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REACTION TIME MEASUREMENT APPLIED TO MULTIMODAL HUMAN CONTROL MODELING

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Abstract − The final goal of this research is to analyze the human visual and force sensory feedback integration related to a manipulation task and build a control model of a human operator. In this primary work the reaction time was measured to determine the time lag constant of each subject. During the measurement of the reaction time, fluctuations in the pupil size and heart beat were verified and the both had first order lag characteristics but there were no correlation with each other. In order to improve the human control model the identification and implementation of this kind of fluctuation will be discussed.

Keywords: Reaction Time, Sensory Feedback, Human-Machine Interface

1. INTRODUCTION

The human operator has the capability to learn, adapt and control various types of machines. It is of a great interest to understand how the human operator analyzes and processes different modalities of sensory feedback information in order to design directly or remotely operated machines. The aim of this research is to analyze the human control characteristics in respect to the visual, force and audio feedback information and build a human control model that can also represent a control strategy based on multi-sensory feedback (Fig. 2). In this primary work the time lag related to the human control model was measured using cognitive psychological experiments as single reaction time and choice reaction time. This control model would be useful to assist the design, simulation and evaluation of human-machine systems like telerobots[1] and also computer assisted systems as power-assist and drive-by-wire vehicles.

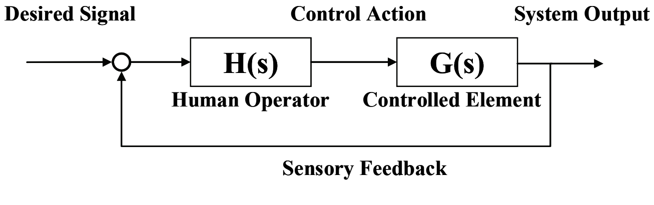

Fig. 1 A General Human-Machine System

2. HUMAN CONTROL MODEL

Early researches have already shown that it is important to consider the human dynamic characteristics when designing and evaluating man-machines systems. The major part of the analytical theory on manual control of vehicles was developed in the 60's. One of the important results was the Crossover Model proposed by McRuer et al. [2], which showed that the human-machine dynamic characteristics presented a first order lag near the crossover frequency. Another empirical result of McRuer [3] works showed that the human operator can change his dynamic characteristics according to the operated machine. A general model of the human control can be represented as Equation (1).

$$H(s) = K\frac{(1+T_L s)}{(1+T_I s)}e^{-\tau s} \quad (1)$$

Here,

$e^{-\tau s}$: Time delay due to human responses

K : Proportional gain

$(1+T_L s)$: Time lead element

$(1+T_I s)^{-1}$: Time lag element

In this primary work the time lag τ due to human responses was measured using the single reaction time (SRT) and the choice reaction time (CRT).

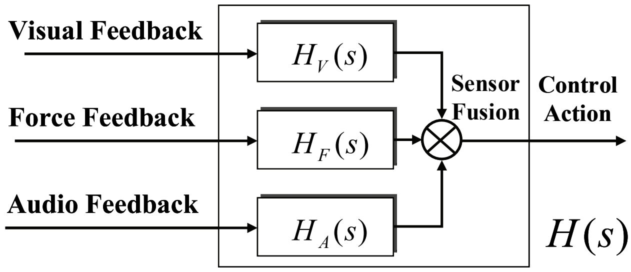

Fig. 2 Multimodal Sensory Feedback Human Control Model

3. REACTION TIME EXPERIMENT

In order to identify the time lag due to human responses the single reaction time (SRT) and the choice reaction time (CRT) was measured with 3 subjects. The experiments were conduct using a master-slave type seesaw experimental device that was developed in order to analyze the human sensory feedback properties separately. It consists of a 1 DOF master haptic device with a force sensor that can be manipulated by rotating a dial or by gripping a joystick. The slave is an actuated linear guide that works as a seesaw with a sliding object over it. In the reaction time experiment 2 LEDs were used as visual cues, positioned at the left and right field of view of the subject. (Fig. 3)

In most cases the reaction time is defined as the time necessary to the subject to turn the dial more than a pre-defined angle after the visual cue is presented. Since the final goal of the proposed human control model is to obtain an operator model of a continuous manipulation task, the reaction time was defined as the movement onset time. In this case, the movement onset corresponds to the time necessary to the dial's angular velocity reach 20 deg/s after the visual cue was presented. This velocity corresponds to about 1% of the maximum rotation velocity achieved by the subjects. During this experiment the gaze movement, pupil diameter and the pronator/supinator muscles EMG was also measured. The experiment setup is shown in Fig. 3.

