Integrated Driving Aware System in the Real-World: Sensing, Computing and Feedback

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Abstract
We have developed an integrated driving-aware system that allows us to effectively conduct driving user experience (UX) studies. Our system senses driver and vehicle status, analyzes the collected data, and makes a decision about what feedback to provide a driver in a single Android application. We also propose a graphical experimental authoring tool to plan driving routes and manage UX experimental factors. This research with real-world experiments should have great positive impact on further driving-related UX studies.

Author Keywords
In-vehicle user experience; Sensing framework; Modality design; Experimental design tool

ACM Classification Keywords
H.5.m. Information interfaces and presentation

Introduction
Recently, we have seen significant advances in the area of in-vehicle information systems. However, there are still few systems that allow us to understand what drivers are doing in their cars, the contextual driving situations, and how to present information to them in a thoughtful manner. A common approach is to instrument a test vehicle, but this has limitations.

Drivers are required to use the test vehicle rather than their own, the instrumentation is often quite expensive and complex to install, and the instrumentation is usually limited to data collection.

Instead, we propose an Integrated Driving Aware System (IDAS) that supports inexpensive and lightweight instrumentation of any vehicle, supports computation and analysis of driver actions and the driving situation, and supports the presentation of information to drivers in response to these actions and situations. There is currently no system that supports all three of these functions in a single, simple integrated system.

In addition, in order to support driving experimentation, the system also needs to support experiment design and management. We also propose an experiment design tool that allows us to create and manipulate one's driving route, add mashup information, such as advertising, roadwork, or notification message, on the route, and specify test conditions. To evaluate interoperability and applicability of our system components, we performed real-world driving experiments on two different routes. Finally, we discuss our results and describe how the IDAS can be utilized for further driving-related studies.

System Requirements

In order to identify system requirements, we first surveyed previous studies. Felipe *et al.* [1] attempted to monitor vehicle status using professional acquisition devices. Lu *et al.* [2] analyzed driving distraction using electrocardiogram (ECG) signals. Derick *et al.* [3] divided driving style into typical and aggressive categories using a smartphone as a sensor platform. In our lab, Kim *et al*. [4] utilized two different wearable sensors and an on-board diagnostics (OBD) sensor to identify when a driver is susceptible to interruptions. Matt *et al.* [5] developed a graphical authoring tool for virtual driving experiments. Based on this survey, we identified the following four requirements for in-car sensing and experimentation:

- Sensing – Integrated monitoring of vehicle and driver status
- Computing – Real-time data computation
- Feedback – Modality switching and combination
- Experiment Authoring – Graphical user interface to design and setup driving experiments.

Integrated Driving Aware System (IDAS)

We designed the IDAS architecture to fulfill the system requirements as shown in Figure 1.

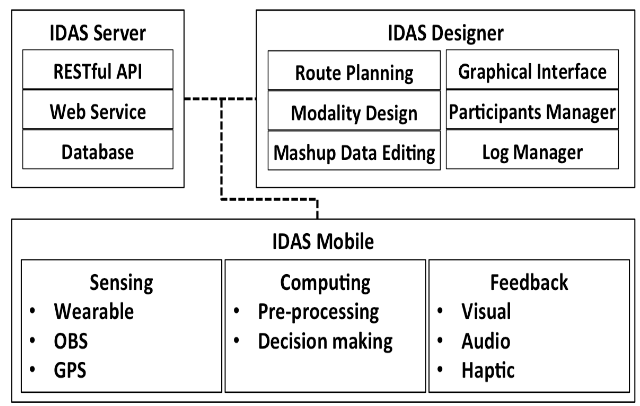

Figure 1: System architecture of the IDAS.

Figure 2: A dashboard to visualize sensing data and check data communication before starting driving.

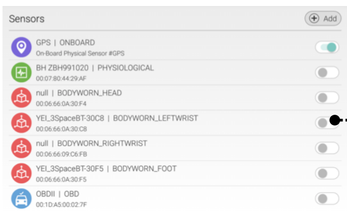

Figure 3: A sensor manager to add or remove required sensors.

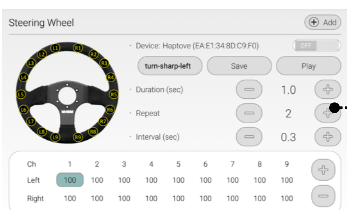

Figure 4: A haptic feedback pattern designer to control our custom-built haptic device, which called Haptove.

