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Measuring and Evaluation of Dynamic Properties of Human Operator

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Abstract: This paper deals with an interaction between human and controlled element called MMS (Man-Machine Systems) and presents a methodology of measurements, evaluation and modelling of human behavior using modern simulation and computation technologies and statistical methods. For this purpose, mathematical models of human behavior must be described. Based on these models can be evaluated actual state of human abilities in terms of dynamic properties, e.g. reaction delay, adaption on controlled element ability, etc. These abilities expressed by the model parameters and their changes in time are observed. The nature of this approach is data acquisition and processing from a real environment. This data are obtained from flight simulator at Brno University of Defense where two sets of test measurements with real pilots were realized.

Keywords: MMS, human behavior, behavioral model, flight simulator, MATLAB.

1. INTRODUCTION

Currently, the human operator still constitutes and indivisible part of most control systems. If we assume that the human and his/her behavior are the key elements in controlling a machine, then human abilities significantly affect the whole control process. Early studies about the possible representation of typical human regulation elements (McRuer & Krendel, 1974) were more or less informative. Nowadays, since modern simulation systems are becoming available, these ideas have started to be studied in more detail. (Boril & Jalovecky, 2012)

The main goal of this paper is to verify the potentiality of using flight simulators and subsequent application of mathematical and statistical methods to evaluation of actual state of human abilities in terms of dynamic properties, e.g. reaction delay, ability of adaption on controlled element, etc. during a time. For this purpose, the interaction between human and controlled element must be described. Another important assumption is describing mathematical model of human behavior.

2. MAN-MACHINE SYSTEMS (MMS)

An interaction between man (human) and machine can occur at several levels. One of the most complex interaction is car driving or flight control. In scientific literature, these interactions are referred to as MMS, i.e. Man-Machine Systems. (Havlíková et al., 2014)

The human operator in an MMS system performs working and controlling operations at various stages of difficulty. The knowledge and description of the operator are among the necessary preconditions for the creation of accurate MMS models. In terms of cybernetics, MMS can be described as a control loop composed of a controlled element (such as the machine) and a controlling element (such as the human controller), see in Fig. 1.

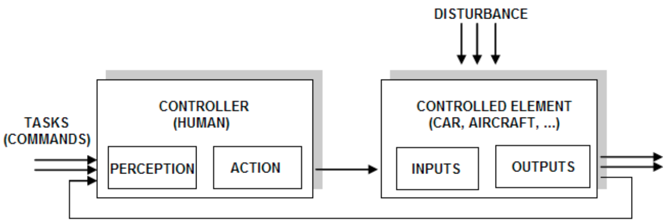

Fig. 1. MMS as a control loop.

In the given context, a human being actively uses his/her mind to reach a goal or to accomplish an aim, and he/she regularly adapts his or her behavior towards achieving a purpose.

The main assumption for description and analyzing of MMS as a control loop is, that a human's behavior can be evaluated based on a corresponding behavioral model.

3. MATHEMATICAL MODELS OF HUMAN BEHAVIOR

The issue of human behavior modelling is fairly complex. One of the first scientists dealing with a description of human's behavior was J. Rasmussen. He presented a human's model consisting of three levels (Rasmussen, 1983):

- the control level,
- the coordinating level,
- the cognitive level.

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At the lowest level, the control level, human being assumes the role of the controller to perform control activities and machine-controlling interventions. This level is also named a compensatory level. At the coordinating level, the human operator must recognize several states of the controlled system, analyze the situation, and select a relevant activity to make the actual state of the system conform to specific rules, standards and techniques. This level is also known as a control based on rules. At the top level – cognitive level, the human brain is activated and the operator incorporates his/her own mind into the system control procedures. This level includes planning, optimizing, etc. The Rasmussen's model is shown in Fig. 2.