3.1. Single Reaction Time Experiment (SRT)

This experiment consists of moving the dial as fast as possible after the visual cue is shown to the subject. In SRT experiment the subject does not need to decide which direction to move, it is a reflexive visuomotor action. After the subject became familiar with the experiment device 10 trials were made by each subject. The visual cue presenting time was randomly selected.

Fig. 3 SRT and CRT Experiment Overview. Gaze movement, pupil diameter and the EMG of pronator/supinator muscles was also measured

3.2. Choice Reaction Time Experiment (CRT)

In this experiment the subject has to decide in which direction to move according to the visual cue. If the right LED turns on the subject has to turn the dial in the clockwise direction. If the left LED turns on the subject has to rotate the dial in the counter clockwise direction. In this CRT experiment a computational load is added to the subject due to the decision making about which direction to move. The appearance of the visual cue was randomly in time and space. Here the reaction time was also defined as the movement onset time. After some training each subject performed 20 trials.

3.3. SRT and CRT Movement Onset Time Results

The movement onset time results of SRT and CRT experiments are shown in Table 1 and Table 2. The difference between the fastest A, C (0.20s) and slowest B (0.26s) subject was about 30% in SRT and more than 33% in CRT experiments. Thus it can be inferred that the time to make a decision varied from 0.04s in Subject A to 0.07s in Subject C.

It is interesting to notice that even though the SRT onset time of subjects A and C are the same, the CRT onset time varied considerable. Further considerations will be discussed at 3.4.

Fig. 4 and Fig. 5 showed typical angle and velocity profiles respectively. In both profiles a similarity can be noticed between the subjects A and C. All the subjects showed a pre-programmed target angle which is reached about 0.3s-0.5s after the movement onset. (Fig. 4).

3.4. SRT and CRT EMG Measurement Results

From Fig. 6, Fig. 7, Fig. 8 and Fig. 9 it can be noticed the activation of pronator and supinator muscles before the actual movement starts. The time necessary to send the motor command after the visual information was acquired varied from 0.18s to 0.21s in SRT experiments and 0.19s to 0.28s in CRT experiments. This time includes the decision making time and motor command activation which are difficult to identify separately.

Table 1. SRT Experiment – EMG Activation and Onset Time

	Subject A	Subject B	Subject C
EMG	**0.18s ±0.03s**	**0.21s ±0.04s**	**0.15s ±0.03s**
Onset	**0.20s ±0.03s**	**0.26s ±0.04s**	**0.20s ±0.03s**

Table 2. CRT Experiment – EMG Activation and Onset Time

	Subject A	Subject B	Subject C
EMG	**0.19s ±0.02s**	**0.28s ±0.04**	**0.21s ±0.04s**
Onset	**0.24s ±0.02s**	**0.32s ±0.05**	**0.27s ±0.04s**

