrid computer is constructed. Detailed circuit configuration and flow chart for three parameter identification are presented and discussed. Experimental results show that this proposed method will be valuable for man-machine systems and on-line adpative control systems.

1. Introduction

Extensive research has been devoted to the response characteristics of human operators engaged in manual tracking tasks, but little work has been done on the change in response characteristics with the lapse of time[1)-4)]. Wierwille, in his paper,[5)] presented a valuable method that can determine the time-varying characteristics of operators, but this method needs digital computer for real time identification, Nagumo and others presented a method[6)] for identifying suitable weighting function with random input signals in a short time, and they also presented a display system including an on-line computer.

The method presented in this paper needs iterative type differential analyzer or analog-hybrid computer and needs no digital computer or digital data processor, so it is easy for mechanization and good for quick identification. And as this method is based on transfer function concept, it is easy and familior for automatic control engineers and designers.

A principal configuration of parameter search problem for human transfer function is shown in Fig. 1. From the figure it is evident that the problem itself is devided into the following parts:

1) selection of form of model,
2) selection of a criterion function by menas of which the goodness of fit of model response to the actual system response can be evaluated, when both model and actual systems are forced by the same input,
3) selection of algorithm or strategy for adjustemnt of parameters in such a way that the

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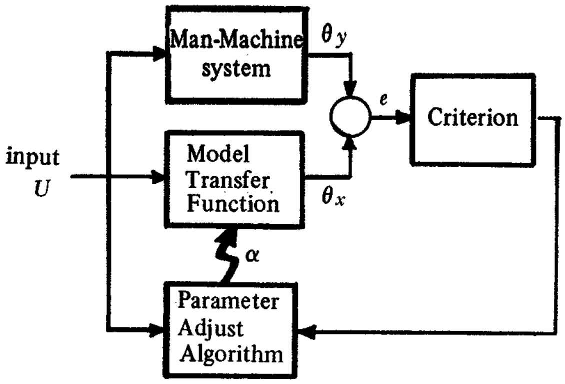

Fig. 1. Principal Configuration of parameter search problem.

differences between model and actual system responses as measured by the criterion described above, are minimized.

The above principal configuration is performed by the following steps:

1) system is simulated on mode controlled analog computer or analog-hybrid computer,
2) algorithms for the above parameter search and adjustment are proceeded by digital logic which is integrated in analog/hybrid computer,
3) parameters are searched automatically,
4) for quick identification the above procedure should be iterated very quickly.

Our experimental man-machine control system for obtaining pilot transfer function is composed of Link-trainer with stick control and CRT display in which command and

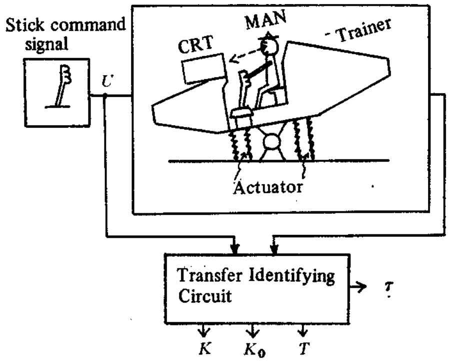

Fig. 2. Experimental system.

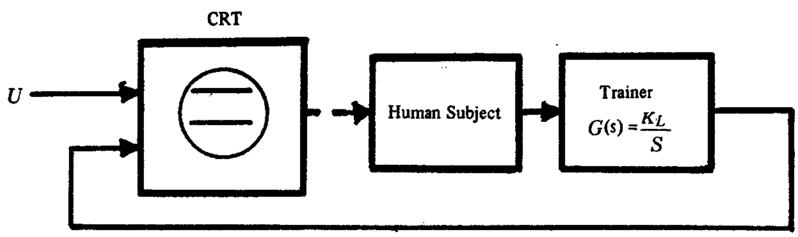

Fig. 3. Man-machine system block diagram.

response characteristics or time responses are displayed. Fig. 2 shows actual experimental system and Fig. 3 is a simplified block diagram.

2. On Human Transfer Function

In our system containing Link-trainer as shown in Fig. 2, operator controls a stick in a compensatory task, where only actual input command and actual system output are displayed on CRT. But even if the system has no displayed error or error rate signals, the human subject almost feel and predict system error and error rate from displayed data on CRT and his attitude feelings (for the experimental system pitching, rolling and yawing are controlled by stick and control foot-pedal). Therefore human transfer function proposed by Tustin

$$H(s) = K(1+TS)/S \cdot e^{-\tau S}$$

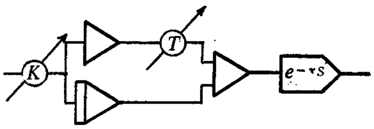

Fig. 4. Tustin model.

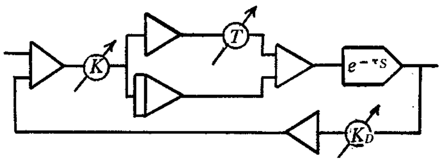

Fig. 5. Model used in this paper.

