# Situation Awareness in Cognitive Transportation Systems

Joni Jämsä, Sakari Pieskä, and Mika Luimula

*Abstract*— **Inter-cognitive communication plays a key role in the development of engineering applications where natural and artificial cognitive systems should work together efficiently. Situation-awareness is essential in that cooperation. The focus of this study is to report our experiences and applications of situation-aware robots and transporters. Industrial robots are an important part of production in several fields of industry. Mobile robots and wheeled transporters, such as forklift trucks, will be key elements in the future in material handling and transporting tasks in production and in warehouses. In addition, robots will also play key roles in wellness services in response to the aging population. Situation-awareness, and especially location-awareness, is essential in the development of efficient human–robot interaction. In the future, cognitive communication processes between operators and intelligent transporters may benefit from many features developed for intelligent traffic systems. We also present our experiences from the development of a situation-aware traffic system.**

## I. Introduction

Situation-awareness is an essential feature for cognitive systems. Barany et al. [1] defines inter-cognitive communication as an information transfer between two cognitive beings with different cognitive capabilities. In this paper, this type of communication will refer to communication between human users and transportation systems. At present, experienced operators and advanced industrial machines, such as robots and transporters, can utilize knowledge about different situations. The major challenge to the construction of successful engineering applications is the interaction of these natural and artificial cognitive systems and capabilities. Situation-aware information usually requires data collection from several sources together with data fusion and decision-making algorithms. The situation-aware control system of a robot or transporter should improve the operator's situation awareness to provide a better perception of the task status.

Wheeled transporters, such as forklift trucks and wheel loaders, are key elements in material handling and transport in warehouses and factories. These material handling and transport operations are often integrated into the information systems of the company. In addition to wheeled transporters, mobile robots will be used more widely in industrial settings in the future. The big challenge for cooperation between human user and automated system is how an effective cognitive communication process based on situation-awareness can be developed for inter-cognitive communication.

Location-awareness is often the most important part of situation-awareness in industrial applications. One popular technique is called SLAM (Simultaneous Localization and Mapping) [2, 3, 4]. This technique involves having a robot build a map of a local area and tracking the robot's position. While humans find it easy to create such mental maps in this way, it is difficult and time-consuming for a robot to perform the same task [2, 3]. Location-awareness can be based, for example, on people using a combination of simultaneous localization with mapping and conceptual maps for tracking [4]. Integration of situation-aware autonomous and tele-operated activities is a central issue in many tasks, including rescue scenarios [5].

## II. Location-aware Technology Experiences

Our location-aware studies include data from many years of field experiments and industrial pilots. In the first development phase, we focused on a remote control for a mobile robot [6]. Location-aware technology for mobile transporters was developed and tested in laboratory pilots and industrial pilots. RFID-augmented environments were constructed for mobile robots to explore the issues related to creating user interfaces for efficient remote navigation with a mobile transporter in such environments.

Encouraged by these results, we proceeded with experimental techniques that displayed the position of a robot on an indoor floor plan (figure 1.) augmented with the following: 1) a video view from a camera attached to a robot; 2) a display of nearby obstacles (identified with RFID technology) on the floor plan; and 3) both features. Ten subjects controlled the mobile robot through predetermined routes in an indoor environment as quickly as possible, avoiding collisions. The results of this field experiment with the 10 test subjects showed that the system and interface techniques were successful for controlling a mobile robot. The results from the comparison of the visualization techniques showed that the technique without a camera view was the fastest, and the number of steering motions made was smallest using this technique, but it also had the highest need for human physical intervention. The technique with both features was subjectively preferred by the users.

### A. *Location-Aware Solutions for Warehouse Transporters*

Location-aware technology for mobile transporters was tested in two industrial pilots. First, UHF-based RFID technology was tested for automatic identification in a warehouse with a

J. Jämsä is with the RFMedia laboratory, Centria University of Applied Sciences, Ylivieska, Finland (corresponding author to provide phone: +358-44-4492-524; fax: +358-8-4492-599; e-mail: joni.jamsa@centria.fi).