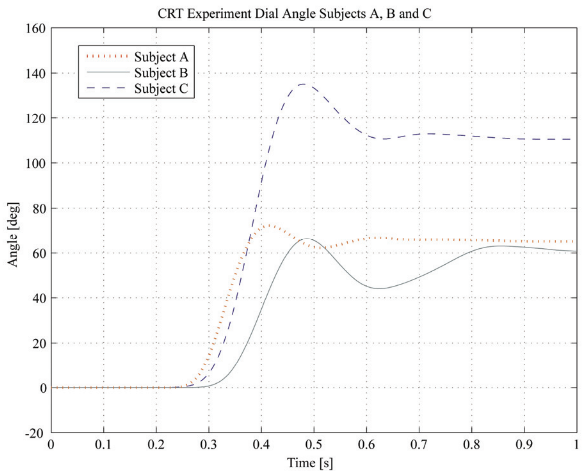

Fig. 4 CRT Experiment Dial Angle Subjects A, B, C

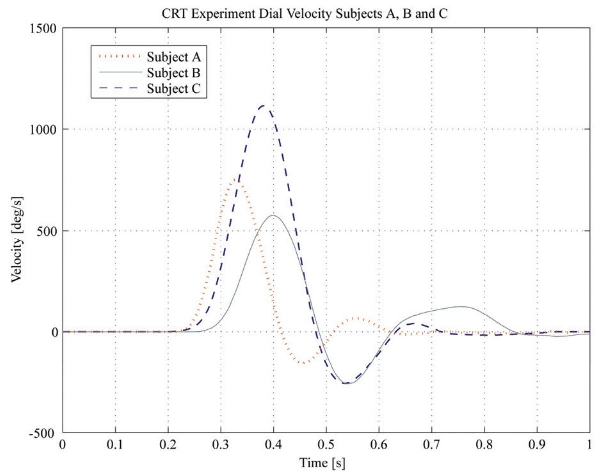

Fig. 5 CRT Experiment Dial Velocity Subjects A, B, C

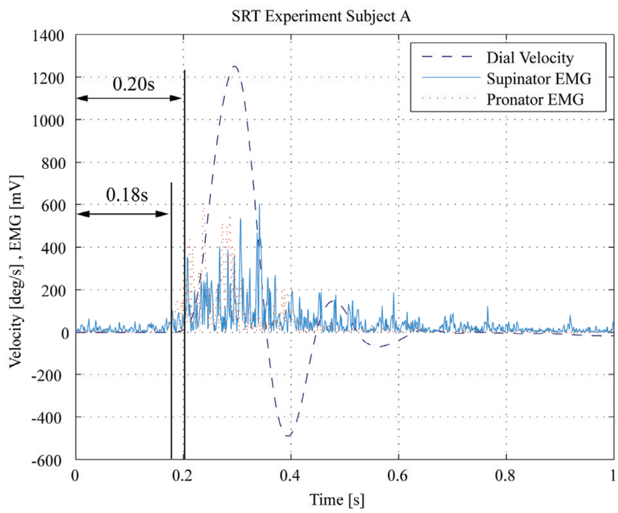

Fig. 6 SRT Experiment Subject A

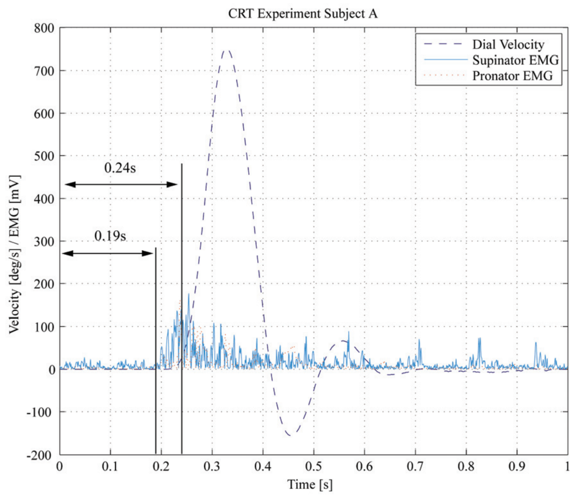

Fig. 7 CRT Experiment Subject A

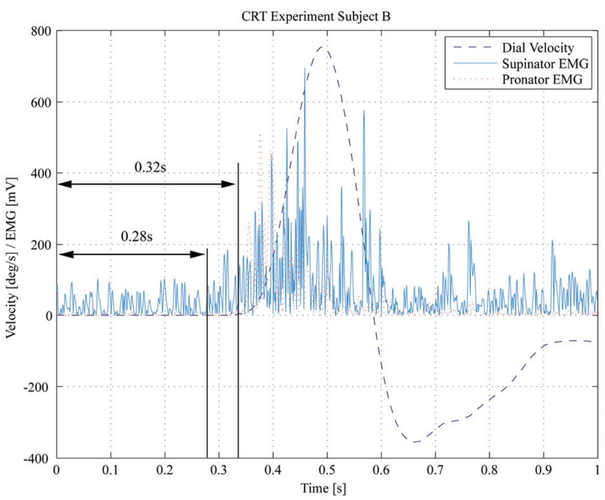