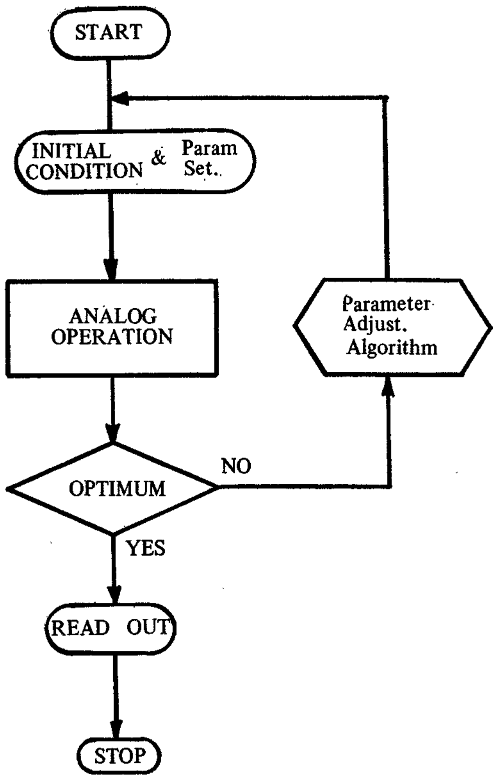

Fig. 6. Flow chart for parameter search.

as shown in Fig. 4 is modified to the transfer function with rate feedback for such a system (see Fig. 5).

The response characteristics or transfer function of manual tracking system with pursuit operation of the subject may be regarded as linear undei certain circumstances[7]. If there are some non-linear characteristics, describing function concept is good. However, transfer function of the subject gradually changes with the lapse of time due to fatigue, feeling, proficiency, psycological and circumstanced conditions, so that it is desirable that identification of transfer function be completed in the shortest time possible. Transfer function obtained by averaging over a long period of time is meaning-less if changes take place during the course of experiment.

3. Quick Identification

In order to identify parameter of human transfer function, actual input and output data must be read-in real time and read-out very fast (repetitive read-out with very high frequency). For this purpose track-store networks with logic are simple and effective. In practice, input and output signals are sampled in real time and memorized on zero-order hold networks using track-stores. Mode-controlled analog integrators are also effective for this purpose. For high speed read-out, high frequency clock signals are fed into the above networks.

IC	OP	HOLD	IC	OP	HOLD
Set initial K, K_D T	High Speed computation	Hold cost, compare & process	Set other initial condition to improve cost	High Speed computation	Hold cost, compare & process

Fig. 7. Timing diagram of parameter search.

Fig. 6 shows simplified flow chart for quick identification using analog-hybrid computer. Human transfer function is simulated by integrator and summers as shown in Fig. 5. High speed multipliers are used as automatic potentiometers and these setting are memorized by track-stores. Parameter adjusting signals are fed to memory-pairs by logic signals.

4. Criterion and Parameter Adjusting Algorithms

Criterion function for parameter search of human transfer function is based on a comparison of system and model outputs with same input forcing signals, so the following criterion function of the form

$$J = \int_0^T |e(t)|\, dt \quad \text{or} \quad J = \int_0^T \{e(t)\}^2 dt$$

are presented.

On parameter adjustment algorithm, there are many techniques and methods[8] such as Brute force, Random, Reluxation, Gradient etc., but for our experiment incrementally changing (this increment will be adjustable depending upon the gradient) method is applied for simplicity in mechanization and in logical algorithms. The form is

$$\boldsymbol{\alpha}^{(i+1)} = \boldsymbol{\alpha}^{(i)} - \text{sgn}\, \{\nabla_{\alpha} J(\boldsymbol{\alpha}^{(i)})\} \cdot \Delta\boldsymbol{\alpha}$$

where $\boldsymbol{\alpha}$ is vector quantity depending upon K, τ, K_D and T in the figure 5, and $\Delta\boldsymbol{\alpha}$ is small vector increment, i denote ith iteration.

Fig. 7 shows an example of timing diagram for parameter search, in which IC or reset mode is for parameter setting due to logical algorithm and OP mode is for dyanmic system computation and HOLD mode is for checking or comparing due to criterion function. Although this timing diagram do not include timing for data memory, this signal is also needed. This signal for data memory is easily obtained from interval timer or BCD counter. Timing diagram written in Fig. 7 is for only two iteration period, but in practice these timing mode must be iterated with high frequency.

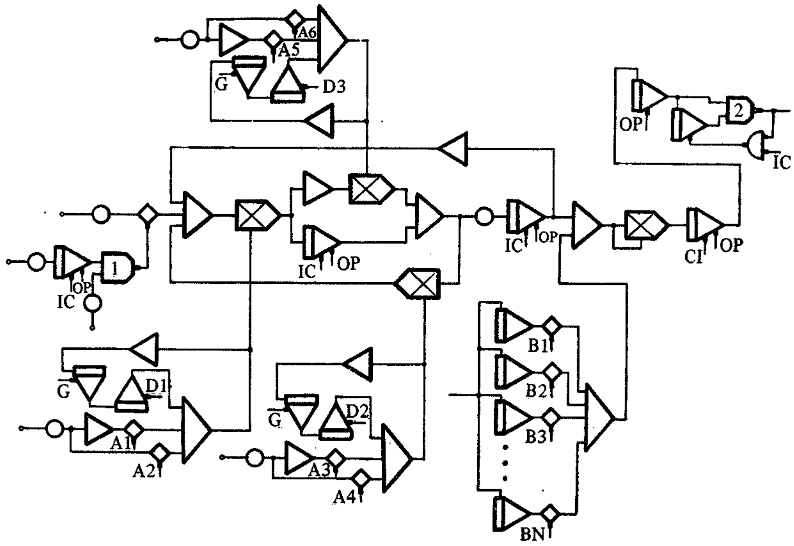

Fig. 8 (a). Circuit configuration (analog).

