# Socio-Cyberphysical System for Parking Support

Alexander Smirnov, Nikolay Shilov, and Oleg Gusikhin

*Abstract*—**The paper proposes an approach and its supporting technologies for building a socio-cyberphysical system aimed at intelligent driver support. The approach is based on usage of such technologies as smart space for communication possibilities, behavior analysis for personalized support and human decision foreseeing, and fuzzy constraint satisfaction for treating uncertainties arising in stochastic systems such as traffic. The application of the approach is illustrated via a parking spot searching case study.**

*Index Terms*—**Socio-cyberphysical system, parking support, behavior analysis, uncertainty.**

## I. INTRODUCTION

Cyberphysical systems are one of new developments that can produce valuable results that can be used to support people in different aspects of their lives. Such systems tightly integrate heterogeneous resources of the physical world and IT (cyber) world [1], [2]. This term is tightly related to such terms as Web 4.0 [3], [4] and Internet of Things [5]-[7]. Currently, there is a significant amount of research efforts in the area of cyberphysical systems and their applications, e.g., in transportation [8], production [9], and many other.

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 [10]. They integrate not only the physical and cyber worlds, but also the social world. 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. [11].

One of promising tasks is integration of different mobile applications with on-board infotainment systems. 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 [12]. 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. In accordance with the forecast of [13], the market of such technologies as mobile Internet, automation of knowledge work, and Internet of Things by 2025 can increase 20 trillion USA dollars.

In this paper, we consider an example of socio-cyberphysical system aimed at driver support in searching for a parking spot. Today there are exist various techniques aimed at driver support based on the analysis of information from various devices and sensors. Some of them (e.g., 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 unoccupied 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 intensions could significantly improve the situation detection and situation development mechanisms.

Configuration of cyberphysical systems is a complex task, which is currently researched intensively [14]-[16]. The situation becomes significantly more complicated when dealing with socio-cyberphysical systems, the considered system comprised of connected vehicles and drivers falls to. Such systems belong to the class of variable systems with dynamic structures. Their resources are too numerous, mobile with a changeable composition. Planned resource interactions in such systems are just impossible.

However, taking into account not only combination of information from cars, including speed, location, unoccupied 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 [17], [18]. 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

person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves [19]. More information about context and context management can be found in [19]. Thus, context-driven decision support is required in situations happening in dynamic, rapidly changing, and often unpredictable distributed environments such as roads. Such situations can be characterized by highly decentralized, up-to-date data sets coming from various information sources. The goals of context-driven support to operational decision making are to timely provide the decision maker (drivers) with up-to-date information, to assess the relevance of information & knowledge to a decision, and to gain insight in seeking and evaluating possible decision alternatives.

The proposed approach has a service-oriented architecture. Such architecture facilitates the interactions of service components and the integration of new ones [20]-[22]. The services are integrated through service fusion. The idea of service fusion originates from the concept of knowledge fusion, which implies a synergistic use of knowledge from different sources in order to obtain new information [17], [23]. 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.

The rest of the paper is structured as follows. The parking support case study is described in the next Section. Behavior analysis techniques required for such a system are explained in Section III. Section IV addresses the mechanism of treating uncertainties. The developed research prototype is presented in Section V. Major results are summarized in the conclusion.

## II. CASE STUDY: PARKING SUPPORT

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 toll-free parking and does not mind to have a walk for 200-300 meters. Analyzing the information about available parking places nearby, as well about which parking spots are currently unoccupied or will be unoccupied 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 occupied or not), 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 toll-free street parking in vicinity. The availability of this toll-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 (car A in Fig. 1), leaving, or just passing by (car B in Fig. 1). Unoccupied 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.

The Internet of Things supporting ubiquitous connectivity could be used for information sharing. The most common view of The Internet of Things refers to the connection of physical (smart) objects, while the core of technology is in information interconnection and convergence [24]. Smart spaces can be thought as advanced computing environments implementing The Internet of Things concept that acquire and apply knowledge to adapt services in order to enhance user experience. Each physical object is made a "smart" digital device operating in its environment realizing continued processing of many data flows, originated from various sources and consumed by multiple applications.

To lead the driver to the chosen parking spot the system is integrated with a navigation service, which calculates 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.).

## III. 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 recommendations. For this reason methods of human preferences revealing have been developed.
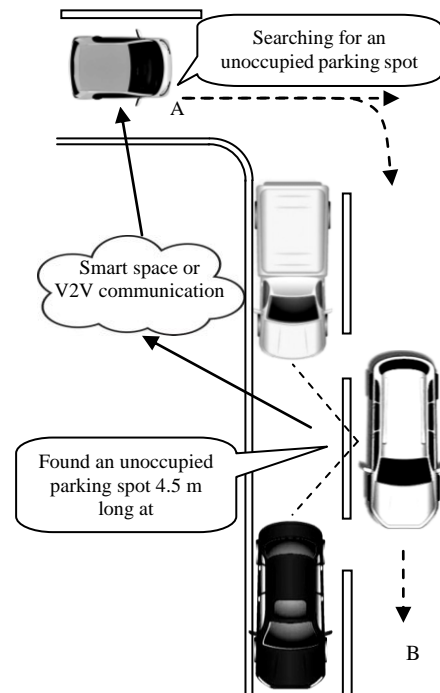


Fig. 1. Parking spot information sharing: the car doesn't fit into the unoccupied parking spot but it shares this information so that other cars can use the spot.

