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Modeling of the manuo-ocular coordination during object guiding through a path

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Abstract—**Knowledge on human eye-hand coordination can be used for human-like system design and medical diagnosis. This document analyses and briefly presents the parameters of the coordination while executing different eye-hand related tasks. Existing quantitative model of manuo-ocular coordination, capable of simulating the human performance in target tracking, is redesigned for a capability to simulate the performance of object guiding through a visible predefined path. Qualitative model, based on quantitative model, is proposed and explained.**

Manuo-ocular; eye-hand coordination; eye movements; arm movements; coordination control; object guiding.

I. INTRODUCTION

Human eye-hand coordination is an interesting and, despite its popularity in scientific community, is still a promising area of research and investigation. Functions and structure of this system is not only a fundamental question, but also has a number of possible uses in a range from designing synthetic human-like systems to the diagnosis of CNS (central nervous system) disorders.

The most attractive feature of disease diagnosis using investigation of eye movements or eye-hand coordination no doubtfully is the observation that performance of the coordination declines noticeably even when the serious CNS disorder is at its first stages. Possibility to diagnose such illnesses as Parkinson's disease at their very early stage is not possible or is very complicated using other diagnostic methods or tools [1].

Regardless of astonishing achievements of science and technology, human's body is still a superlative system. It is very difficult, but possible to design a partial system having the performance adequate or better than a sub-system of the human. However, nobody has succeeded in designing a full system, capable to outdo the human in all possible situations. It is obvious that biological systems are excellent examples for engineers. The eye-hand coordination system is not an exception – it is the best known universal coordination system.

Much of research in eye-hand coordination area has been done, but most of them used a target – usually a visible dot, moving in a predefined trajectory. Also, there were some investigations, in which, the subjects controlled the hand-moved target themselves. In most of experiments, targets were implemented in an empty space (i.e. an empty computer screen) or a similar environment. All mentioned researches were exploring at a fundamental level (or very close to it) and did not allow the full range of eye-hand coordination parameters to be revealed. Only some investigations were task-oriented (i.e. eye-hand coordination while using the particular software). But these display the characteristics of the software (its comfort and efficiency) – not of the human.

All mentioned above are the main reasons why we aimed to investigate and to model the human behavior while performing one of the common real-life tasks: an object guiding with arm through a predefined visible path.

II. HUMAN BEHAVIOR

A. *Eye movements during ocular pursuit*

If a subject visually tracks an object, which starts to move, the eye movements in corresponding direction are introduced after a latency of 130 ± 29ms. Later, the subject elicits a saccade to catch up with the target. In this manner, the position error of the gaze is compensated. Then the target is being followed with slow eye movements, fewer saccades and no lag [2]. This is possible because the 130ms smooth pursuit delay is eliminated using a target trajectory prediction. Such coordination pattern consisting of smooth pursuit (slow eye movements) and catch-up saccades (rapid eye movements) is the typical behavior while tracking a target moving in a predictable trajectory [3]. In a case when the target moves in a non-predictable trajectory, the average lag of pursuit depends on the target velocity [4].

B. *Eye and arm movements during oculo-manual pursuit*

The eye movements are the same as in previous condition if the subject pursuits the target with his eyes and his arm [2]. If the trajectory is non-predictable, the lag of eye movements is non-zero and because of an additional manual task, increases up to 20%. Tracking errors of eye movements increases too [4].

The latency of the arm is higher with a respect to the latency of the eye. Lags of the arm are compensated by eliciting corrective movements which velocity is higher than the velocity of the target. Target, moving in a predictable trajectory, can be pursued oculo-manually without lag [2]. If it moves in a non-predictable trajectory, the lag of the arm is determined according to the velocity of the target [4].

C. *Eye movements during the pursuit of the self-moved target*

If a subject visually tracks a target, which is being actively moved by his own arm, the delay of the smooth pursuit system at the onset of target (arm) motion reduces from average 130ms to -5±35ms. In this case, eyes can track the target movement without any lag starting from the onset of target movement. Also the ocular pursuit contains no catch-up saccades [1].