S. Pieskä is with the RFMedia laboratory, Centria University of Applied Sciences, Ylivieska, Finland (e-mail: sakari.pieska@centria.fi).

M. Luimula is with the Faculty of Telecommunication and E-Business, Turku University of Applied Sciences, Turku, Finland (e-mail: mika.luimula@turkuamk.fi).

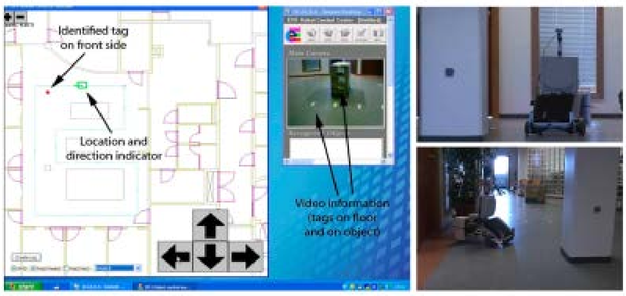


Figure 1. Indoor control experimental study

forklift truck equipped with an RFID reader and an antenna. These tests were promising and showed that

RFID technology can be used if the reader, antennas, and tags are placed in the appropriate locations. Second, UHF-based RFID technology and GPS positioning were tested outdoors, in summer conditions and in harsh winter conditions, for transporting tasks. In this case, a smart wheel loader was implemented based on a location-aware system platform equipped with a map of the outdoor warehouse area and a GPS system for localization (Figure 2).

RFID technology was used for pallet identification and positioning inside the covered warehouse buildings. When wood packages were left inside the warehouse, GPS technology could not be used; therefore, the location of that storage point was read from the RFID tags placed in the ceiling (Figure 3, left). One antenna was placed in the roof of the wheel loader's cabinet. In the tests, all RFID tags could be read from the ceiling. These examples showed that the results achieved with the remote control of mobile robots could be applied as a part of industrial pilots [7].

We have also successfully tested in another industrial environment the placement of QR codes on the roof of a forklift cabinet to track the forklift (Figure 3, right). QR codes were identified with smart cameras, which were mounted in the ceiling. In production plants, tracking of incoming and outgoing traffic in a certain area with two smart cameras will often give enough information. If more accurate indoor positioning is needed, it is possible to place a matrix of QR codes in the ceiling and a smart camera in the roof of the transporter. The solution we developed in the case of the

Figure 2. Smart wheel loader with location and product information and RFID tags inside warehouse

Figure 3. Transporter tracking with RFID tags in the ceiling or QR codes in the roof of a forklift truck

smart wheel loader can radically change the way wheel loader operators work. Currently, the operator must first stop the wheel loader, hop off, and manually scan the bar codes located on product packages before loading or unloading them. Our main concept is that the operator does not have to leave the wheel loader to scan the product labels or provide manual information regarding the unloading point and the package left there. The situation-aware information is brought to the operator, the transporter control system, and the whole warehouse information system. The operator's user interface on the smart wheel loader can be seen in Figure 4.

### B. *Indoor Position Experiences*

With regards to indoor positioning methods, there are different directions that can be taken. For example, Alippi et al. [8] used RFID tag-readers to cover an area of tag movement. With this, an accuracy of about 0.6 meters is achieved when readers are less than 3 meters away.

Radio positioning systems are used in many ways. The Chirp Spread Spectrum signal was used successfully by Huang et al. [9] to compensate positioning errors at low noise conditions with SNR values below -20dB. This noise level accuracy of location remains better than 1 meter. Still, there is a need for a synchronized clock between the transmitter and receiver. Yoon et al. generated an anchor-free positioning system using Chirp Spread Spectrum radios [10], showing that there is no need to give any position an anchor,