5. Circuit Configuration

Actual circuit configuration for obtaining pilot transfer function of a experimental man-machine system is presented in Fig. 8 (a) and (b). Former is analog part with logic signals and include zero-order-hold type memories. Logical processing and parameter algorithms are shown in the latter. Logic signals corresponding in both figures must be connected. Control signal for read in real time is not shown in the figure for simplicity.

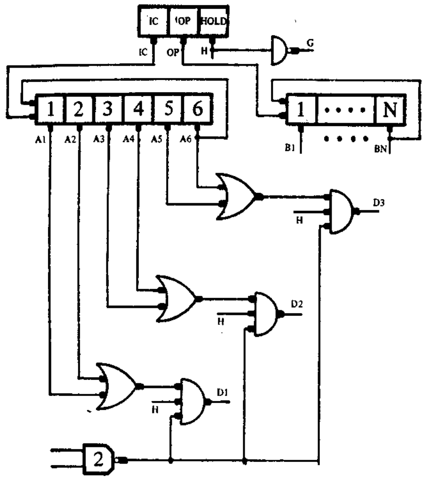

Fig. 8 (b). Circuit configuration (logical part).

6. Experiments

Block diagram shown in Fig. 3 and system mechanization shown in Fig. 2 are used for our experiment. Bright two horizontal lines are displayed on CRT screen, the one is input signal controlled by command input and the other is output signal of trainer. A subject seated on in front of the CRT synchroscope controls stick, which generates a voltage depending on pitching angle of trainer, and the voltage is displayed on CRT screen. The subject controls the stick so that the output signal on CRT screen remains as close to the input signal as possible, watching the movements of both on the screen.

Fig. 9 is an example of parameter search where T is time constant and K is feedback constant when a step function input is applied to the system. In this experimental case, three parameter optimization are performed, and Fig. 9 is a trajectory projected to K-T plane. Final value of the trajectory gives optimum parameters and these par-

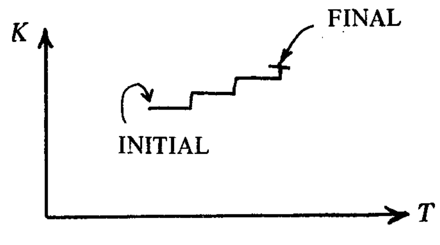

Fig. 9. An example of parameter search (final value $T=0.788$ sec and $K=1.38$ deg/sec).

ameters agree with that of system transfer function within very small cost value. For convenience of recording on X-Y recorder, slow speed iteration are performed, but if high frequency clock is applied quick identification can be done easily, because high speed up to 10—30 kHz iterative operation is available using Applied Dynamics AD-5 analog-hybrid computer in our laboratory.

7. For Adaptive Control

A discussion of adaptive control cannot proceed without at least a tentative diffinition. One widely accepted is that an adaptive control system can monitor its own performance, evaluate the effectiveness of its response, and then modify its parameter automatically to achieve desired perofmrnace. When applied to airplane control system with human pilot or something like that, this implies that the adaptive control system will identify pilot transfer function in short time, and activate some suitable compensation device to improve the system. As shortest time identification is urgent, the method proposed will easily be applicable. Fig. 10 shows an example of our porposed adaptive control system with high speed analog-hybrid computer.

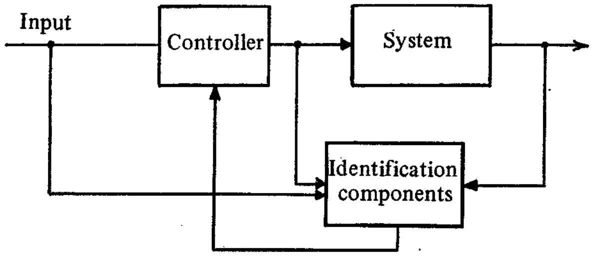

Fig. 10. Block diagram of adoptive control.

8. Discussion and Conclusion

This experiment is done using five track-store pairs, but even such a case finding optimum parameters can be succeeded with satisfaction. For analysis of parameter identification, refer to Meissinger and Bekey's paper[9].

Averaging original sampled data with the time-shifted signal is good for elimination of error due to sampling. Fractional time-shifting will be more effective.

This system has fortunately no local minima, but if there are some local minima this method have to be used with different initial conditions or assumed values.

The proposed method in this paper is very simple for mechanization and circuit configuration, so this is good for quick of on-line adaptive control and optimum feedforward control systems.

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