Fig. 8 CRT Experiment Subject B

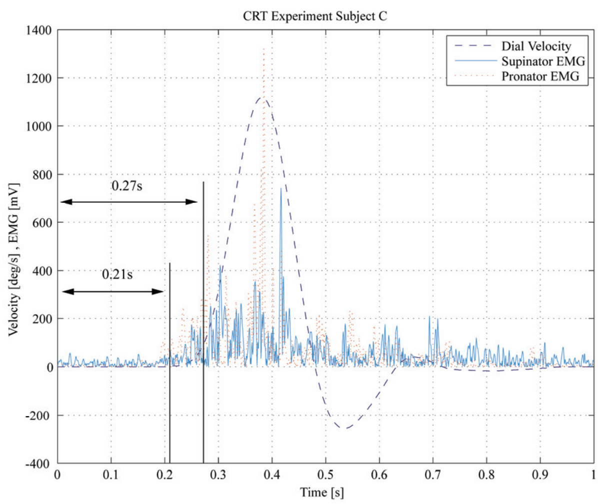

Fig. 9 CRT Experiment Subject C

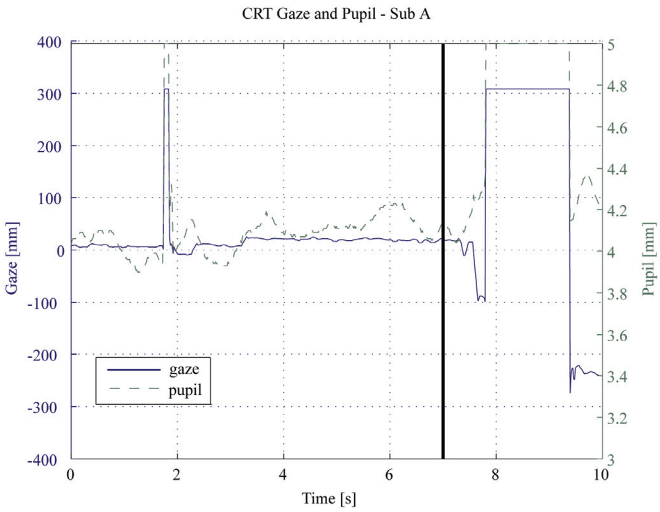

Fig. 10 CRT Experiment Subject A. Gaze and Pupil Diameter.

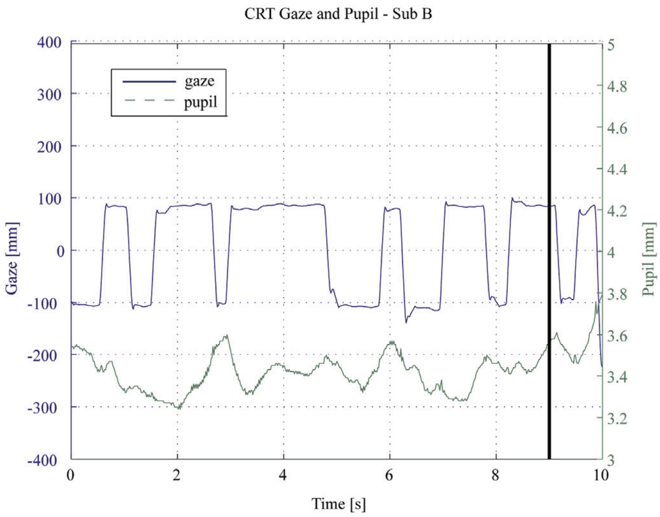

Fig. 11 CRT Experiment Subject B. Gaze and Pupil Diameter.

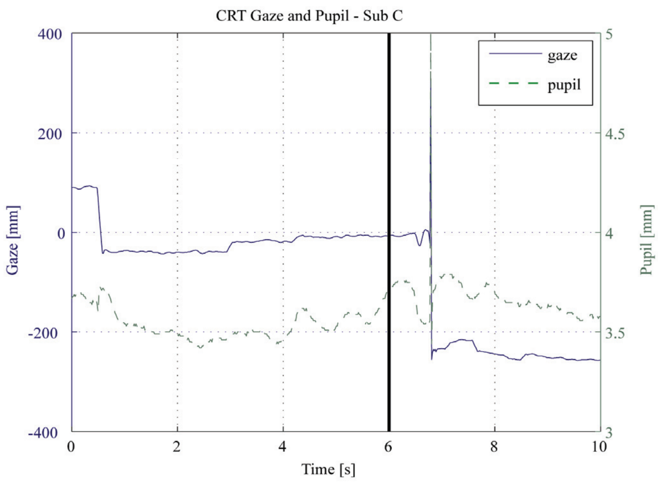

Fig. 12 CRT Experiment Subject C. Gaze and Pupil Diameter.