Figure 5: Navigation view used by a driver in this study. This view performs as a basic navigator by displaying maneuvers, speaking driving direction guides. It also demonstrates mash-up information that was designed and configured in our experimental authoring tool.

Sensing

The driver's motion can be determined by using body-worn accelerometers. Four wearable motion sensors to monitor the head, both arms and right leg can be supported in the IDAS Mobile app. A physiological sensor can be connected with the IDAS Mobile app to monitor how the driver reacts to driving situations. For example, heart-rate variability (HRV) can be used to infer the nervousness of the driver. A vehicle equipped with OBD can measure engine RPM, vehicle speed, etc. and then transmit the data to the IDAS Mobile app. To detect location, AGPS with GLONASS in a tablet has been adopted in the IDAS Mobile app. All sensors can communicate with the IDAS Mobile app through Bluetooth. Researchers can easily extend the sensing capability of the IDAS Mobile app by adding the name and the communication protocol parser of a sensing device.

Computing

With the evolution of computing power in mobile platforms, it is now possible to use machine learning

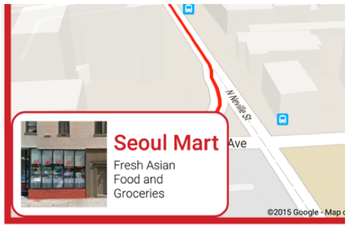

Figure 6: An example of visual feedback in the IDAS Mobile app.

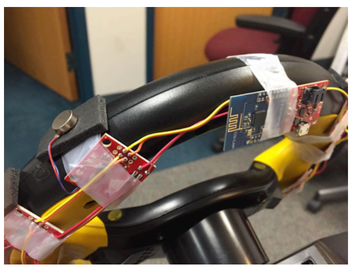

Figure 7: A gaming steering wheel equipped with Haptove

algorithms to infer high level context. As a preliminary trial, we have used the IDAS to compute road curvature and right hand acceleration deviation in a real-time operation. However, computing parameters, feature extraction, and classification algorithms could be added later.

Feedback

Researchers can select or combine modalities to gain visual, auditory, or haptic information. As shown in Figure 6, the navigation view delivers additional information as a pop-up view, along with an existing map and navigation guide. Auditory feedback is presented using the Google Text-To-Speech engine. In order to deliver vibration feedback, we designed and developed an attachable 20-channel haptic device called Haptove. This battery-powered device is controlled by a custom Bluetooth LE Characteristic and is placed on the steering wheel. As shown in Figure 4, the researcher can design haptic patterns for each driving maneuver. Haptove was evaluated before actual deployment by utilizing a gaming steering wheel in our lab, as shown in Figure 7.

Experiment Authoring Tool: IDAS Designer

Preparing driving experiments is started with route planning. Once a researcher enters starting and destination points, our authoring tool retrieves the best route using the Google Direction API. Then, the researcher can add mashup information using a map marker and the Google Place API (Figure 8). After the researcher completes the experimental route and mashup data, he can design information trigger conditions and their modality combinations using the IDAS Designer.

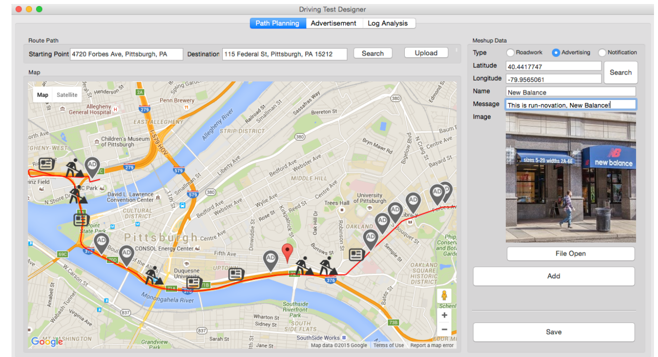

Figure 8: Screenshot of the IDAS Designer

IDAS Server

The IDAS Server was developed based on the Spring Framework and MongoDB to store and retrieve experiment configuration, sensing data and participant information.

Experiments

The primary purpose of our experiment was to evaluate how the proposed system can effectively be used to design and conduct driving monitoring experiments. We also wanted to demonstrate the feasibility of the system in real-world driving situations so that we can provide a reliable driving experimental tool.

