Eye-Based Driver State Monitor of Distraction, Drowsiness, and Cognitive Load for Transitions of Control in Automated Driving

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***Abstract*—Automated driving vehicles of the future will most likely include multiple modes and levels of operation and thus include various transitions of control (ToC) between human and machine. Traditional activation devices (e.g., knobs, switches, buttons, and touchscreens) may be confused by operators among other system setting manipulators and also susceptible to inappropriate usage. Non-intrusive eye-tracking measures may assess driver states (i.e., distraction, drowsiness, and cognitive overload) automatically to trigger manual-to-automation ToC and serve as a driver readiness verification during automation-to-manual ToC. Our integrated driver state monitor is overviewed here within the scope of this brief system description/demonstration paper. It combines gaze position, gaze variability, eyelid opening, as well as external environmental complexity from the driving scene to facilitate ToC in automated driving. As both driver facing and forward facing cameras become increasingly commonplace and even legally mandated within various automated driving vehicles, our integrated system helps inform relevant future research and development towards improved human-computer interaction and driving safety.**

Estimates by experts [1] and the common public [2] envision wide usage of automated cars by the year 2030. Standardized frameworks have been published by the German Federal Highway Research Institute (BASt), the National Highway Traffic Safety Administration (NHTSA) and the International Society of Automotive Engineers (SAE) for characterizing and defining different levels of automated driving, and recent reviews indicate many different kinds of transitions of control (ToC) both between and within various levels, for example as in [3].

Driver state monitoring (DSM) can help achieve goals of safety and driver acceptance by ensuring appropriate roles/responsibilities for a human driver within the full driving system. DSM could help a "joint" human-machine functional allocation driving system to select different automation levels [4] based upon driver alertness and attention levels. Many different ways could be imagined for a vehicle to observe its driver at different times. Non-intrusive physiological measurements such as eye tracking of a driver would not require him/her to keep hands on the wheel or feet on the pedals and so may achieve utility across a wide spectrum of human and automated driving scenarios. The aim of this paper is to provide an overview of the current developmental state of our system through a description of its general design and present workings (i.e., situated automation as back-up).

I. System Description

A. Simulation Environment

The driving simulation was designed and implemented within the PreScan software from TASS International. The simulated environment consists of three major worlds (W#) for the purposes of evaluating/demonstrating the progressive capabilities of the developing DSM system. In W1, an early version of the system has been tested with 31 participants [5]. In W2, a closed test grounds environment is simulated to artificially expose the DSM system and its driver to various interactions of hazards and infrastructure (moving and standstill vehicles, bicycles, pedestrians on straight/curved roads of various lane number with/without bordering walls, guardrails, etc.). In W3, a natural environment is modelled after a stretch of open Swedish country road transitioning between farmland fields and the outskirts of a small town. An automation (combined lateral/longitudinal control) status bar and LEDs signaling driver states may be emulated in the driver's view or removed out of the simulated scene.

A green bar with white text reading "Normal Driving" indicates that automation is off (i.e., manual control) and a red bar with white text reading "Auto Backup Control" indicates that the automation is on. The automation was designed in such a way that when it switched on, it would steer the car towards and maintain a programmed trajectory as quickly as possible (e.g., center of right lane at pre-determined speeds) while also maintaining adaptive forward collision avoidance technology (i.e., slowing/stopping in cases of detected collision conflicts).

B. Eye Tracker Apparatus

The driving simulation visuals were presented on a desktop screen measuring 24" diagonally (52 cm wide by 32.5 cm tall) at a distance of approximately 65 cm in front of the eyes. Two eye tracking cameras with IR emitters were enclosed within a horizontal black bar attached to the bottom of the screen as part of the SmartEye DR120 that measured eye data samples at 120 Hz, although these were down sampled to 60 Hz by scripts for pragmatic integration with the simulation software.

C. System Integration

MATLAB scripts were produced to read measurements in real time from the eye tracker, classify driver states, and trigger ToC between driver and automation. The designed integrated DSM system first assesses a state of driving to provide an ecologically-tied vigilance reference of driving scene complexity to ground driver state assessments within. Current plans are to accomplish this at a later development point via a road facing camera and Open Source Computer Vision (OpenCV) image processing algorithms readily contained and seamlessly connected within RTMaps. At the present point of publication, the state of driving is assessed through emulated radar systems contained within PreScan. If the vehicle is tracking on course and free of collision conflicts, it remains in manual control regardless of driver state. However, if either course stray or collision conflicts are detected, driver eyes are then evaluated for any of three compromised sub states: distraction, fatigue, or cognitive overload. At this point, if an elevated driver aberrant state is detected by presence of any of these sub-states, a manual-to-automation ToC is triggered. If either the complexity or aberrance in driver state is resolved, an automation-to-manual ToC is triggered.

State of Distraction/Inattention

Gaze positions on the screen of the simulation are first calculated with trigonometry from known screen dimensions and real-time SmartEye measures of camera-to-eye distances before then being normalized around a 0,0 x/y coordinate origin in the middle of the screen (i.e., upper right corner = +1, +1; lower left corner = -1,-1). As vetted within Janssen (2016), 90 consecutive off-screen gaze samples (1.5 s) is used to assess and signal a state of distraction. This distraction state is reset by 270 consecutive on-screen gaze samples (4.5 secs).

State of Drowsiness/Fatigue

Size of eyelid opening measures is measured in real-time by SmartEye and is used in lieu of pupil coverage for the standardized measure of PERCLOS (i.e., percentage eye closure). This is calculated as the proportion of time in a moving window that the eyes are at least 80% closed [6]. When the eyes are closed at least 80% for at least 48 cumulative samples within a moving second window, the drowsiness state is applied. Less than 48 aberrant eye lid opening samples per second removes the fatigue state assessment.

State of Cognitive Overload/Mental Workload

After the first two minutes, cognitive overload is assessed every sample update (i.e., 60 Hz) by computing the product of 1 standard deviation of horizontal gaze degrees and 1 standard deviation of vertical gaze degrees over the last 120 seconds of samples. While gaze variability over the last two minutes is thus constricted below a threshold of 15 square degrees (cp. results Table 1 of [7]) the cognitive overload state of the driver is assessed/applied and otherwise lifted.

D. Value of Proposed DSM System Design

Performance of drivers degrade and rebound differently based on underlying casual mechanisms and so may have implications for warning/resolution strategies in driver support systems. For example, fatigue assumes more rhythmicity with periodic recovery whereas distraction may be more momentary with punctuate failures [8]. Our integrated DSM presently detects multiple aberrant states of drivers from a single eye-tracking system (i.e., fixations indicative of distraction, eye lid closures indicative of drowsiness, and gaze variability constriction indicative of cognitive load) and triggers transitions of driving control. A key benefit of the automation-as-backup stance within this system design integration scheme, is that automation which falls short of full autonomy is not precariously left to human supervisors who may become susceptible to degraded vigilance [9]. Instead, the automated driving functions as an active safety system rather than convenience commodity, becoming active only on an as-needed basis and disengaging per the situation no longer requires it. Further driver-in-the-loop evaluations are planned to tune state assessment parameters, develop HMIs and iterate the DSM system design both in future simulation and on-road scenarios.

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