Due to the musculoskeletal and the haptic inertial properties another approximately 0.05s were necessary until the movement actually started. The time between the visual cue and the emergence of EMG is called ElectroMyoGraphical Reaction Time: EMG-RT or PreMotor Time. ElectroMechanical Delay: EMD is defined as the time between the EMG activation and the starting of the movement. It corresponds to the elctromechanical characteristics of the muscles. [5]

Comparing the EMD of SRT and CRT experiments it can be noticed a very short EMD time in SRT experiment (Fig. 6). This short latency can be inferred as a resultant of a preactivation of motor patterns since the movement is already known.

Even though the SRT onset time of subjects A and C were similar, the considerable difference in CRT experiments is presumed to be attributed to the proficiency of the decision making loop. It can be noticed from a typical trial in Fig. 7 that the motor activation of subject A is faster than subject C showed in Fig. 9.

3.5. SRT and CRT Gaze Movement and Pupil Diameter

The significant difference between the decision time in Subject A and B can probably be related to the gaze movement, i.e. the strategy chosen by the subject to acquire visual information. The fastest subject A used mainly the peripheral vision to cognize which LED turned on because he had his eyes fixed in the middle of the right and left LEDs (Fig. 10). On the other hand the slowest subject B used his central vision to identify which visual cue was presented moving his eyes from left to right and vice-versa (Fig. 11). Subject C also performed a similar strategy to subject A (Fig. 12). The thick vertical line indicates when the visual cue was presented to the subject. This different type of strategy became even more accentuated when the gaze movement coincided with the visual cue presentation like in trial of Fig. 11. This contributed to a large response action by the subject B.

The pupil diameter was also measured in these experiments (green dashed line in Fig. 10, 11, 12). The discontinuity is due to eye blinking. A slightly retraction of pupil can be noticed when the visual cue is presented but it depended on the trial, not being as prominent as expected.

4. DISCUSSION

First, the variation of the pupil diameter will be discussed. Although there are some indications that the pupil diameter can vary depending on the respiration, heart beat, level of concentration, it is very difficult to control all these factors in a single experiment. At a first tentative, the effect of the heart beat peak to peak was analyzed by asking the subject to hold his breath while looking to a constant light source. (Fig. 16)

By analyzing the power spectrum of the heart beat peak-to-peak at a long period and the pupil diameter variation it was verified that both has a first order characteristic. (Fig. 18 and Fig. 20)

This type of characteristic is commonly found in human related measurements but hard to be generated artificially as a pink noise. The study about how the neural motor command controls the muscles, gaze movement, pupil diameter, respiration, heart beat offers a possibility to understand how this kind of fluctuations are generated.

Furthermore, no significant correlation was found between heart beat and pupil size variation as it can be seen at the correlation diagram (Fig. 17). On the other hand, a slightly correlation (Fig. 15) was found between the gaze movement and the pupil size but further observations should be done to confirm this tendency.

Second, as it was pointed out in Section 3.3 the subjects rotated the dial to a pre-determined angle. This behaviour looks similar to a step response which can be represented as Equation 2.

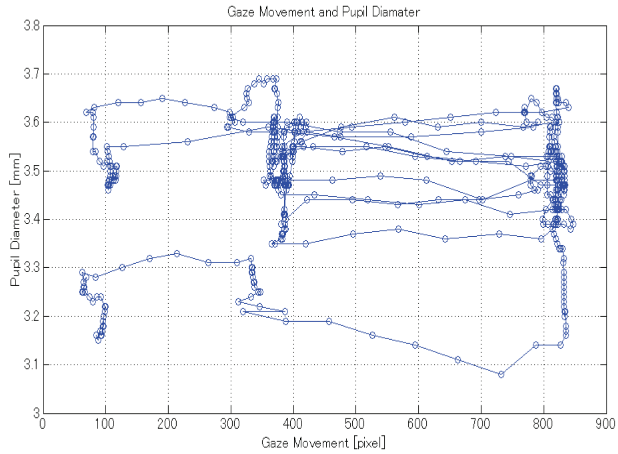

Fig. 15 CRT Experiment Subject B (cue at 6.0s). There is a slightly correlation between the gaze movement and the pupil diameter. The pupil contracts when the gaze moves.

