Socio-cyberphysical System for Proactive Driver Support
Approach and Case Study

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Abstract: Recent developments in the areas of decision support, data and decision mining, on-board infotainment systems have produced valuable results that can be used to support people in different aspects of their lives. Infomobile driver support is one of the possible applications of these, what can significant increase the quality of the user experience. The paper presents a developed approach and enabling technologies for implementation of an intelligent driver support system that takes advantages provided by such modern developing technologies as context-based collaborative recommendation systems, proactive information support, smart space, and V2V communication. The developed concept is illustrated via a parking assistance scenario.

1 INTRODUCTION

Recent developments in the areas of decision support, data and decision mining, recommendation systems have produced valuable results that can be used to support people in different aspects of their lives.

Cyberphysical systems tightly integrate heterogeneous resources of the physical world and IT world. Socio-cyberphysical systems go significantly beyond the ideas of the current progress in cyber-physical systems, socio-technical systems and cyber-social systems to support computing for human experience (Sheth, et al., 2013). They tightly integrate physical, cyber, and social worlds based on interactions between these worlds in real time. Such systems rely on communication, computation and control infrastructures commonly consisting of several levels for the three worlds with various resources as sensors, actuators, computational resources, services, humans, etc. (Teslya, et al., 2014).One of promising tasks is integration of different mobile applications with on-board infotainment systems.

There are exist various techniques aimed at driver support based on the analysis of information from various devices and sensors. Those, which are based on the information accumulated within one car, are commercially available (e.g., parking assistance systems). Cyberphysical networks provide for extended possibilities in this area. Integration of several nearby cars with their sensors into one cyberphysical network makes it possible to increase the quality of situation detection (e.g., sharing information about free parking slots) and to provide for certain situation development prediction (sharing information about parking slots that are currently being occupied or will be in the nearest future). The concept of socio-cyberphysical systems adds one more dimension – humans (drivers in this particular example). Analyzing drivers' needs, preferences and intentions could significantly improve the situation detection and situation development mechanisms.

Such systems can be classified as infomobile driver support assuming distribution of dynamic and selected multi-modal information to the users, both pre-trip and, more importantly, on-trip (Ambrosino et. al., 2010). It is a new way of service organization appeared together with the development of personal mobile and wearable devices capable to present user multimodal information at any time. Recent advances in car on-board infotainment systems make it possible to organize infomobile driver support.

Configuration of socio-cyberphysical systems belonging to the class of variable systems with

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dynamic structures is a very complex task. Their resources are too numerous, mobile with a changeable composition. However, taking into account not only combination of information from cars, including speed, location, free parking spots, directions (from the navigation system, etc.) but also application of behavior analysis techniques for predicting future (both short term [few seconds] and long term [minutes-hours]) actions of drivers (some drivers might prefer to park "next to the door" even if it is expensive, others prefer to have a walk and save on parking fee; some might be seeking for a parking spot, others are about to leave, etc.) could significantly improve the efficiency of parking situation prediction and consequently improve it via regulation of its controllable components.

In dynamic environments correct decisions can only be made in the right context related to the current situation (Smirnov, et al., 2010; Smirnov, et al., 2005). Context is any information that can be used to characterize the situation of an entity where an entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves (Dey, et al., 2001). Thus, context-driven decision support is required in situations happening in dynamic, rapidly changing, and often unpredictable distributed environments such as roads.

The paper proposes an approach that has a service-oriented architecture. The services are integrated through service fusion, originating from the concept of knowledge fusion, which implies a synergistic use of knowledge from different sources in order to obtain new information (Smirnov, et al., 2003; Smirnov, et al., 2015). Thus, service fusion in this work can be defined as synergistic use of different services to have new driver support possibilities not achievable via usage of the services separately. Context-based service fusion can provide a new, previously unavailable level of personalised on-board information support via finding compromise decisions taking into account proposals of various services and driver preferences.

2 CASE STUDY SCENARIO

The following scenario can be considered as the basis for the case study. *A driver has a meeting scheduled for 3pm. The navigation system leads the driver to the meeting place. The driver's profile has information that the driver prefers free parking and does not mind to have a walk for 200-300 meters.*

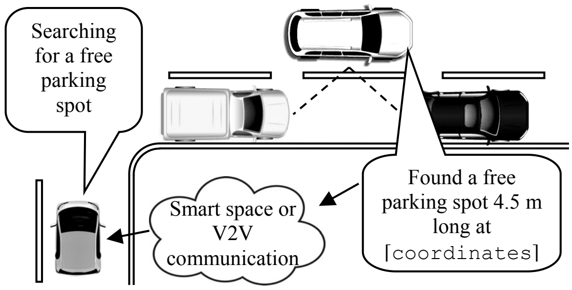

Figure 1: Parking spot information sharing: the car doesn't fit into the free parking spot but it shares this information so that other cars can use the spot.

