Detection of Driver Fatigue Caused by Sleep Deprivation

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***Abstract*—This paper aims to provide reliable indications of driver drowsiness based on the characteristics of driver–vehicle interaction. A test bed was built under a simulated driving environment, and a total of 12 subjects participated in two experiment sessions requiring different levels of sleep (partial sleep-deprivation versus no sleep-deprivation) before the experiment. The performance of the subjects was analyzed in a series of stimulus-response and routine driving tasks, which revealed the performance differences of drivers under different sleep-deprivation levels. The experiments further demonstrated that sleep deprivation had greater effect on rule-based than on skill-based cognitive functions: when drivers were sleep-deprived, their performance of responding to unexpected disturbances degraded, while they were robust enough to continue the routine driving tasks such as lane tracking, vehicle following, and lane changing. In addition, we presented both qualitative and quantitative guidelines for designing drowsy-driver detection systems in a probabilistic framework based on the paradigm of Bayesian networks. Temporal aspects of drowsiness and individual differences of subjects were addressed in the framework.**

***Index Terms*—Bayesian networks (BNs), camouflage, drowsy driving, sleep deprivation, stimulus-response tasks, tracking tasks.**

I. INTRODUCTION

UNTIL recently, most safety-related research has focused on methods to reduce damage caused by transportation accidents while they are occurring or after they happen. Passive safety systems such as seat belts, airbags, and crashworthy body structures help reduce the effects of an accident. In contrast, active safety systems help drivers avoid accidents by monitoring the state of the vehicle, the driver, or the surrounding traffic environment and providing driver alerts or control interventions. Examples of active safety technologies include traction control systems, electronic stability control systems, forward-collision warning and lane-departure warning systems, panic brake assist, lane-keeping aids, and automatic braking systems [1]. Systems that monitor driver states such as where the driver is looking or driver drowsiness also fall under the category of active safety systems.

Our research interest centers on the detection of drowsiness among fatigue-related impairments in driving. This paper makes two major contributions. First, the *camouflage nature of drowsiness* is revealed. Drivers that are deprived of sleep can still maintain performance in some routine driving tasks. However, their ability to cope with unusual or unexpected driving situations deteriorates. Second, a probabilistic framework based on Bayesian networks (BNs) for inferring drivers' state of drowsiness is introduced.

Online driver monitoring devices in motor vehicles have received renewed attention for helping detect fatigue in the U.S. and Europe since the late 1990s. These devices rely on a wide range of parameters, as there is no single commonly accepted metric to detect driver fatigue in an operational context [2]. Our study does not employ physiological signals such as EEG or physical changes of drivers such as eye-closure rate, but deals with data from driver–vehicle interaction. There are moments when a driver still looks awake (eyes wide open) but does not process any information [3]. Although explicit sleep-onset episodes can cause serious performance failures, some effects resulting from sleepiness can occur without microsleeps [4]. This implies that falling asleep may not be the only cause of fatigue-related accidents; performance deterioration due to drowsiness may not be induced only by sensor degradation such as eye closure but may be affected by controller degradation such as brain functions associated with sleep deprivation. To address this issue, our approach mainly uses the performance of drivers extracted from the driver–vehicle interaction.

The rest of this paper is organized as follows. After a brief introduction on the background and motivation (Sections I and II), Section III presents the experiment design, which includes a detailed explanation of different sleep-deprivation levels of drivers, simulated driving and nondriving tasks, performance metrics, and laboratory setup. Next, Section IV presents the analysis on experimental results. Section V discusses the application of BNs to detecting drowsy drivers based on the experimental data. Section VI summarizes the study and provides future research ideas.

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