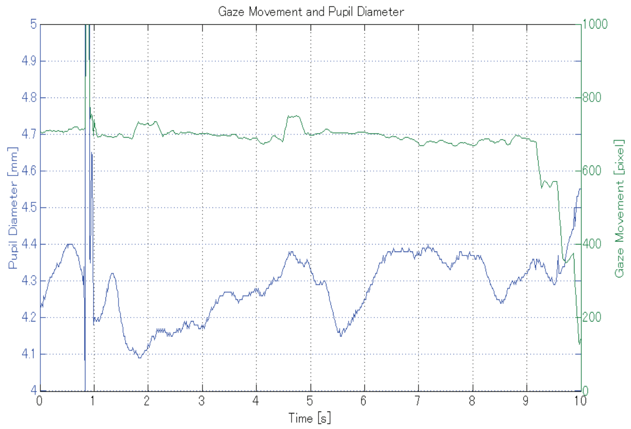

Fig. 13 CRT Experiment Subject A (cue at 9.0s).
Use of Peripheral Vision. Fastest Subject. The discontinuity is due to eye blinking.

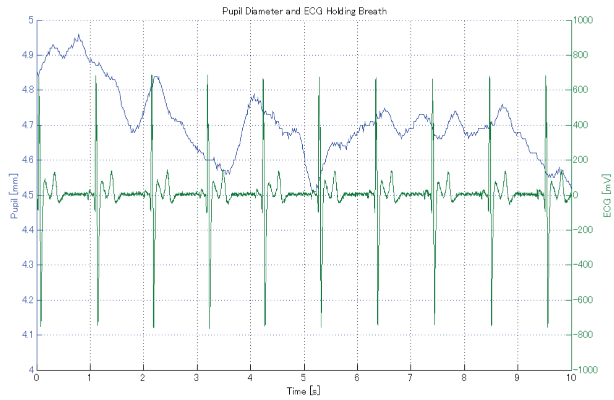

Fig. 16 Pupil Diameter Variation and Heart Beat while Looking to a Fixed Point and Holding Breath.

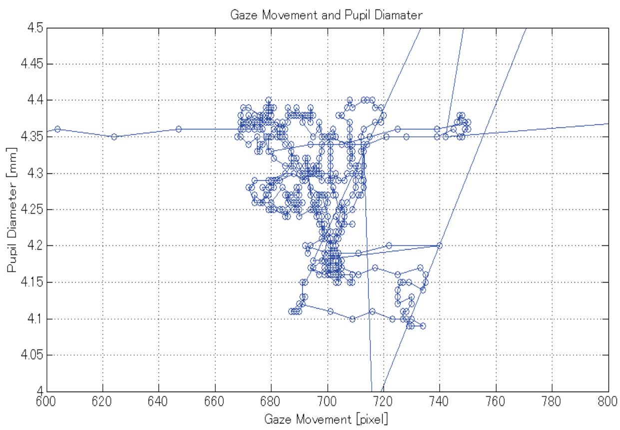

Fig. 14 CRT Experiment Subject A (cue at 9.0s).
No correlation between the pupil diameter and the gaze movement fluctuation during gaze fixation. The discontinuity is due to eye blinking.

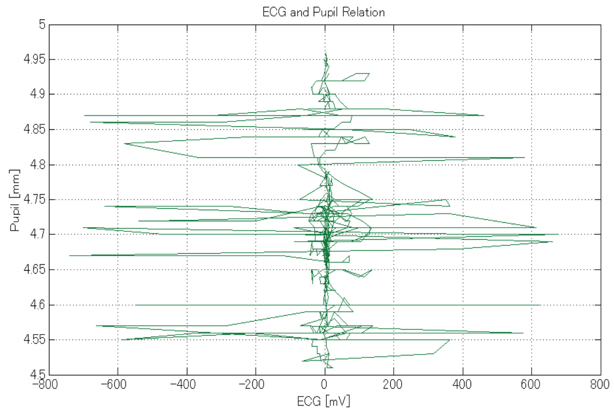

Fig. 17 Correlation Diagram of Pupil Diameter and Heart Beat Variation. No significant correlation can be verified.