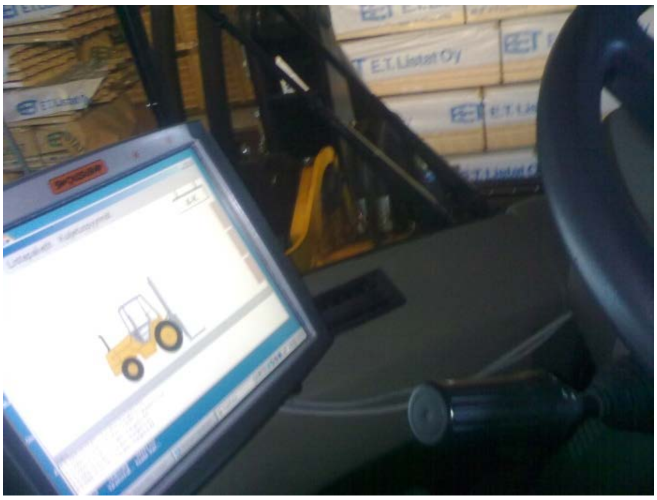

Figure 4. User interface of the smart wheel loader

because the networks locate themselves among each other and a mobile phone is used as a gateway to collect nearby location information.

### C. *Laser-Scanned 3D Models and indoor Positioning*

The main research topics in our indoor mobile robot development were related to location-awareness and to secure, interactive robot applications. The research group recognized that there is high demand for these types of applications in industry and in the wellness sector. As mentioned above, in order to improve on reliability and security in robotics, we studied how safety scanners can be utilized to provide information regarding obstacles to the user. However, the use of laser scanners in environments with humans is limited and decreases the accuracy of scanning. Therefore, we developed a three-dimensional indoor positioning system for the metal industry [11].

The system we developed consists of a three-dimensional map-based user interface scanned with a Leica ScanStation 2, Chirp Spread Spectrum (CSS) modulation indoor positioning technology, and a user positioning algorithm. For that interface creation, we used the Nanoloc CSS development kit. Radios were based on the Ultra Wide Band (UWB) frequency range, which uses bandwidth and increases frequency repeatedly to create an "up-chirp." Because of the large amount of bandwidth used (80MHz), CSS pulses are not sensitive to electromagnetic distortion. Instead of that, multipath fading won't occur there. CSS could even use radio frequency (RF) echoes for strengthen receiving power [12].

Positioning is an advanced method for measuring time of flight. Instead of requiring synchronized clocks between the transmitter and receiver, this method uses Symmetric Double-Sided Two-Way Ranging (SDS-TWR). Distance measuring is done from one node to another and then back to complete a round trip. Signal processing time on the remote end should be resolved, so protocol measuring is repeated on the other side. After all, function returns value measured distance in meters.

These advantages together provide an opportunity to get better results in rough industrial conditions in comparison with RSSI. As a result of this study, we proved that moving objects such as mobile robots, autonomous transporters, and working machines can be tracked in a three-dimensional virtual environment (Figure 5).

In our studies, we have also tried to find new application areas for anonymous transporter service robots. In cooperation with our Japanese partners from Ochanomizu University, we developed the ItemFinder, an application that we implemented based on the WiFiBoT robot [13, 14]. This robot is able to help users find items in a room by using UHF-based RFID technology and the robot's laser scanner. In this pilot, RFID technology was used to detect objects, and the scanner was used to detect obstacles and autonomous movements.

In practice, the user can connect from the ItemFinder Robot-Client program to the Robot-server, the Laser scanner-server application, and the RFID-server application based on

