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# THE MATHEMATICAL MODEL OF AN OPERATOR IN A HUMAN – MACHINE SYSTEMS. PROBLEMS AND SOLUTIONS

That's why many people have already worked within this subject. In publications and articles the main structure of a human model is based on second order system. The transfer function was developed mainly by D. T. McRuer in 60's. Later on, transfer function proposed by McRuer was developing constantly. This paper concentrates on variables that influence onto operator. In other words, there is a discussion if it is possible to develop a new model of a human operator including not only the attributes of a man but also other variables like stress or fatigue.

The difficulty of this problem is first to define what variables may influence on the human behavior and second is to model them properly. To identify a human transfer function there will be done some tests on a flight simulator.

The solution of this problem might be very helpful for all companies which for example use flight simulators to improve the skills of pilots. With the accurate model of a human behavior we could verify better if the training was good enough. What is more, we could compare the changes before and after the training. Base on this we could see clearly which of the variables of a man augmented and which doesn't. After many test we might prepare better missions and tasks to train the pilots. So that we know on which parameter we would influence the most.

## 1. Introduction

The main goal of this paper is to study the role of the operator in human–machine systems and define an appropriate mathematical model. Knowledge of a human behaviour in control systems often is very helpful in simulations. That is why it is worth to identify how human acts during a dynamic process. Knowing the dynamics of an operator it is easier to predict and simulate some missions that might be difficult to execute in real life. But before that, it is necessary to get closer to human and verify how it works. First step to obtain a mathematical model of a human is to define what form of a transfer function will it has. Then, using different tests and simulations it is possible to identify some parameters of a human.

## 2. Main problems

The biggest problem is that the human behavior under the same circumstances isn't always the same. The repetitiveness of the response of humans is

much lower than that of machines. This is the biggest difference between them. Even if we assume a transfer function that is quite similar to human dynamics, it is not certain that this model would always closely correspond to reality. The behavior of humans depends on their, judgment and fatigue. It means that human may repeat the task, but the response may vary. This complicates the process of identification a lot.

The next emergent problem is how to define the general form of a transfer function that describes the dynamics of a human operator.

Form of the mathematical model depends on the accuracy that is needed to carry out the given task. There are some tasks, where operator's role is almost negligible. In such a case the model of a human operator does not have to be very complicated. But there are some systems where humans play a dominant role. To describe the operator's response in a precise way it is necessary to specify a mathematical model for his behavior. To find out the person personal transfer function we have to identify the factors that might affect the behavior of an operator and describe the basic features of a human operator.

It is necessary to analyze step by step what would be the operator's response in a dynamic system. For example, a pilot in the plane needs to collect the data from the environment. To do this pilot uses his eyes and ears. That process in a control system is responsible for feedback. By observing his response human can minimize the error. On the basis of the collected data the pilot must decide what to do, and after the decision the impulse is sent to his muscles. All of those processes are independent. Each of those steps might be represented by different function. For example in [2] a simple human model in a pursuit task was used. In this experiment the dynamics of an operator was represented by a transfer function in following form:

$$H(s) = \frac{K}{s(Ts+1)} \, .$$

(1)

We can say that this is a basic model of a human operator. But it does not take into account all features of a human. Duane T. McRuer was one of the first who examined operator factors in human–machine systems. He developed a model that was subsequently widely expanded and verified. In [1], [2], and [3] the model of a human operator has the following form:

$$H(s) = \frac{K(1+T_{lead}s)e^{-\tau s}}{(1+T_n s)(1+T_{lag}s)} \, ,$$

(2)

where: $K$ — denotes the operators gain,

$e^{-\tau s}$ — is the reaction time delay,

$\dfrac{(1+T_{lead}s)}{(1+T_{lag}s)}$ – describes the „lead" or „lag" element, and

$(1+T_n s)$ – represents the neuro–muscular lag characteristic of human.