D. *Eye-arm coord. while guiding an object through a path*

If the subject guides an object through a visible path, the eye-arm coordination is different. In this case, characteristic of the eye-arm coordination varies between two strategies. One boundary strategy is called "Gaze Jumps" (GJ). If it is used, gaze follows a path using saccades. After each saccade, eyes are fixated for some time, allowing arm-moved object to come up with the gaze-point. Usually eyes perform the next saccade when the distance between the gaze-point and arm-moved object position becomes sufficiently small [5]. Fig. 1 illustrates eye and arm movements when GJ strategy is being used.

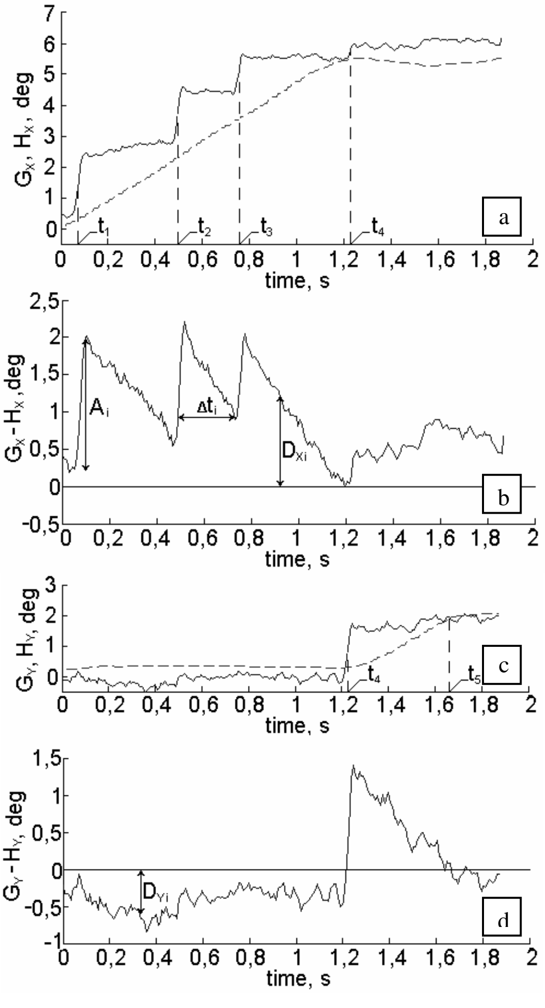

Figure 1. Eye and arm movements for GJ strategy (a, c): self-moved object (dashed line), gaze (solid line) and difference between them in the horizontal (b) and vertical (d) axis [5].

More parameters for GJ strategy (average saccade amplitude and frequency, arm lag time and distance) are defined in a paper [5].

If the path has a visual preclusion, changes its direction (i.e. path follows an angle) or changes its width (in this paper all these complexities will be called "preclusions"), gaze fixation is always done to this complex location. In such case, next saccade is elicited only after arm-moved object passes through. At very complex sections, changes of the eye-arm coordination strategy are even possible [6].

The subject chosen strategy varies in an interval of transitional strategies from boundary strategies GJ and "Gaze Moves Smoothly" (GMS). GJ and GMS are the contrary strategies. If a subject uses GMS strategy, his eyes are moved smoothly, almost together with an arm-moved object. Gaze can follow or lead it by a small distance. This is similar eye movement behavior as the one seen in section C: pursuit of the self-moved target. It is similar not only by its nature, but by the timing parameters also. Eye-arm coordination using GMS strategy is illustrated in Fig. 2.

The choice of the strategy is mainly influenced by an intended task fulfillment velocity/accuracy ratio. If the subject intends to be quick – he uses strategy close to GJ. If he intends to move the object accurately – he uses strategy close to GMS [5].