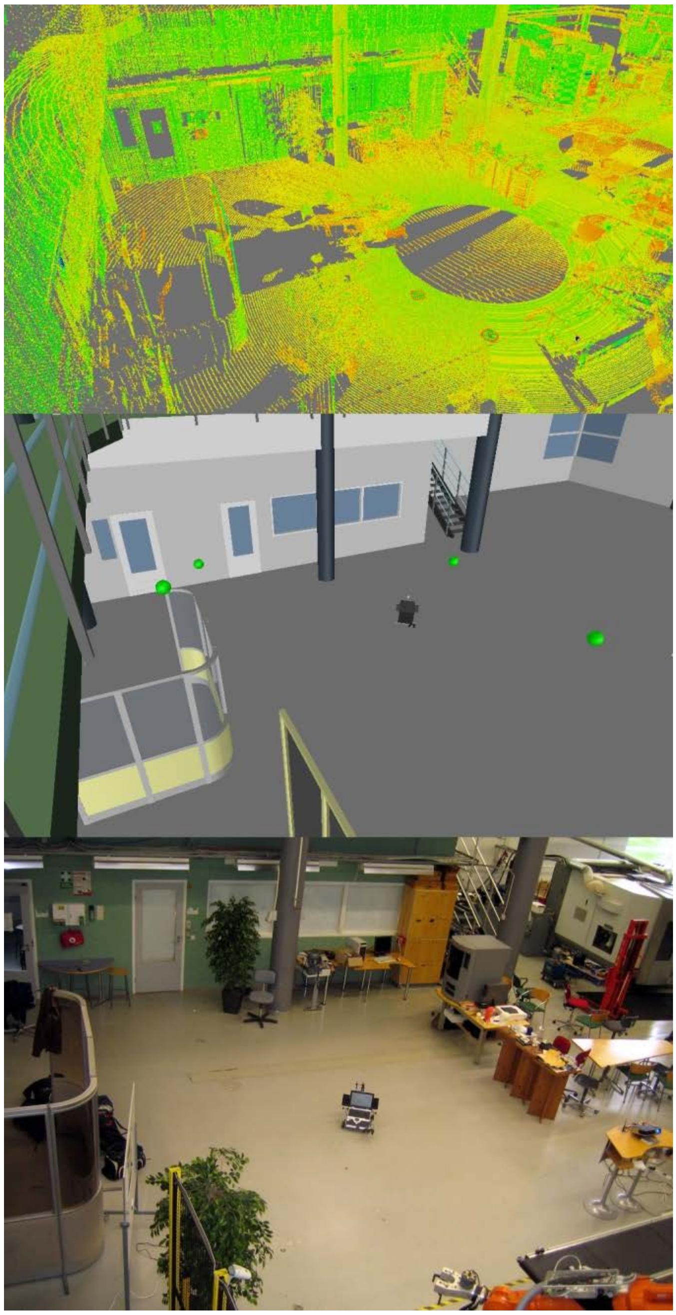

Figure 5. Pictures of production engineering laboratory together with a 3D model and a point cloud

a certain IP address and port number. After connecting, the robot sends laser-scanned information to the client PC. The client PC then calculates the next possible robot movements (go forward, turn left, turn right, stop) by using the laser scanner information. In this manner, the robot can detect objects and move around the room automatically without collisions. At the same time, the robot reads the RFID tags in the room. Based on the detected tags, the robot is able to identify objects and their locations by simultaneously detecting tags fixed in certain locations and tags attached to objects. After detecting the object information together with its location, this information is sent to the client PC and is

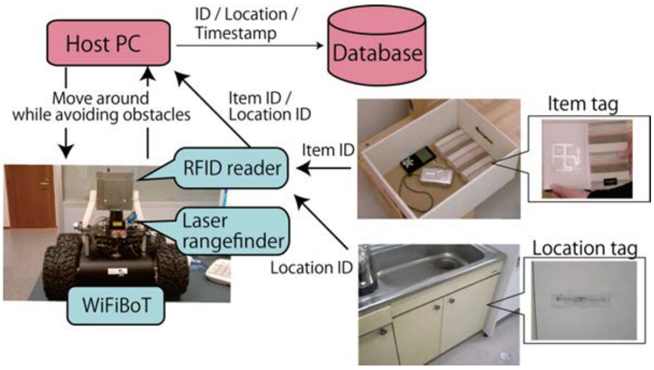


Figure 6. ItemFinder application designed for the Wifibot robot [13]

stored in the database. The user can browse the location of the items on the web page, as shown in Figure 6.

## III. Situation-aware Experiences in Traffic Systems

Centria has developed a map-based interface using Nokia Ovi Maps as an example of situation-aware traffic services [15]. Several activities and tasks can be performed with this interface, including the following: 1) interaction with a wireless sensor network and roadside sensors from inside a car; 2) environmental monitoring through the mobile phone's radio; and 3) using the mobile phone as a router on a movable environment between roadside sensors and a server.