It is evident that the model (2) is more sophisticated and takes into account more attributes of a human. It is possible that for different people the coefficients in this formula may be different. It appears however that it is possible to specify the individual intervals for each trait of a human. In this form of a model we can describe several traits of an operator. Also, after many tests it was found out that it is possible to specify the probable intervals for the coefficients. For example, the authors of [4] found:

$\tau \in (0.2:0.5),$

$T_n \in (0.1:0.16),$

$T_{lead} \in (0.25:2.5),$

$T_{lag} \in (5;20),$

while the authors of [5] give:

$\tau = 0.2 \pm 20\%,$

$T_n = 0.1 \pm 20\%,$

$T_{lead} = 0 - 2.5,$

$T_{lag} = 0 - 20/$

For further experiments we can either take those values or repeat the test and collect new data. After that we can compare them with [4, 5]. Also from medical point of view the time intervals for each feature are similar:

1.  Eye time reaction: 0.035s. to 0.070s;
2.  Optic nerve reaction: 0.05s. to 0.11s;
3.  Time of data transition from brain to arm: 0.02s. do 0.05s.

As we can see these delays are independent and they may be summarized as one time delay effect in the range of:

$\tau \in (0.15:0.23)$

which is similar to the data obtained in [4, 5]. Some of these characteristics do not depend on the individual; in particular, they cannot be changed by training.

It must be remembered that different operators have various features which make the model a little bit different. Nevertheless, the general form of the transfer function proposed in [1] may be used for further examinations and tests. In most of the papers the tests employed to identify the human transfer function were similar. The basic trial was the so-called pursuit task or tracking task. An

operator using a joystick was to maneuver in such way that he follows the object in the given trajectory (fig. 1).
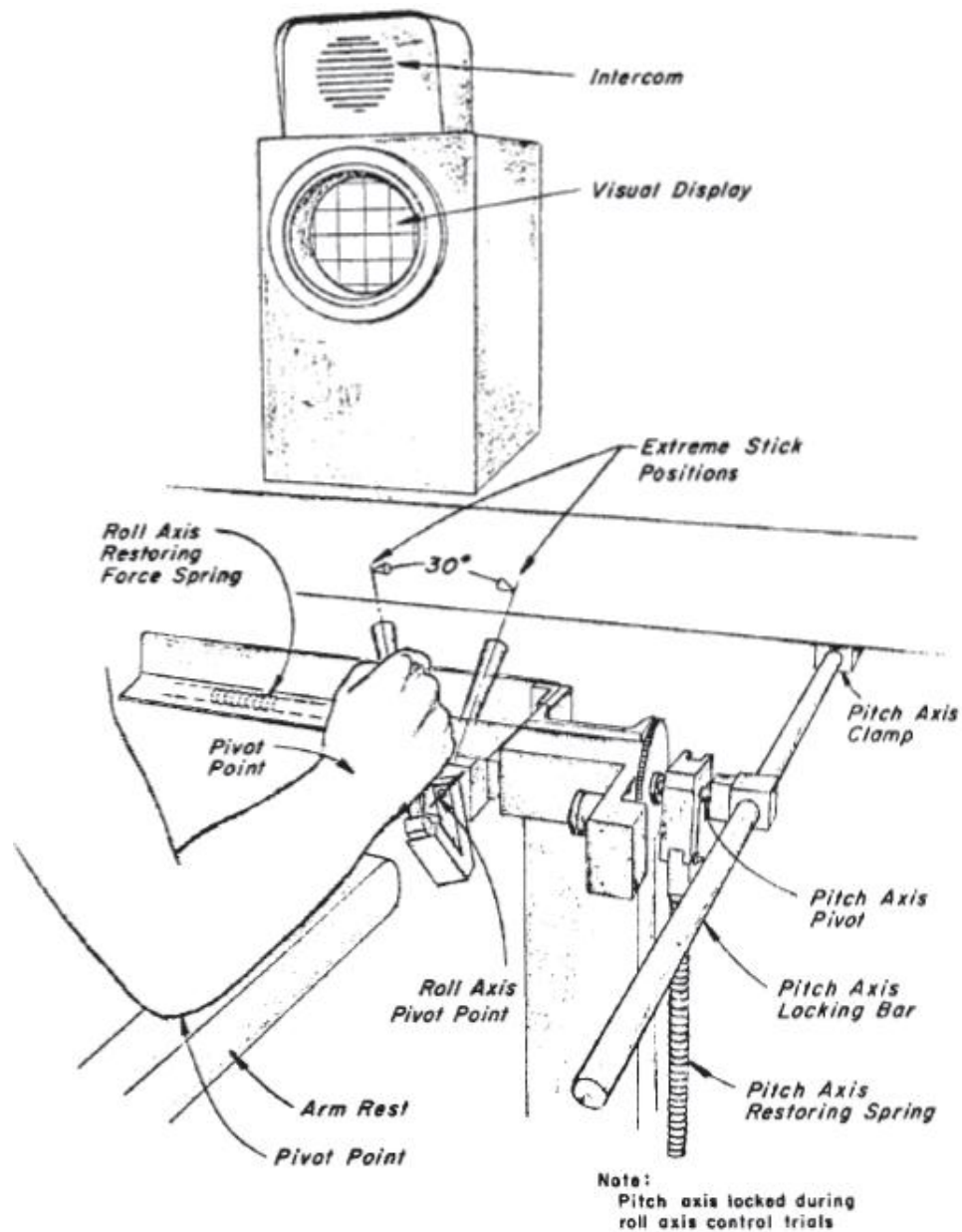


