Exploring the Estimation of Cognitive Load in Human Robot Interaction

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ABSTRACT
In recent years robot design is becoming more and more focused on the ability to adapt to the human environment and to interact with humans. In order to achieve a more natural interaction, robots need to understand human behavior and to appropriately react to it. In this framework, an important skill for robots would be to understand and adapt to the cognitive load of their human partners. Cognitive load can be estimated by a number of methods, one of which is pupillometry, where the measure of the change of the pupil diameter is used to quantify the person's attentional workload. In this paper we discuss how this method has been used in human computer interaction (HCI) studies and how it can benefit human robot interaction (HRI) research. We also present a simplified model of the robot's eye/gaze interaction which includes cognitive load estimation, gaze and blink behavior. Our hope is that a cognitively more aware robot could benefit both robotics (by yielding to a more accepted device) and neuroscience (by providing a controllable display of different levels of cognitive load and, more generally, a more humanlike research tool).

Keywords
Human robot interaction, cognitive load, pupillometry.

1. INTRODUCTION
As humanoid robots are becoming more able to function autonomously in the human society, their behavior needs to become more compliant to human behavior. In this sense, robots need to understand their environment not only by using their sensors to map objects and persons, but also to decipher people's cognitive state. An important aspect of this state is the cognitive (or mental) load (or workload) of humans.

Cognitive load is usually defined as the relationship between the cognitive demands placed on a user and the cognitive resources of that person [10]. If the cognitive load is higher, the user will be more likely to make an error while performing a task. There is a number of ways how cognitive load can be estimated. The methods can be categorized into three groups: performance, subjective and physiological measures. Performance measures estimate how well the user performs an additional task. If the performance on the task is bad, the cognitive load might be too high. In the group of subjective measures, the users estimate their own workload by filling out a questionnaire. Finally, in the third category, a physiological measure is monitored which is known to be related to the rise of cognitive load (e.g. heart rate, skin conductance, pupillometry).

To estimate cognitive load using pupillometry, the so called Task Evoked Pupillary Response (TEPR) effect can be used [1]. According to this phenomenon, the subject's pupil will expand when s/he is faced with a complex task, while the pupil will shrink in diameter when the task is over and the human is not experiencing any additional cognitive load (see Figure 1). This widely observed effect is used in estimating mental workload in human computer interaction.

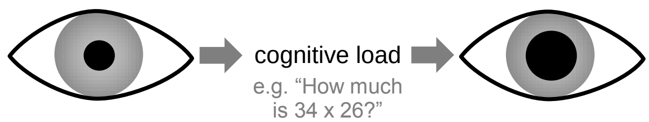

Figure 1. Task Evoked Pupillary Response

The pupil size is not only affected by cognitive load but also by light, as the primary function of the pupil is to regulate the amount of light that reaches the retina. Thus, if cognitive load is to be estimated, lighting conditions need to be controlled [8].

In Section 2 we will discuss how cognitive load was estimated in HCI using pupillometry. Then, in Section 3, we will propose an interaction model for the robot that includes cognitive load estimation and other eye/gaze related measures.

2. BACKGROUND
Pupil diameter is traditionally measured by head mounted eye tracking devices, but recently even remotely located eye trackers proved to be precise enough for this task. Klingner et al. [3] reported on estimating cognitive load on tasks performed in front of a computer screen equipped with eye tracking cameras. The cognitive tasks included mental multiplication, digit sequence repetition and aural vigilance of different difficulties. Lighting conditions were strictly regulated. They found significant differences in pupil diameters for different levels of task difficulty when the results of many trials were averaged.

Following on the above results Palinko et al. used pupillometry to estimate cognitive load in a driving simulator [7]. Two participants were playing different word games (Last Letter Game and Twenty Questions) while one of them was also driving in the simulated environment. It was shown that on average the driver's pupil was more dilated when s/he was thinking of a new word to say than when it was the other player's turn to think (see Figure 2). Similar results were achieved in another simulator experiment where the subjects were playing the Taboo game [4].