In the pilot, we used servers to gather information and conclude which information was meaningful. Then, mobile-phone-generated JavaScript Object Notation (JSON) messages queried situation-aware information for the phone. Finally, the Ovi Maps user interface displayed the requested information as a separate layer using JavaScript. Radiocrafts' 6LoWPAN sensors were used for wireless networking in vehicles. A frequency of 2.4GHz easily covers pass one vehicle area, even at a low transmission power. Low power consumption makes installation possible without power supply wires, which decreases installation times. The network was self-configured and adding or removing sensors did not require any management for setup new devices.

We used a sensor network to detect temperature and brightness. Data that had been gathered and read was stored in a database. To visually display this information for the driver, we used the Nokia Ovi Maps user interface on the phone. We used a lower frequency of 868MHz to read roadside sensor information. Information from Wisepro radio was also displayed on the Nokia Ovi Map; this service was chosen because it has a wider range of communication and is more useful for information on roadside conditions (Figure 7).

After this pilot, we focused on displaying all critical situation-aware alarms on the vehicle's display while navigating on the roads. We decided to use MirrorLink (formerly Terminal Mode), in which the vehicle could act as a client with display and touch-screen input for a server-side mobile phone. This is a standard virtual networking computing (VNC) connection, in which applications on the phone can be shown on the dashboard [16]. Using this


Figure 7. Temperature and humidity information from 868MHz roadside sensors

method, it was possible to control the mobile phone from the head unit side for better and safer usage while driving. With the phone radio, real-time information could be provided from the backend system to update and add applications to use on the vehicle.

Applications could be updated and managed remotely so the cycle for gathering current information was shortened between dedicated vehicle integrated systems. When real-time awareness is required, manufacturer notification services should be used. The mobile device itself (or its application) informs the service of its willingness to receive messages of a certain type. The Push Notifications service allows a server to push real-time messages to a phone to attract the user's attention [17]. Using this service, the driver could be warned when weather or road conditions are changing. For social networking, this service could also provide information about a friend's location. New modeling and scanning methods provide fascinating options for route planning and enhancing user experiences [18]. A driver can drive a planned route on the web and familiarize himself or herself with route highlights and turnings in advance.

### A. *Visualizing Situation-aware Information in Advanced Car Navication*

We have discussed advanced car navigation services in an advanced seminar paper [15]. In that paper, mobile phones, used both inside vehicles and on the roadside, were presented as our main source of information. We described how the next generation of Information and Communications Technologies (ICT) will be utilized in future vehicle instrumentation in order to improve situation-awareness in car navigation. In addition, the contents will be visualized with rich end-user experiences together with highly usable features, such as multimodal interaction. In that paper, we described a situation-aware traffic service using Nokia's Terminal Mode and Push Notification services together with Nokia's Qt Mobility API [17]. A Bluetooth heart-rate sensor was used to indicate the driver's condition. A low heart rate could mean there is a risk of falling asleep while driving and the system would suggest a break. As a second alarm, CAN bus information was also read over Bluetooth through an OBD2-reader.

Since we wrote that paper, situation-awareness with rich end-user experiences is closer to reality than ever before. For example, car manufacturers and the telecommunication industry are standardizing MirrorLink, which has its basis in the above-mentioned Terminal Mode [19]. One of the main requirements for this service is the availability of geographic information, especially image and laser scanning databases and geosensor databases. According to Google [20], their Street View database is perhaps the largest image database ever collected and is now focusing on laser scanning information. Other companies, including Navteq, have been working with street view information. This information will consist of bitmap graphics and laser scanning information [18]. This information can be used for visualizing better roadside conditions, such as road profiles, buildings, tunnels, and bridges. Geosensor databases are also coming into the market. Geosensors are tiny computers that can be placed in the air, water, ground, body, vehicles, or buildings. These sensors can be used to track and trace human beings or vehicles, direct arms, control restricted areas or power plants, and to form industrial ad hoc sensor networks [21].