Fig. 1. Stick manipulator [7]

### 3. Transfer function improvement

Considering the difficult conditions in which the operator will work, it is worthwhile to analyze other factors that may affect his behaviour. Many of such factors relevant for the behaviour of a human operator (a pilot) are collected in a diagram shown in fig. 2 [6]:

Before the stress function will be added to a model it should be first properly defined. Does the stress affect all coefficients in the human response in the same way? If we assume that this is indeed the case, we may treat the stress

as a disturbance to a whole control system. However, if the stress affects the human response in a different way, the problem may become much more complicated. To determination of the influence of stress on each part of the transfer function may be difficult.
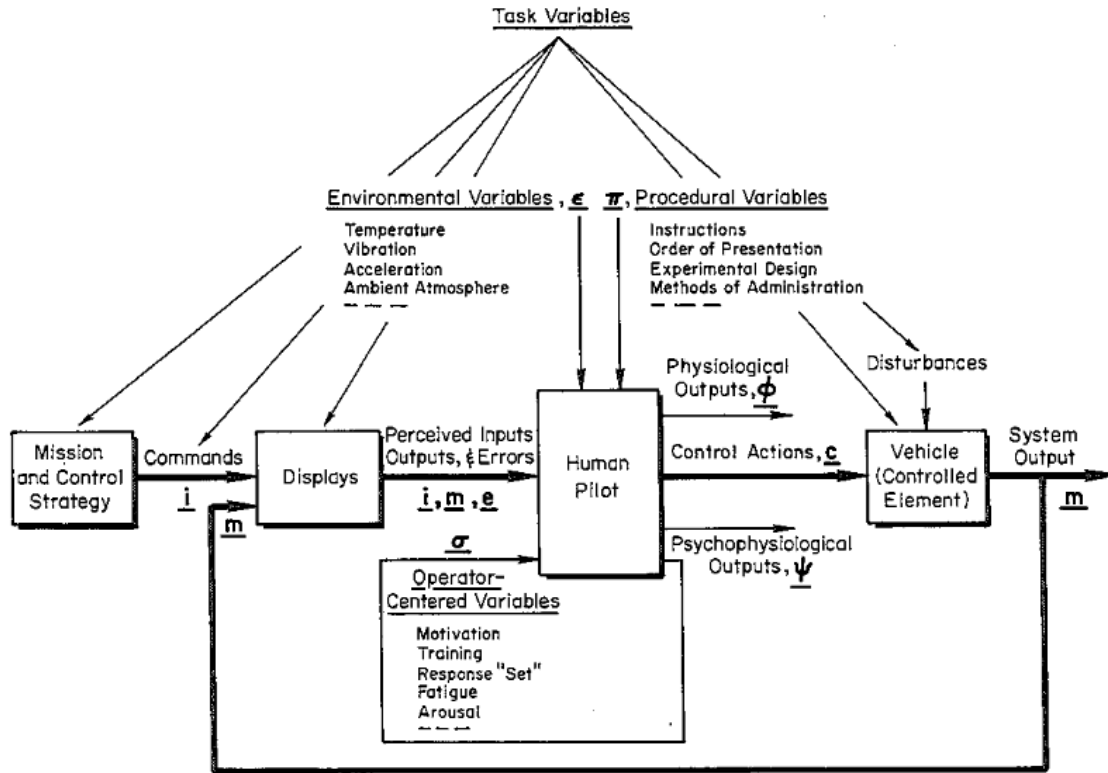