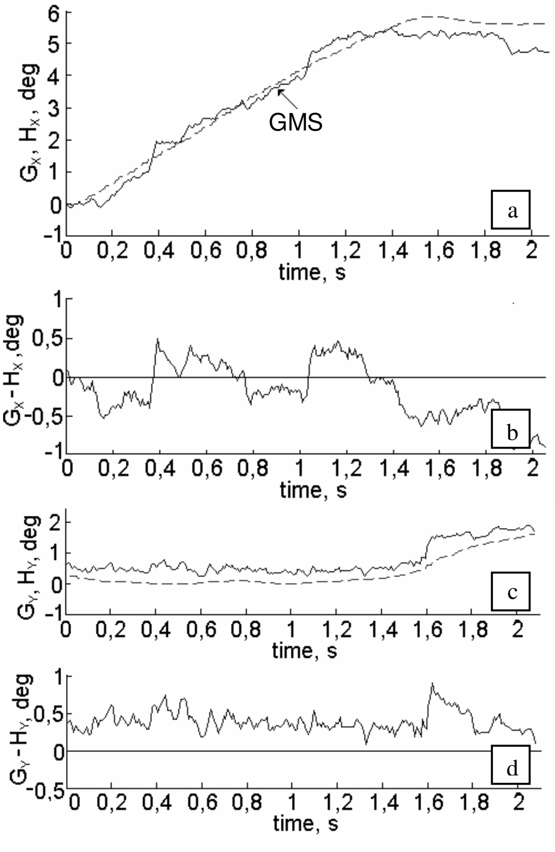

Figure 2. Eye and arm movements for GMS strategy (a, c): self-moved object (dashed line), gaze (solid line) and difference between them in the horizontal (b) and vertical (d) axis [5].

III. MODELLING THE HUMAN BEHAVIOR

S. Lazzari, J.-L. Vercher and A. Buizza has designed and published a manuo-ocular coordination model for target tracking tasks [7]. Its structure is highly parallel with the physiological system of the human. This quantitative model was implemented in "Matlab Simulink" environment and obtained results were compared to human performance results obtained from experimental trials [2]. This existing model is a good start for designing a model, simulating human performance in manual object guiding through a visual path, because it has a simplified arm model, a simple two-part eye model (smooth pursuit and saccadic subsystems) and a Coordination Control System (CCS), capable of simulating ocular pursuit of the self-moved target. Main part of the model is CCS, which has inputs of visual target position, arm afferent signal and efferent copy of arm position. CCS controls the timing of the smooth pursuit and the bandwidth of eye movements. Our task is to augment or partially modify the model to design the system, capable of simulating human performance in the object guiding task.

Our suggested functional diagram for such system is illustrated in Fig. 3. The most important input is a visible path. Because of eye physiology, it is seen in parts – the diameter of the sharply seen image is only few degrees. It is known from experimental investigation, that the gaze is positioned in a sequence to all complicated locations of the path, or, if none of such preclusions is nearby (i.e. path is straight), to the location on the edge of the sharply seen area. This means, that a detection of preclusions in a visible part of the path is done. A next detected corner (or a preclusion) is assumed as the temporal target for the gaze and the gaze position sets the direction for the arm movement. Elicited eye movements determine the visual information which is projected on the retina, thus the visible part of the path.

Eye-arm coordination control system, depending on the aimed accuracy, controls the delay between gaze fixation (to a complex location of the path) and its repositioning to the next preclusion. This delay depends on the complexity of the preclusion and on the aimed accuracy. It is expressed as a distance between the position of the arm-moved object and the position of the gaze-point.

As the visible image sharpness degrades not steeply, but transitively, coordination control system also controls the size of the working image for the detection of the next preclusion. If the aimed accuracy is high – this area will be small, but all seen sharply, if aimed accuracy is low – gaze can be moved to a preclusions which are poorly seen, thus increasing the speed of the task fulfillment and decreasing the accuracy.

The GJ object guiding strategy will be implemented by increasing the aimed accuracy thus decreasing the working area of the preclusion detection to minimum. Then the distance between next preclusion and current gaze position will always be small and the eyes will make no saccades.