Analysing the information about available parking places nearby, as well about which parking spots are currently free / will be free in few minutes, the system proposes a parking spot to the driver.

The required information can be acquired from a number of sources. Usually, there can be several independent parking structures nearby with their on-line services that provide availability (each parking spot might have a sensor indicating if it is busy or free), price, and wait time. The municipal street parking can also provide a service with corresponding parameters such as parking time limit (e.g., 30 minutes or two hours, and the parking enforced from 7:00 am till 19:00). There can also be free street parking in vicinity. The availability of this free parking may be provided by 3rd party service that can provide a probability of finding a spot in the given block at the given time. Alternatively, the availability can be shared by other cars searching for parking spots, leaving, or just passing by (Figure 1). Free parking spots can be estimated via such systems as Active Park Assist, which are already available in the market. The parking facilities might also have customer ratings stored in a social network.

To lead the driver to the chosen parking spot the system should be integrated with a navigation service, which would calculate the route (e.g., going through several possible parking spots) takin into account the driver's schedule and the context of the current situation (traffic, weather conditions, etc.).

Such distributed system is reasonable to be implemented based on the service-oriented architecture. The developed approach to configuration of a service-based socio-cyberphysical network is presented in the next section. Section 4 addresses the issue of proactive driver support, which is essential because the driver has very limited possibilities to input requests and checking all possible solutions. Such systems require behavior analysis techniques described in section 5.

A developed research prototype is presented in section 6. Major results are summarized in the conclusion.

3 PROPOSED APPROACH

The proposed approach to configuration of socio-cyberphysical network assuming negotiation of socio-inspired services. The approach is based on the following principles: self-management and responsibility of the services, and decentralization with network organization (without any social hierarchy of command and control) and co-operation between services. This is motivated by the fact that in order to operate efficiently, the system has to model driver behavior (taking into account preferences, earlier made decisions; see section 5), what is achieved due to the usage of socio-inspired services.

Self-organization of services is considered as a threefold process of (i) cognition (where subjective context-dependent knowledge is produced), (ii) communication (where system-specific objectifycation or subjectification of knowledge takes place), and (iii) synergetical co-operation (where objectified, emergent knowledge is produced). The Individually acquired context-dependent (subjective) knowledge is put to use efficiently by entering a social co-ordination and co-operation process. The objective knowledge is stored in structures and enables time-space distanciation of social relationships.

In order to achieve the realism and dynamics of the self-organizing system, its components (services) have to be creative, knowledgeable, active, and social. The services that are parts of a system permanently change their joint environment what results in a synergetic collaboration and leads to achieving a certain level of collective intelligence. This is also supported by the fact that individual service behavior is partially determined by the social environment the services are contributing to (called “norms”). For this purpose a protocol has been developed based on the BarterCast approach (Seuken, et al., 2014) that originates from the idea of building a network by a service representing all interactions it knows about.

The overall scheme of the approach is shown in Figure 2. The lower part of the figure represents the socio-cyberphysical network and the corresponding service network. The upper part represents the socio-inspired service modelling behavior of a member of the socio-cyberphysical network. The detailed

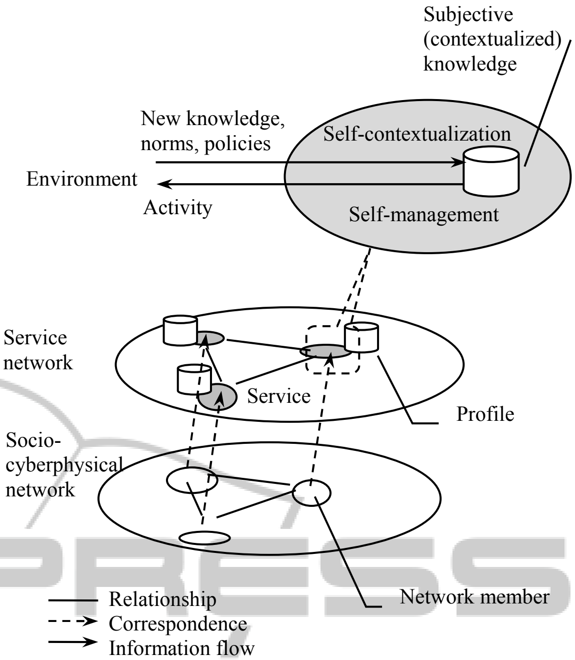

Figure 2: Socio-cyberphysical network configuration approach overview.

description of the service is given in (Smirnov, et al., 2013). The interoperability at the technological level is provided via usage of common standards and protocols, the interoperability at the level of semantics is provided via usage of common semantics and terminology described via ontologies (please, see Smirnov, et al., 2007b for a detailed description of the interoperability support).

