How my car got to know me: reflection on in-vehicle user modelling

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Abstract
This paper provides a reflection of the up-to-date efforts in automotive UI research to model user behavior. In particular, we analyze the benefits of user modelling in developing adaptive vehicular user interfaces that evolve with user interactions and provide personalized driving experiences. We review the available sensors in the cockpit with a focus of real-state monitoring and the competitive knowledge that tracking gestures, driver attention, stress and emotional states provides to customer relationship management systems. Furthermore, we highlight the risks and challenges for a successful widespread application of prediction modelling in automotive.

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1 Introduction
User modelling is not a new field, the consideration of the user, human-in-control of machinery, has always been applied in science and engineering as a design principle. After all, every tool and technology has been invented to aid us in the completion of a certain task. It is however, somewhat ironic that the interest in user modelling has become more prevalent as our technology matures towards intelligent autonomous systems that require less control interactions. It seems that in a sense we need to endow our intelligent systems with a better understanding of the human psyche and behavior before drivers can trust them with complete autonomy.

In the current era of information technology user modelling is pervasive. Practically every system we make use of is mapping and modelling user interactions. Think search engines modelling our query patterns, online shops guiding personalized purchases, social networks creating graphs of our friend circles and even multimedia content providers recommending what we enjoy in our leisure time. The ever-expanding cloud services are clearly making an all-out effort towards user-centered experiences that rely on user modelling at their core.

In automotive, the race towards safety has pushed automakers and researchers to convert behavioral driving patterns into automatized control algorithms. We not only mimic the human driver behavior controlling the steering-wheel, but we strive to optimize the undeniable limitations of human cognition. Aided by the constant push of Moore's law, the embedded processors governing in-vehicle advanced driver assistance systems (ADAS) and in-vehicle infotainment (IVI) systems have reached the ability to apply real-time user models in vehicle cockpits, opening room for new compelling experiences.

Fully scaled autonomous transportation systems will bring benefits such as accurate models of individual vehicle behaviors and large scale municipal traffic patterns. The data will help identify strategies to reduce resources, such as total vehicles on the road at a time or overall fuel consumption. Although not everyone might share this utopic vision, there are some other advantages to the ever-growing myriad of sensors that automakers are placing in vehicles. The lowest hanging fruit may not reside in the exterior-facing sensors and control algorithms, but the interior-facing.

This paper recounts the up-to-date efforts in automotive user interface research to model user behavior. We will have a look at the benefits of user modelling on developing adaptive user interfaces (UIs) that create positively evolving user interactions and provide personalization of the driving experience. To do so we will analyze the focus of user state monitoring from gestures, to attention, stress level and emotional state. We end the paper highlighting the risks we are confronted with in the road to predict user behavior and the most promising areas of application.

2 How to model in-vehicle user behavior

User modelling evolves from designers architecting systems to be personalized by the user. The creation of a user model comprises the aim to identify user's goals, knowledge, intents, traits and context [1]. Much of the work dealing with inferring goals and interpreting user actions looks at short-term, real-time interactions. Thus, such models are very different from each other (application dependent) even when the underlying use of sophisticated machine learning is similar.

Understanding that in many cases models cannot be compared with others, we can still analyze the evolution of user modelling by looking at the input sensors they used to create context awareness.

2.1 Vehicle Controllers

Most of the models for driver performance look at the steering wheel, pedal and gear shifting behaviors. Current vehicle control models already apply highly sophisticated algorithm such as fuzzy logic in models governing ADAS. Applications such as automatic shifting, automatic breaking systems (ABS), Automatic Cruise Control (ACC) or parking assistance systems are widely adopted in the industry.

2.2 Microphones

Speech has been one of the main areas of focus in automotive UI research and development. Microphone arrays cover nowadays the complete cockpit area.

Great advances have been productized in use cases that identify speakers, apply noise cancellation and can parse natural language semantics in real time. Speech has also been a applied as robust source for real-time monitoring of driver stress and emotional states.