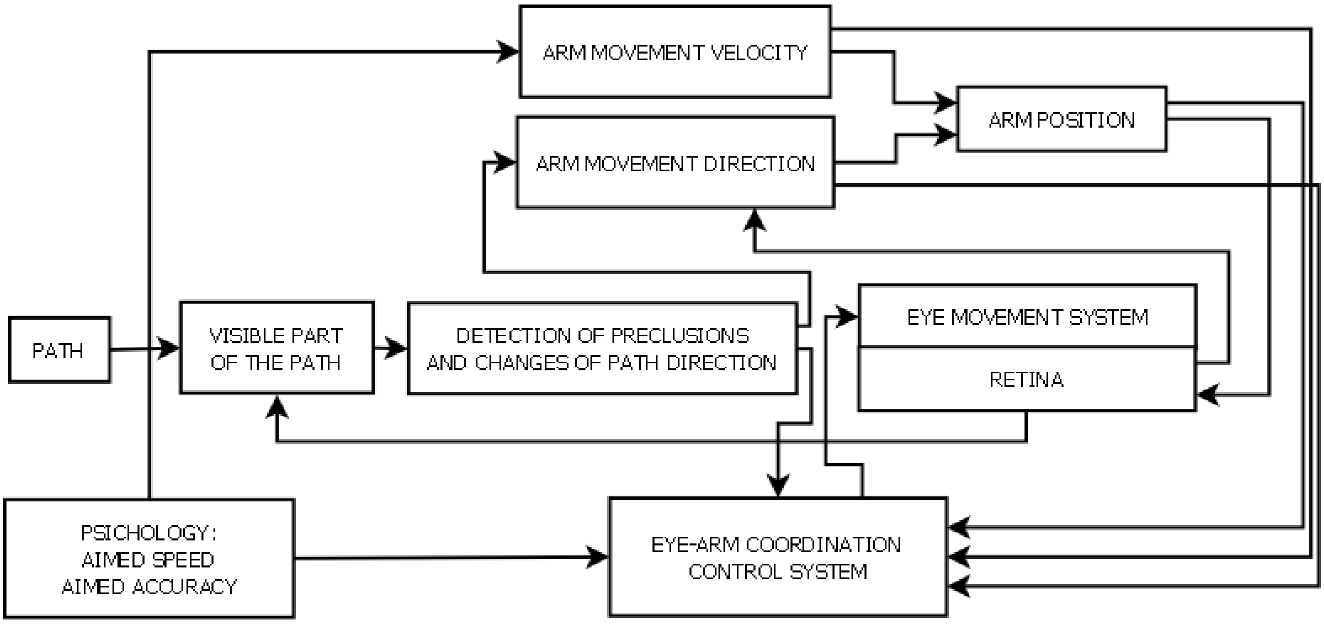

Figure 3. Functional diagram of the model.

The model presented by S. Lazzari, J.-L. Vercher and A. Buizza [6] must be augmented and partially altered to achieve the described functionality. Since we want a model, which simulates only the object guiding task, it is possible to remove the "Setup" block. Also the "Target motion generator" should be replaced by the visual path information. The arm/object position information from the retina is supplied to the Visual space Reconstructor (VR) as in original model, but the target movement trajectory is replaced with a block, supplying the VR with the information about the detected preclusions in the visible partial area of the path image. As the target is no longer presented on a screen, the exit signals of the VR are no longer the position of the visible target. On the other hand, the name "target" is still acceptable for mentioned signals, because they contain the information about the coordinates in a space, where the gaze (or arm) must be positioned soon.

The most important system in a model, the CCS, is augmented with a subsystem, responsible for eye-arm coordination during the manual object guiding task. The operation of this subsystem is controlled by the subjective human factors: the mood, concentration to the task, expected results, etc. Depending on mentioned factors, two of psychology-determined features can be abstracted. They are opposite to each other – the aimed object guiding speed and the aimed object guiding accuracy. The CCS must control not only the parameters of the smooth pursuit, but also the target position for the gaze and the arm-moved object. Since the model determines the target position for the gaze in the VR, it is obvious that the Object Guiding Subsystem (OGS) must be not only a part of the CCS, but also a part of the VR. OGS exit signals are: the intended arm motion trajectory and the target position for the gaze (usually the preclusion or the edge of sharply visible area). The target position for the gaze is formed from two signals: the position (for smooth pursuit) and the retinal error (for saccadic eye movements).