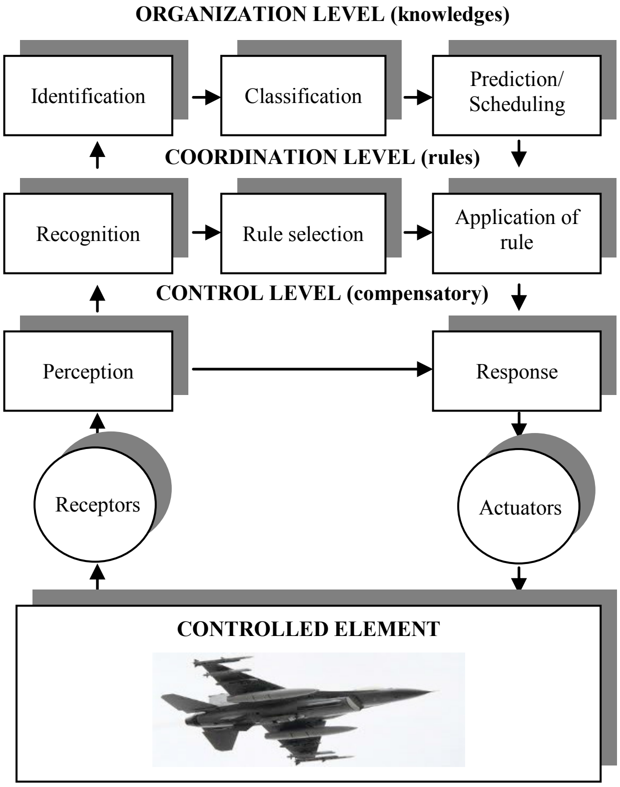

Fig. 2. Rasmussen's model describing human behavior (Rasmussen, 1983).

Based on the general Rasmussen's model, other models were also designed. One of the eminent scientists in the field of modelling of human behavior was D.T. McRuer, whose argument is based on the assumption that human behavior at the control (compensatory) level can be described via the theory of linear dynamic systems after accepting several simplifying hypotheses. During the 1960s, McRuer proposed the principle called Crossover law. According to this concept a human – controller $F_R(j\omega)$ being adjusts his/her control actions to comply with the controlled element $F_S(j\omega)$. Open-loop transfer function in form of (1) describes this principle; where ω_c is a crossover frequency and τ is a transport – reaction delay [s] which indicates the delay between eye perception and the brain response of human. (McRuer & Krendel 1965)

$$F_0(j\omega) = F_R(j\omega)\cdot F_S(j\omega) = \frac{\omega_c}{j\omega}\cdot \exp(-j\omega\tau) \qquad (1)$$

The mentioned equation is an approximation of dynamic properties of MMS expressed as a control system in the nearby area of crossover frequency ω_c. According to this principle, a human is trying to stabilize the whole system and his/her control actions are chosen so that the entire system in the nearby area of crossover frequency ω_c has integrative character, see Fig. 3.

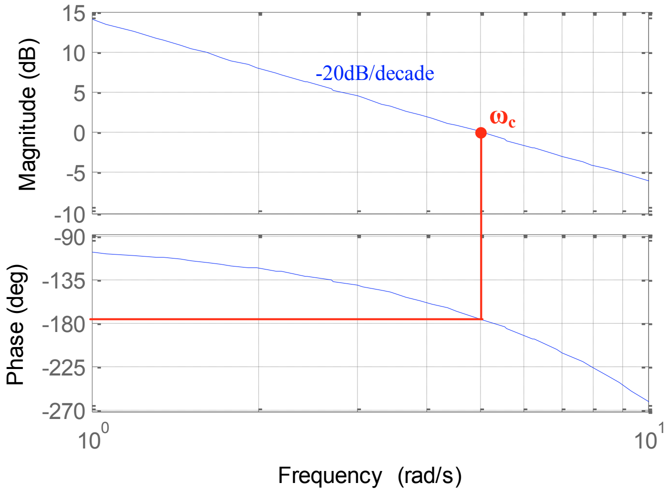

Fig. 3. An example of frequency response $F_0(j\omega)$ according to Crossover law.

To determine the stability of the closed loop of the open-loop frequency characteristics $F_0(j\omega)$, the simplified Nyquist criterion can be used.

The Crossover principle later became the basis for further, more concrete models, e.g. (2). (McRuer & Krendel, 1974)

$$F_R(p) = K\cdot \underbrace{\frac{(T_3 p+1)}{(T_2 p+1)}}_{\substack{\text{human}\\ \text{equalization}}}\cdot \underbrace{\frac{1}{(T_1 p+1)}}_{\substack{\text{neuromuscular}\\ \text{dynamics}}}\cdot \exp(-\tau p) \qquad (2)$$

Here K – human gain, T_1 – the neuromuscular time constant [s], T_2 – the lag time constant [s], T_3 – the lead time constant [s], τ – the reaction delay [s], p – the Laplace operator.

This equation describes a human controller as a proportionally-derivative controller with a second order lag and time delay and it is currently the most widely used model of human behavior. The main advantages of using this model are especially simplicity and possibility of neurological or physiological interpretation of individual parameters. The neuromuscular time constant T_1 represents the pilot's delay in his activity caused by the neuromuscular system. The neuromuscular system includes muscles and sensory organs working at a spinal level (spinal cord). The brain receives information through the spinal cord and then reacts to the external environment. The central nervous system and peripheral nervous system provide information links of the organism to the external environment and continuously regulates processes within the body. Lag time constant T_2 is