2.3 Cameras

Computer vision plays a huge role in the development of ADAS systems. Cameras in automotive come in the shape of infra-red, depth, LIDAR or traditional RGB cameras. Current vehicle models apply vision sensors mostly towards the exterior, although researchers have also widely explored in-vehicle applications of cameras for pose detection, gaze monitoring and user authentication use cases.

2.4 Pressure Sensors

These are probably the most widespread sensors in today's vehicle coming in the shape of buttons, levers, rotary knobs and touch-sensitive surfaces and displays. Pressure sensors have been also applied successfully to vehicle seats to model ergonomic poses and are even present in door handles to allow for comfort access to the cabin. The latter functions remain however available mainly on high-end models.

2.5 Biometric Sensors

Biometric sensors have been traditionally applied in simulator environments to provide empirical metrics on driver distraction. The nature of the sensors is variable: Heart-rate monitoring via electrocardiograms (EEG), skin conductance response (SCR) and even non obtrusive brain computer interface via fMRI or (led-based EEG). Modelling of user behavior with such sensors remains challenging due to the in-between user differences, but wearable technology such as wrist-bands and watches allow us to gather sufficient personal data to create accurate personalized models of physical responses to the environment.

Less applied are chemical sensors able to detect dangerous chemical concentrations; although highly populated urban areas are seeing increase in user demand for modelling air quality and health risk factors. Finally, telemetry data such as global positioning system (GPS) and inertia sensors (gyroscope and accelerometer) data provide accurate measures and insights on contextual information.

Automotive adaptive systems apply learning processes to these sensory data to create behavioral intent models borrowing techniques from artificial intelligence, data mining, signal processing and computer vision.

3 From application specific models to generalist taxonomies

As the interfaces to the described sensors become standardized and accessible via CAN bus to on-board applications, developers are able to model comprehensive user state taxonomies. Islinger et al provided a first approach to a generic architecture for driver monitoring and state analysis in which applications could use several inputs signals to classify a user state (e.g. drowsiness) [3]. Their approach differs from previous control models like Optimal Control Model or ACME driver model in that they abstract the user monitoring architecture from the goal of the model. This is more in line with Engstroem and Hollnagel's conceptual framework for modelling driver support functions [1].

There is certainly the need for a generic user model framework for automotive applications to access real-time sensor data, historic data and existing user state models. One could envision a central model repository on which applications could borrow existing user models or create application specific behavioral models based on context or needs. The goal being to have several applications that can compute model states and perform actions and adaptations in parallel.

4 The road to predicting behavior

A challenging and promising road lays ahead for in-vehicle applications to predict user behavior accurately. Some of the bottlenecks remain on the data acquisition, given the lack of standardized interfaces as pointed by Hess [4]. Model-to-model and brand-to-brand differences on sensor models, restrain nowadays application development to the specific vehicle configuration.

Data storage on vehicles remains a challenging topic due to the amount of real-time data generated as well as to privacy concerns. User modelling applications also have pressing requirements on the compute capability of onboard vehicle processors to achieve real-time data analysis and sensor fusion. Today's vehicle architecture is far from being an optimal compute distributed framework. User modelling could benefit from a platform that enables developers to program logic across FPGA, CPU and distributed scalable resources on data centers. Such a framework would allow vehicles to adapt and update knowledge models on demand.

Finally security concerns in data handling and communications must be addressed appropriately in future transportation solutions. Users demand strict privacy protection control, especially on closely monitored environments such as a vehicle cockpits. Security and information management of vehicle data will continue to be a main focus for industry and academia in the future.

All in all, there are promising tools that allow researchers the exploration and acceleration of user modelling and sensory data fusion, such as Intel® Real Sense™ technology [5]. But a collaborative effort is needed between industry, Government and academia to bring the automotive platform to the next level of user awareness and user acceptance.

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