### *B. Key Components in Visualization of Situation-aware Traffic Information*

Image and laser scanning databases are one of the key components in the visualization of situation-aware traffic information. In our previous studies [11], in which we studied the remote navigation of mobile robots, we focused on improving the visualization of the map-based user interface. We tested this by attaching a SICK S300 safety laser scanner to our ER-1 robot (Figure 8).

This laser scanner is able to detect obstacles at up to 30 meters in its surroundings. In addition, this scanner can scan obstacles in a sector of 270 degrees, including warning (max 8m) and protective (max 2m) fields, with an accuracy of two centimeters [22]. By using this laser scanner, we were able to improve our two-dimensional user interface. Now we could offer totally three components: 1) a traditional two-dimensional map-based user interface; 2) laser scanner information for visualizing obstacles close to the mobile robot; and 3) 2.5 dimensional view of the robot's environment. During the process to convert laser-scanned information to the 3D model, we first scanned our laboratory from four scanning locations. The scanning process produced a point cloud, which contained hundreds of thousands of points. This point cloud was then converted to the AutoCAD Drawing Interchange Format (DXF) using software dedicated to theLeica Cyclone scanner. This conversion enabled the interoperable treatment of point clouds with other software. By using the DXF format, we were able to import a 3D model to the Blender 3D content creation software. The main

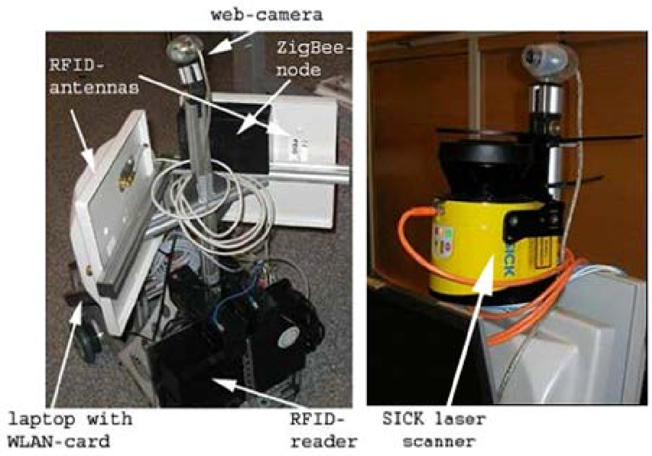


Figure 8. The first installation (left) and the current installation with SICK scanner (right)

3D modeling process was done in Blender and the ready-made 3D model was converted to Wavefront's OBJ format (in ASCII format) to be used in our map engine.

Another key component in the visualization of situation-aware traffic information in advanced car navigation is the map engine. In our previous studies, we focused on the Locawe platform, which offers 2D- and 3D-map-based user interfaces for software developers. Locawe has been used, for example, in 3D mobile navigation [23, 24]. The aim of this study was to develop and experiment with methods for 3D mobile roadmaps, which adjust the map view automatically based on the speed of a vehicle. Results suggested that automatic speed-dependent camera controls can be a beneficial feature in 3D mobile roadmaps. Manufacturers of car navigation systems (e.g., Sony) launched navigators including 3D models of cities years ago, and providers of map materials (e.g., Tele Atlas, Zenrin) are in the process of modeling a large part of major cities worldwide in 3D.

In the current implementation, we built a system that requires information about situations on the road, represented

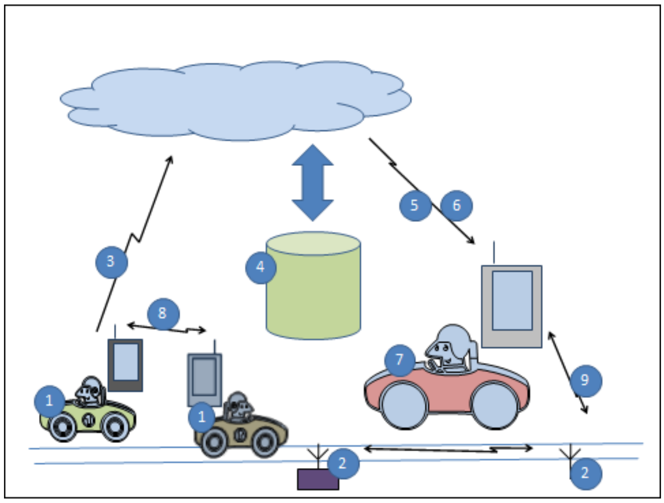


Figure 9. The first installation (left) and the current installation with SICK scanner (right)