4 PROACTIVE RECOMMENDATIONS

Recommendation systems are widely used in the Internet for suggesting products, activities (including tourism), etc. for a single user considering his/her interests and tastes (e.g., Garcia, et al., 2009). The collaborative / group recommendation systems try to find users who share similar interests with the given user and recommend items they choose to that user (Kumar and Thambidurai, 2010). Context-driven collaborative algorithms of recommendation generation increase the quality and speed of decision making due to taking into account not only previously made decisions but also on the contexts of situations in which the decisions were made.

Modern recommendation systems mostly work on the scheme “request-response”; the active party in the interaction is the user, who makes a request, which can contain some additional constraints for the alternative solutions. As a response, the recommendation system offers a list of recommendations (recommended solutions). In on-board recommendation systems, users cannot browse through many search results and suffer from other restrictions in the user experience, because of user interface limitations such as small display sizes or missing keyboards. In such environments, having the user not to submit any request or query to get a recommendation could possibly improve the user experience (Bader, 2013; Woerdnl, et al., 2011).

At the moment, there are hardly any systems that could offer recommendations in the proactive way, without user request, on the basis of the current situation and user profile analysis (Ricci, 2011). One of the reasons of this situation is the high risk of obtrusive offering non-relevant information to the user. However, modern mobile devices equipped with various sensors, make it possible to produce proactive recommendations, which would be useful and convenient due to creation of more precise user behavior models.

Appearance of mobile devices caused a more intensive development of proactive systems. The next step in the development of proactive systems is appearance of systems based on prediction of the user behavior, his/her future locations or actions, as well as situation recognition. Today, integration of proactive systems with recommendation systems can be considered as a perspective research field.

5 BEHAVIOR ANALYSIS

The developed approach assumes description of functionality, preferences and strategies of the socio-cyberphysical network members via updatable and extendable profiles. Usage of the profiles makes it possible to “individualize” the proactive recommenddations. For this reason methods of human preferences revealing have been developed.

The preferences are revealed via the analysis of the situations the network member faces most often, parameters of objects and actions most often occurring or avoiding in the decisions (actions) made by the network member, optimization criteria the network member most often follows or not. One of the main features of the developed profile model is presence of the information related to antecedents and consequences of the made decisions and under-taken actions what makes it possible to perform the functional analysis of the human behavior.

The functional behavior analysis is one of the behavior analysis techniques considering frequency of key behavior events related to certain human activity (Kraus, 1995). It is also known as ABC analysis (antecedent, behavior, consequence) and is based on identification of both antecedents and consequences of the behavior. As a result, it is possible to build a conditional behavior model, which would let one know (to predict) how a human (e.g., a driver or a pedestrian) would act in a given situation. For example, the research of application of this technique to the driver behavior prediction has resulted in some positive results (Taniguchi, et al., 2012).

The result of such an analysis produces typical decisions (actions) made by the considered person in certain situations (behavior patterns). Example of behavior pattern is presented below:

- **Context:** the traffic is heavy; the traffic in the lane in the left moves a bit faster; the driver is hurrying.
- **Antecedent:** there is a traffic congestion ahead in the lane; the vehicle ahead slows down.
- **Possible behavior:** stay in the lane and slow down; switch to the left lane.
- **Preferred behavior:** switch to the left lane.
- **Consequence:** the vehicle moves faster than vehicles in the congested lane, but slower than it moved before; vehicles in the left lane behind slow down.

The behavior pattern revealing techniques used in the proposed approach include:

1. Revealing human behavior patterns for problems with the same structure but different parameters. In this case, the structural knowledge constituent will be the same, and the parametric knowledge constituent will be different.
2. Revealing human behavior patterns for different problems solved by the same person. This technique assumes analysis of structures of different problems trying to find similarities associated with the same decisions / actions.
3. Revealing human behavior patterns based on the optimization criteria (problem parameters with highest or lowest values) the person tends to follow or avoid (e.g., the driver prefers moves faster or with less maneuvers). Aggregated (e.g., weighted average) criteria can also be analyzed.
4. The above techniques applied not to one person but to different persons with similar profiles. This technique utilizes collaborative filtering mechanisms (Schafer, et al., 2007).