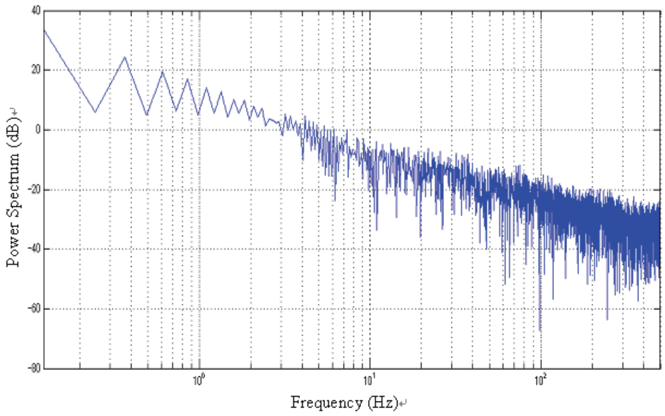

Fig. 18 Power Spectrum of Pupil Diameter Variation.
The spectrum shows the characteristic of first order fluctuation.

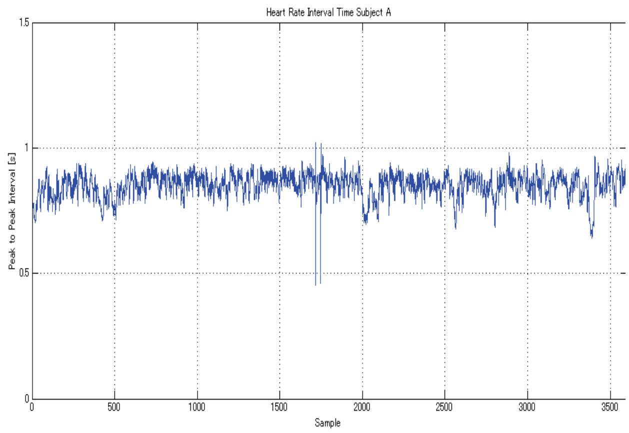

Fig. 19 Heart Beat Peak-to-Peak Fluctuation Measured for 1 hour. The two prominent variations are due to overstretch by the subject.

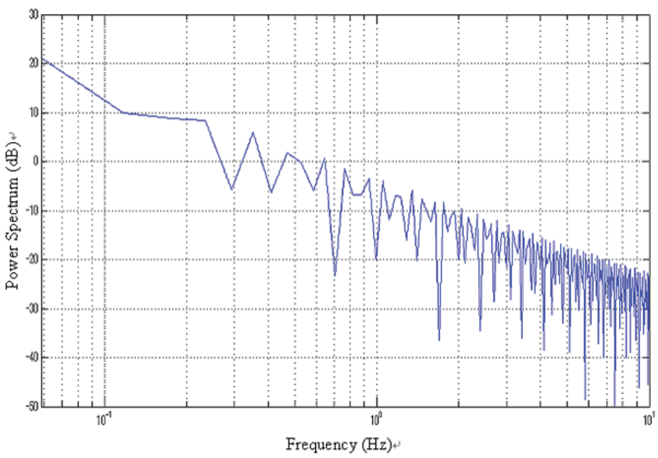

Fig. 20 Power Spectrum of Heart Beat Peak-to-Peak Variation.
The spectrum shows the characteristic of first order fluctuation.

$$H(s) = \frac{K\omega_n}{s^2 + 2\varsigma\omega_n s + \omega_n^{\,2}} e^{-\tau s} \qquad (2)$$

Here,

$e^{-\tau s}$: Time delay
K : Proportional gain
ω_n : Natural frequency
ς : Damping ratio

Future work will be conducted to identify the time delay using the step response and compare it with the SRT and CRT results. This will be a primary step to analyze the time delay identified using control system identification and make a comparative study with the psychophysiological measurements of the human operator.

5. CONCLUSIONS

This primary study is a part of a research to build a human control model represented as a transfer function. In order to identify each control parameter, first the time lag was measured since SRT and CRT are directly associated with the human responses. This work measured the human time responses related to visual perception, motor command and decision making. It was verified that fluctuations in pupil size and heart beating have the same first order characteristic and the implementation of such variations in the construction of human model offers the possibility of a more natural behaviour closer to human responses. The measured human responses will be used in future works to build the human control model related to visual, force and audio feedback information.

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