in Figure 9. Vehicles (1) and roadside sensors (2) collect this data and deliver (3) it to the database (4). The service provides (5) and preprocesses it to create push notifications for critical information (6) information to vehicles (7). Collected data can be handled simultaneously and used for history trends. Wireless vehicular network connections between cars (8) and roadside sensors (9) provide local information to vehicles. The vehicles' cellular radios can be used to deliver this information to the database if the sensors don't have a connection. Ad-hoc (8) networks make local networking possible if connections to infrastructure are not in use.

In order to show how it is possible to improve the visualization of situation-aware traffic information, we undertook the following steps. We asked the city of Turku for a sample of their laser-scanned spatial database. For this study, we utilized 3DStudioMax instead of Blender. In addition, the 3D model was not converted to OBJ format because we wanted to test the Unity 3D game engine during this process. Unity 3D is currently one of the most popular game engines and supports various graphic formats [25]. As a result, we were able to implement user interfaces with a low number of polygons and non-photo-realistic models quickly.

Using Unity 3D with MirrorLink technology opens up a lot of new possibilities for software developers in car navigation. Mobile phones can gather traffic information and can integrate them with social networks, which enables new business opportunities for advanced car navigation service providers. One example of the use of a social network in traffic is Waze Mobile's driving community [26]. Based on our experiences applying Unity 3D with laser scanning databases, we believe that we will see more services in the near future dedicated to providing driving communities with rich user experiences. Figures 10, 11, and 12 show potential user scenarios in which situation-aware traffic information is useful with 3D visualization.

## IV. CONCLUSION

In this paper, we have described various technologies and applications for how cognitive infocommunication could provide situation-awareness for controlling objects. User recognition increases the need for cognitive infocommunication with indoor and outdoor positioning. User recognition is critical when industrial pilots and commercial products now offer possibilities for fulfilling the needs of reliable communication and information gathering. Sensor information and actuator control may be utilized through wireless systems. With movable robots, wireless connections through backend systems and device sensors are an actual possibility. A wide range of possible systems, described in this paper, could be used. Today, development continues from the earlier location-awareness technologies to full situation-awareness. Different sensors in various locations could be used to provide complete situation information in order to manage automated tasks. Combining sensor values, history data, and objectives offers a wide perspective with which to proceed with transporter missions.

Figure 10. Visualizing route planning based on height curves (information needed in electrical cars with a low battery level)

Figure 11. Visualizing situation-aware information, such as traffic jams, in 3D maps

Figure 12. Visualizing situation-aware information in car instrumentation

Automated operated wheel loaders and forklifts are only the first steps in the future use of technology for transportation. These first field tests will demonstrate how technology is ready to serve a greater number of users. As described in this paper, many earlier technologies that were restricted to inside areas can now serve intelligent transport systems. Similar situation-awareness is needed to enhance drivers' abilities in everyday traffic in order to help save human lives and avoid accidents. To accomplish this range of uses, further standards development is needed. Throughout Europe, using global harmonization and suggested data formats, wider markets are being created for companies who offer these products. These wider markets will lead to decreased costs without need for customization. Based on our experiences, using factory-proofed components and combining them in new ways and in new applications provides a way to develop these solutions. This approach makes it possible to construct designs piece by piece for which the plan has already proven the functionality of the application. This will expedite the total evolution process from design to accomplished application, and the possibility of failures will be decreased. Overall, the pilots described in this paper answer questions about how situation-awareness can be utilized in a formal way and how to create technology pilots to introduce possible use cases in given environments.

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