To implement the first three techniques the following methods have been developed:

1. Decision / action clustering method. The decisions made by the person and actions undertaken are grouped into clusters. Based on the clusters built the common properties (parameters) of the problems and decisions / actions grouped into one cluster are identified. The results of this method can be refined if there is enough historical data accumulated and clustering can be done taking into account the context of the situation when corresponding decisions have been made (including and preferences of the person at the moment of decision making as well as information about behavior antecedents and consequences).
2. The alternative analysis method. Unlike the previous method searching for similar person's decisions, this method is aimed at the analysis of differences between decisions made by the person and actions undertaken. Based on the analysis of the identified differences taking into account the situation context (as well as preferences of the person and information about behavior antecedents and consequences) namely definition of the main generic differences of the made decisions, the behavior patterns are revealed.

To implement the fourth technique of human behavior pattern revealing, a method based on the collaborative filtering mechanisms used for building collaborative recommendation systems. This technique would enable to predict human behavior even in situations, in which this person has never got. For this reason, the decisions made by persons with similar properties are used.

Application of the above techniques would enable to generate proactive recommendations based on prediction of behavior of real people (e.g., via usage of opportunistic planning (Hayes-Roth, 1980) mechanisms).

6 PROTOTYPE DESCRIPTION

The developed research prototype has a service-oriented architecture based on the usage of the smart space concept implemented in the Smart-M3 platform. The smart spaces technology (Balandin and Waris, 2009; Korzun, et al., 2013) aims at the seamless integration of different devices by developing ubiquitous computing environments, where different services can share information with each other, perform computations, and interact with each other for joint task solving. A detailed description of the developed smart space-based architecture can be found in (Smirnov, et al., 2014b).

The interaction between services is presented in Figure 3. It is based on usage of AppLink for interaction with the vehicle. In addition to the information already stored in the services (associated databases, user settings, revealed preferences, etc.), they acquire the following information from other services, namely:

- Local road infrastructure provides information about parking places, their restrictions and prices.
- Nearby cars share information, which parking spots are currently free and occupied, will be free if the car is about to leave, are about to be occupied if the corresponding driver is going to park at the selected spot.

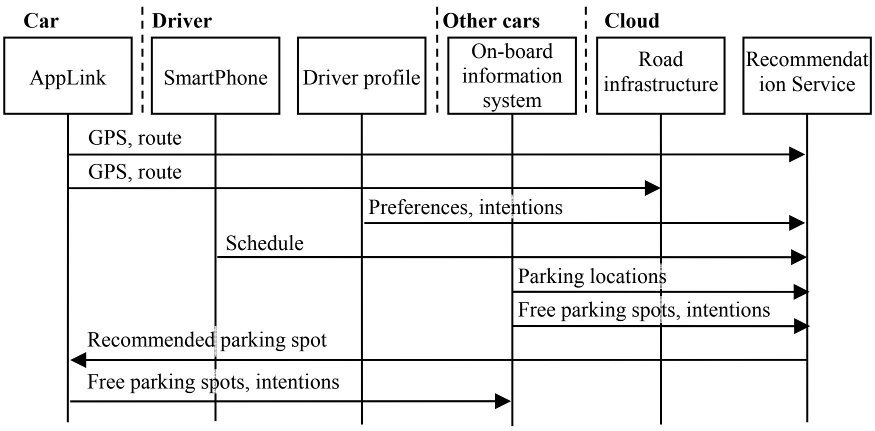

Figure 3: Service interaction example.

Figure 4: Example of In-vehicle information support implemented in AppLink emulator.

- Weather acquisition service provides information about the current and forecasted weather conditions.
- Recommendation service obtains driver's schedule from his/her smartphone to estimate current time restrictions, predefined driver preferences and information obtained from the above mentioned sources.

The generated solutions are transferred to the AppLink screen so that the driver could choose the most appropriate one, and to the in-car navigation system (Figure 4). If parking can be paid online, the payment can be done automatically, when the driver is parking.

7 CONCLUSIONS

The paper presents a developed approach and enabling technologies for implementation of an intelligent driver support system that takes advantages provided by such modern developing technologies as context-based collaborative recommendation systems, proactive information support, smart space, and V2V communication. The developed concept is illustrated via a parking assistance scenario.

The work is at an early stage of development. The paper proposes generic solutions for the key problems that may arise during the implementation of the proposed system. Particular methods and models supporting these solutions are subjects of the future research.

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