We designed two different round-trip routes using the IDAS Designer. The first route included city streets, bridges and highways leading from the CMU campus to a public parking lot in downtown Pittsburgh. We utilized 10 advertisements, 5 roadwork signage warnings, and 5 breaking news alerts for the first route. A driver traveled 10 miles, two different times, under high and medium traffic conditions. We designed the

Sensor	Frequency
Motion	4~5 Hz
Physiological	20 Hz
OBD	1 Hz
GPS	2 Hz

Table 1: Sensing frequency per each sensor

Field	Condition
Engine RPM	< 2000 rpm
Right wrist acceleration RMS	> 0.45
Upper body angle	< 100 °
Road curvature	< 5 °
Range	< 100m

Table 2: Information triggering thresholds for the first and second route

second route similar to the first route except we changed the destination to a shopping mall that was 7 miles away from CMU. For the second route, the driver covered 14 miles, two times, under high and medium traffic conditions.

During these experiments, the driver wore battery-powered Bluetooth devices consisting of four YEI 3-Space motion sensors and one BioHarness physiological sensor. The four motion sensors were placed on left and right wrists and the head and right leg of the driver. The driver had the physiological sensor on his chest to measure heart rate, respiration, upper body posture and ECG. An on-board diagnostics (OBD) sensor was connected to the experimental vehicle through a SAE J1962 port and transmitted engine RPM and speed via Bluetooth. A-GPS and GLONASS in the Android tablet continuously monitored the location and speed of the vehicle. Table 1 summarizes the frequency of each sensor. All measured data was synchronized and stored into a log file.

In these real-world experiments, feedback received from the advertising, roadwork, and breaking news alerts for the designed routes was presented via the use of a combination of three modalities: visual, auditory and haptic. Visual and auditory feedback was delivered to the driver on the screen (Fig. 6) and using the speaker of the Android tablet. We used our Haptove to give vibration feedback to the driver as shown in Figure 9.

In these experiments, we specified an information-triggering threshold as shown in Table 2. We selected four representable sensing values from each sensor: i) engine RPM from OBD, ii) right hand motion from 3-Space YEI, iii) upper body posture from BioHarness, and iv) road curvature from GPS and experimental route.

Figure 9: Driving experiments using the IDAS

Discussion

In terms of cost, the IDAS has allowed us to cut experiment costs, by about $1000. For installation time, we were able to install our system in 5 minutes. We also created a test-driving route and added mashup information within 10 minutes using the IDAS Designer. However, design time varies by experiment complexity.

The experimental conditions presented focus on interoperability of the IDAS components and applicability for UX studies. First, we established that heterogeneous sensing data could be gathered and computed in a single application. We assumed that the sample triggering thresholds in Table 2 indicated interruptible moments during driving since the thresholds could be interpreted as low acceleration, free right hand and a static driving route. Our system was able to both collect the sensing data and compute on the data to identify the triggering conditions.

Second, we explored how sensing and computing components of the system can be utilized for UX studies such as understanding when to change the feedback modality. Once sensing data matches the thresholds, we delivered the mashup data through visual (V), auditory (A), and haptic (H) channels simultaneously. Otherwise, we just visually displayed the mashup data without any sound and vibration. As summarized in Table 3, the modality of the mashup data presentation was changed based on the computed sensing data.

NO	Route	Traffic	V+A+H	V Only	Total
1	CMU ↔ Parking Lot	High	4	35	39
2	CMU ↔ Parking Lot	Medium	13	24	37
3	CMU ↔ Mall	High	10	30	40
4	CMU ↔ Mall	Medium	24	16	40

Table 3: Experimental results of modality change by the pre-defined thresholds and the computed sensing data.

Conclusion and Future Work

In this project, we proposed an integrated driving aware system that allows us to facilitate driving user experience studies. We also investigated our sensing framework with four motion sensors, one physiological sensor, one OBD, and one embedded GPS sensor synchronously. We analyzed the aggregated data and changed feedback modality by comparing processed data and pre-defined conditions in real-driving situations. The IDAS will have great impact on designing and conducting real-world driving UX studies.

There are a number of interesting directions for future driving research. One direction involves how best to find personalized and optimal information triggering thresholds in terms of safety and usability. In our experiments, the thresholds were just configured based on an assumption. We will develop an intelligent and adaptive threshold model for each user by using machine learning, and evaluate the model through the IDAS.

Another direction of interest would be to explore modality presentation techniques for in-vehicle information systems. For example, we will be able to not only combine different modalities, but also transform the graphic interface or change the length of the audio feedback.

We suspect there will be a lot of experiments relating to how users interact with autonomous driving cars. The IDAS can also be utilized to model driver behavior and explore what interfaces of those cars might look like in a more automated driving environment.

Acknowledgement

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