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 undertaken 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 [25]. 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 [26].

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:

1) **Context**: the traffic is heavy; the traffic in the lane in the left moves a bit faster; the driver is hurrying.
2) **Antecedent**: there is a traffic congestion ahead in the lane; the vehicle ahead slows down.
3) **Possible behavior**: stay in the lane and slow down; switch to the left lane.
4) **Preferred behavior**: switch to the left lane.
5) **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 [27].

Two 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.

3) 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 [28] mechanisms).

## IV. TREATING UNCERTAINTIES

Since proposed system is supposed to deal with the stochastic environment, information sources having different levels of reliability, as well as behavior analysis, the results of which are also characterized by a certain level of probability, the factor of uncertainty has to be taken care of. This uncertainty is a reason to implement the fuzzy constraint satisfaction model for such a system.

In accordance with the formalism of object-oriented constraint networks the knowledge is described as $CNet = (O, Q, D, C, I)$ where $O$, $Q$, $D$, $C$ are sets of ontology elements (classes, attributes, domains, and relationships respectively) and $I$ is an information content (class instances) of the constraint network. Information content is a set of instances with fixed attribute values (known or not).

*Fuzzy constraint network* is an extension to the above constraint network and can be described as $(O, Q, D, C_\mu, W, T, I_p)$, where

$O$, $Q$, and $D$ are the same as above;

$C_\mu$ is a set of constraints, where each constraint contains a function $\mu$ of membership to $[0,1]$ associated to weight $\omega_c$ representing its weight (importance) or priority; $W$ is a weight scheme, i.e. a function combining satisfaction degree of constraint $\mu(c)$ to $\omega$, for estimation of weighted

satisfaction degree of $\mu^{\omega}(c)$; $T$ is an aggregation function, which performs simple partial regulating on defined values, defining $C_{\mu}$; $I_p$ is an information content of the constraint network, which has a nondeterministic or probabilistic nature.

Uncertainties are introduced in the set of constraints in the following way:

1) A fuzzy relation between classes and attributes can be defined as:

$$R : O \times Q \rightarrow [0,1];$$

$$R\{o_j, q_k\} = \mu(c), \, o_j \in O, \, q_k \in Q, \, c \in C^I.$$

In other words, class $o_j$ and attribute $q_k$ can be connected at the moment $t$ when $\mu(c) \geq \alpha_t^I$ where $\alpha_t^I$ is the system truth threshold defined by expert.

2) A fuzzy relation in the compatibility structural constraints, hierarchical structural constraints and "one-level" structural constraints can be defined as:

$$R : O \times O \rightarrow [0,1];$$

$$R\{o_j, o_k\} = \mu(c), \, o_j \in O, \, o_k \in O, \, c \in C^{III} \cup C^{IV} \cup C^V.$$

In other words, classes $o_j$ and $o_k$ should be connected at the moment t when $\mu(c) \geq \alpha_t^i$ where $\alpha_t^i$ is the system truth threshold defined by expert and $i \in \{3,4,5\}$.

3) A fuzzy relation of the accessory of domains to attributes can be defined as:

$$R : O \times Q \times D \rightarrow [0,1];$$

$$R\{o_j, q_k, d_n\} = \mu(c), \, o_j \in O, \, q_k \in Q, \, d_n \in D, \, c \in C^{II}.$$

In other words, attribute $q_k$ belonging to class $o_j$ can be equal to $d_n$ (or have a value from $d_n$) at the moment t when $\mu(c) \geq \alpha_t^{II}$ where $\alpha_t^{II}$ is the system truth threshold defined by expert. This relation can be described by, for example, trapezoidal membership function.

4) Uncertainties can be penetrated into functional constraints using linguistic variables. In [29] it is presented relation between fuzzy and linguistics variables, i.e. "… fuzzy rules and fuzzy graphs bear the same relation to numerically-valued dependencies that linguistics variables bear to numerically-valued variables". Using verbal scales and linguistic variables an expert can assign a weight to each functional constraint.

Linguistic variables and verbal scales [30] could be useful to define constraints contained in user requests. Naturally a user formulates the goal in a verbal style with preferring quantity properties (small, medium, and large cars) rather than quantity attributes (length up to 4,5 meters, 4 – 5 meters, and more than 4,7 meters respectively). Using the appropriate fuzzy relation (Table I) it is possible to formalize the goal numerically.

TABLE I: AN EXAMPLE OF VERBAL AND NUMERIC SCALE TO FORMALIZE THE GOAL

| Verbal goal value | Numeric goal value |
|---|---|
| Small | 0 - 4,5 |
| Medium | 4 - 5 |
| Large | $4,7 - \infty$ |

Uncertainties could be useful to extend a list of possible answers to the user and estimate answer relevance. Since any crisp variable is a special case of fuzzy variable it can be generalized that all attribute values of a fuzzy object-oriented constraint network are described by fuzzy variables.