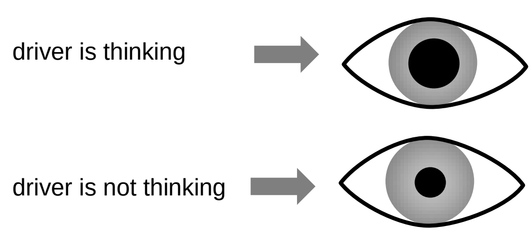

Figure 2. Pupil reaction during the driving study in [6]

In the above discussed experiments the lighting conditions were not closely controlled. Therefore another experiment was designed to distinguish between the pupil's change due to light reflex and the effect of the TEPR [6]. In this study Palinko et al. measured how subjects' eyes react to the onset of light and designed a mathematical model of this reaction. In particular, they were able to compensate for the pupillary light reflex and thus end up with a clearer estimate of cognitive load. In a further experiment, the authors explored how lighting in different parts of the subject's field of view affects the pupil diameter [5]. The results showed that the further the light stimulus is from the optical axis of the eye, the smaller its reaction on the pupil diameter is going to be.

The previously described experiments were designed to study human computer interaction, but the methodology could also be used to study human robot interaction. Cognitive load is an important measure in HRI as knowing the mental state of the human participant could be used to design more natural interaction. For example, if the robot's estimation indicates that the human is cognitively loaded, then it could adapt to the situation by refraining from adding to the human's high workload.

3. MODELING

We propose for discussion a preliminary robot eye-gaze perception model which would not only incorporate cognitive load estimation but also other aspects of the human eye: gaze tracking, saccade frequency, blink rate, etc. On the other hand an action model could describe how a robot's eyes and gaze should react to ensure a more natural interaction [2], see Figure 3.

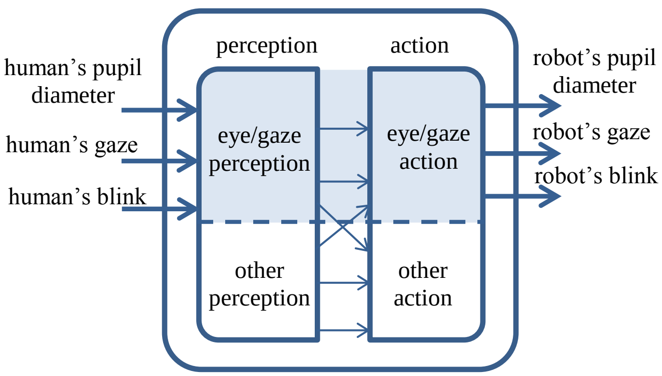

Figure 3. Simplified diagram of a robot's interaction model

According to the proposed model the perception stage would monitor the human conversant's eye and gaze behavior, trying to conclude about the mental/cognitive state of the person. For example, if the pupils are dilated, the blinks are frequent and irregular, the gaze is changing rapidly, the subject might be experiencing high cognitive load. Thus the inputs to this stage could be the human's pupil diameter, gaze direction, blink rate, etc. These would be obtained using an eye tracking algorithm either on the cameras of the robot itself, or by using a separate eye tracker. The outputs of the perception stage could lead to further cognitive processing (omitted from Figure 3 above for simplification) or directly to the action stage. The actions might be generated by the eye/gaze system of the robot or other systems (speech, motion, etc.)

The eye/gaze action stage of the robot would add to the naturalness of the interaction by mimicking the behavior of the human visual system. The robot's pupil size could adjust to its cognitive load. The robot's gaze could track the human conversant's eye position or objects being discussed. Blinking could follow the natural human blink rate in normal situations and increase when the robot is "confused".

4. CONCLUSION

The design of robot behaviors has often been focused on reducing cognitive load and correctly managing partners' attention [9]. At the same time substantial research has been conducted on individuating real-time indicators of cognitive workload, especially in the context of human computer interaction (e.g., [4-6]). We propose to implement on a humanoid robot the monitoring of human pupil expansion, together with other implicit gaze signals, to make the robot aware of the attentional status of its interaction partner and to make it appropriately adapt its own behavior in real-time. We believe that this study could represent a good example of coupling between robotics, psychology and neuroscience. In fact, the knowledge of a specific aspect of human human interaction (HHI) is exploited to make robot behavior more natural and hence potentially more accepted in the human environment. On the other hand, the robot can serve as a tool for studying neuroscientific mechanisms in HHI, playing the role of a natural but fully controllable participant in our environment.

5. ACKNOWLEDGEMENTS

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