Fig. 2 Variables affecting the pilot-vehicle system, according to [6]

The new transfer function might be written for example in the following form:

$$H(s) = \frac{K\left(1 + T_{lead}\left(S\right)s\right)e^{-\tau(s)s}}{\left(1 + T_n\left(S\right)s\right)\left(1 + T_{lag}\left(S\right)s\right)} \ . \tag{3}$$

## 4. Simulation tests

To determine the range for the stress-related parameters (equation (3)) it is necessary to carry out some experiments. To this end in the Department of Automation and Aeronautical Systems of the Warsaw University of Technology robot simulator has been built. With the help of this simulator some tests of a human operator manipulating a mobile robot would be performed within the PROTEUS project. An attempt would be made to identify the appropriate values of the parameters, using a random sample of operators and a group of well trained operators as well. In this way it would be possible to pinpoint yet another parameter that has a big influence on the behaviour of an operator the training. On the basis of data collected from those test it will be possible to compare the

results obtained when the influence of stress was negligible and those obtained when stress could strongly affect the operator. Then it would be possible to create dependencies between transfer function and stress. There will be always a bit of doubt that it is never certain if the same "stress test" will affect in the same way all the examined people. Nevertheless those experiments might lead us to more accurate solution.

## 5. Conclusion

The precise model of a human operator may be very helpful in further studies of human - machine systems. The knowledge of the human transfer function would help predict the human behaviour under the difficult work conditions. Information collected during these experiments could result in a more general formula describing the impact of some of the external parameters on the operator's behaviour. The transfer function used in [2] might be a good starting point for further improvements. It is hoped that all test which are going to be done would result in a generalization of this model to a stress-dependent model.

## 6. REFERENCES

1.  Duane T. McRuer (1957) Dynamic Response of Human Operator. WADC Technical Report 56-524 ASTIA Document nr AD-210693.
2.  Duane T. McRuer, D. Graham (1965) Human Pilot Dynamics in Compensatory system. AFFDL-TR-65-15.
3.  T. F. Potts, G. N. Ornstein, A. B. (1961) The Automatic Determination of Human and Other System Parameters. Clymer North American Aviation, Inc., Columbus Ohio.
4.  Aidan O'Dwyer (2006) Engineering modeling in transfer function form for diverse learners. AISHE Conference 2006, 31st August 2006.
5.  Barry Gittleman, Terry E. Dwan (1992) System Identification: Human Tracking Response. IEEE Transactions on Education, Vol. 35, NO. 1, February 1992.
6.  Duane T. McRuer (1972) The Development of Pilot-in-the-Loop Analysis. AIAA Guidance and Control Conference, Stanford, CA, August 14-16, 1972.
7.  Duane T. McRuer, R. E. Magdaleno (1966) Human Pilot Dynamics with Various manipulators. RTD Technical Report, STI- TR- 134-3.