E.g., if we consider a medium parking place, it is possible to define a restriction to its length as from 4 meters to 5 meters (an object of class "Parking spot" must have a value of the attribute "length" between 4 and 5 meters). Using a fuzzy relation of the accessory of domains to attributes it is possible to define that an object of class "Parking spot" having a value of the attribute "length" 3.8 is also fitting to the user. But quality of this answer is less then 1.

Another example can be an estimation of the parking spot occupancy. E.g., if the occupancy of a parking spot is between 75% and 90% we consider the parking place as "likely unoccupied", if it is between 90% and 100%, we consider it as "unoccupied".

## V. 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 [31]-[35] 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 [36].
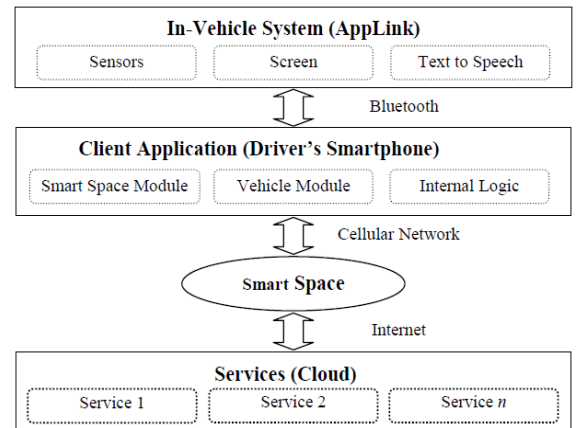


Fig. 2. Technological framework of intelligent driver support.

The technological framework is presented in Fig. 2. The user's smartphone has a special client to interact with the smart space. The client consists of smart space module,

vehicle module, and internal logic. Internal logic determines the client functionality (including driver's preferences, contacts, calendar, etc.), whereas smart space and vehicle modules responsible for communication with smart space services and in-vehicle system correspondingly. For privacy reasons, the preferences and other personal data is stored on the driver's device and not transferred to the cloud. Only information required at the current context is shared with the cloud services. Vehicle module communicates with the in-vehicle system for getting context information (such as location, speed) from vehicle sensors and convey location-based service results in a convenient for the driver form (using vehicle screen or text to speech function of the in-vehicle system). The smart space module shares this context information with the smart space for other services, which process it and share results back.
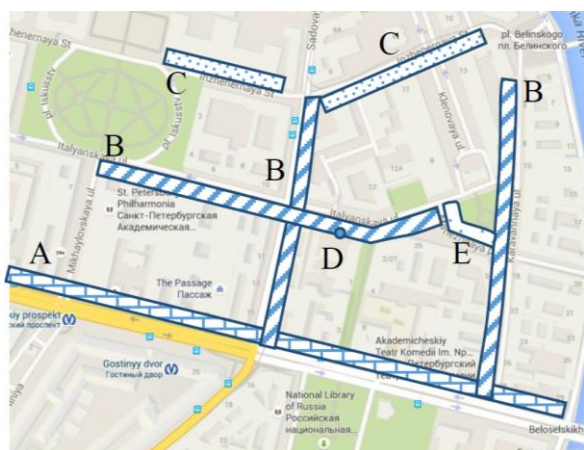

Fig. 3. Area parking data.


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

In-vehicle system provides information about vehicle state (sensors), allows to convey location-based system results, and provides possibilities to convert text information to speech for providing it to the driver in a convenient form.

The client application is located in the user mobile device while other services (cloud services) use powerful computer systems. Communication between in-vehicle system and client application is implemented via Bluetooth network that allows exchanging information with the speed up to 2 Mb/sec. Communication between client application and smart space services is implemented via cellular network. The quality and speed of this kind of information transfer depends on the vehicle location.

The interaction between services 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:

1) Local road infrastructure provides information about parking places, their restrictions and prices.
2) Nearby cars share information, which parking spots are currently occupied and not, will be unoccupied if the car is about to leave, are about to be occupied if the corresponding driver is going to park at the selected spot.
3) Weather acquisition service provides information about the current and forecasted weather conditions.
4) 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.

In the considered area the following parking possibilities are known (Fig. 3): A – parking is not allowed, B – toll-free street-side parking is allowed but is unlikely unovvupied; C – toll-free street-side parking is allowed and likely unoccupied; D – unoccupied parking spot identified by another car several minutes ago; E – paid outside parking with an IT system identifying occupied and unoccupied parking spots.

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 (Fig. 4). Due to the restrictions of the AppLink, the following abbreviations are used in the screen: L. – likely, P. – parking. If parking can be paid online, the payment can be done automatically, when the driver is parking.

## VI. Conclusions

The paper presents a developed approach and enabling technologies for implementation of a socio-cyberphysical system aimed at intelligent driver support. It takes an advantage of such technologies as smart space that together with V2V communication enables interoperability between different devices and services, behavior analysis that makes it possible to predict human behavior for a higher level of personalisation and foreseeing of human decisions and actions, as well as fuzzy constraint satisfaction for dealing with uncertainties caused by the stochastic nature of such systems as traffic. 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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