The model with all mentioned modifications is presented in Fig. 4. The large black dots mark the exit signals of the OGS.

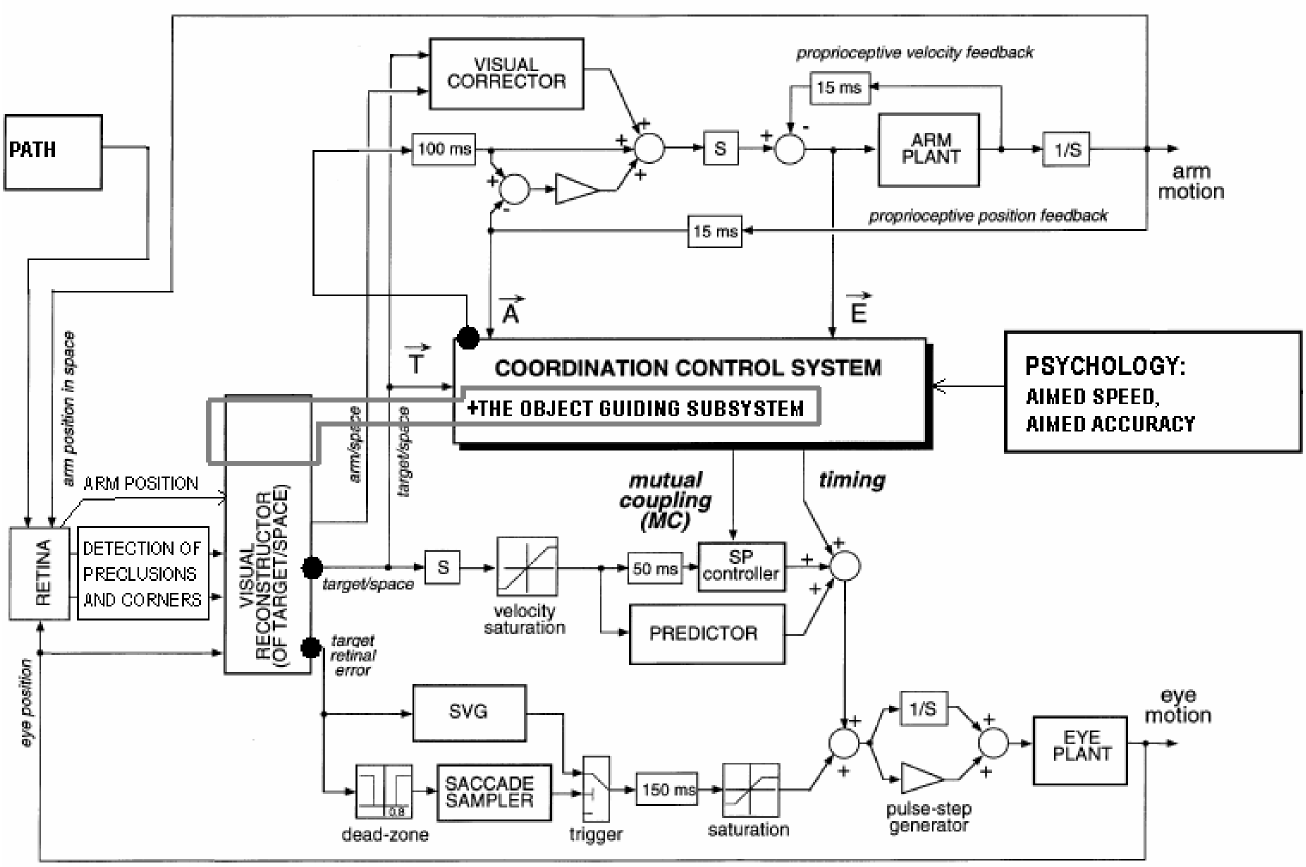

Figure 4. The altered model.

The functional diagram of the OGS is illustrated in Fig. 5. Preclusions become targets for the gaze in a sequence with a variable holding delay. This hold time is determined by a distance between the gaze and the arm-moved object and the subjective parameter – maximum eye to object distance. Another subjective parameter – accuracy constant is used for variation of the diameter of the visible part of the path. If this measure is high – preclusions in a sequence are detected not so accurately because of the use of the peripheral vision. Both subjective parameters depend on aimed task fulfillment speed and aimed accuracy.

IV. CONCLUSIONS

Eye-arm coordination while guiding the self-moved object through a path is a complex action. It consists of features seen in an ocular pursuit, oculo-manual pursuit and the pursuit of the self-moved target. Since these features are already explored (unfortunately not very deeply) and some models are developed, it was possible to modify one of them to achieve a qualitative model for a more complex task simulation. All the features observed in previous experimental research were logically implemented in a model. The next step undoubtedly is a design and fitting of the quantitative model. It is possible to convert obtained qualitative model to quantitative system because of data, collected in previous experimental trials. In addition to that, this model is based on existing quantitative model capable of simulating the self-moved target pursuit. This is presumed to be a great aid in the design of quantitative model.

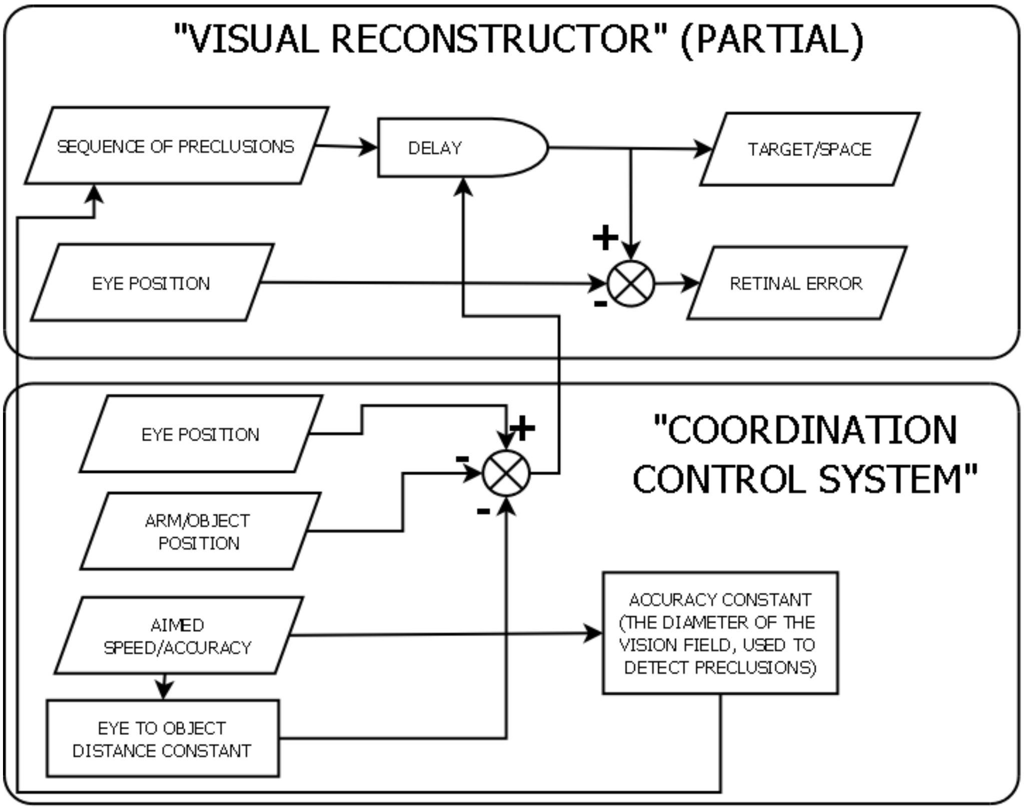

Figure 5. Functional diagram of the OGS.

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