Intelligent vehicles as the robotic applications

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Abstract

In the recent years, intelligent vehicles became an important part of the service robotics. Besides routine tasks for the service robotics, such as localization and navigation, intelligent vehicle must solve many specific tasks. Although fully autonomous intelligent vehicle does not exist, there are many support systems nowadays for which vehicles are closer to the vision of self-piloted vehicle. This article presents state of art in this section of service robotics. The main body of the article introduces a definition of intelligent vehicle and automated functions used in such vehicles. Future challenges of the intelligent vehicles are also presented.

1. Introduction

In the last 25 years robotic vehicles, usually named intelligent vehicles, became important part of service robotics. It is estimated that over 1 billion passenger vehicles travel the streets and roads of the world today. With such traffic, it is clear that there are many situations where the driver has to react quickly. In many cases, the driver is not able to react, that is why applications of automated systems are involved in the vehicles. These automated systems solve various tasks, with which the driver meets during normal operation of the vehicle. An intelligent vehicle is defined as a vehicle equipped with perception, reasoning, and actuating devices that enable the automation of driving tasks such as safe lane following, obstacle avoidance, overtaking slower traffic, following the vehicle ahead, anticipating and avoiding dangerous situations, and determining the route [1]. The general motivation for the development of intelligent vehicles is safer, more convenient and efficient road traffic.

Current research on intelligent vehicles is focused on realistic conditions. Therefore, mainly because of legal issues, it is not the ultimate aim of research teams to construct a fully autonomous vehicle. Automotive industry itself sees its task in research of supervisor and assistance systems. In addition, the transport authorities in the world do not attempt to address the autonomous transport systems, but in particular to reduce fuel consumption of vehicles, expansion of road network and increase the life of roads and vehicles.

The development of intelligent vehicles has social, environmental and economic benefits. Intelligent vehicle can anticipate driving scenario and respond in times of danger, what can in 90% of cases avoid accidents caused by human error. Ultimately, this leads to saving human lives. Vehicles capable of running at high speed and close behind each other
can reduce fuel consumption, pollution emissions and increase road capacity. Vehicles able to perceive traffic restrictions may prevent misinterpretation of these restrictions and anti-social driver behavior. Fully autonomous vehicles will provide a greater degree of mobility and quality of the whole population, because driving of such vehicles will not need to have a driving license [1].

The most famous project in the field of intelligent vehicles is DARPA Grand Challenge competition [2]. This competition is for autonomous vehicles which must follow a route in unstructured environment with no traffic. In recent years DARPA focuses on standard traffic conditions. The first autonomous vehicle whose operation is authorized in normal traffic is Google Driverless Car. This car is based on the robotic vehicle Stanley which won the 2005 DARPA Grand Challenge [3].

Mainly due to legal reasons, fully autonomous vehicles are not expected to be integrated in standard traffic. Therefore, only advanced assistance control systems are used in these vehicles. These systems solve tasks such as:

- Prevention of collisions when reversing (e.g. solved with multi-camera system) [4].
- Prevention of collisions when following another vehicle [5-6,9].

![Fig. 1. Collision warning with brake support for Volvo S80 [9].](image1)

![Fig. 2. Valeo blind-spot detection system [4].](image2)

1. Prevention of collisions when overtaking (blind-spot detection) [4-9].
2. Prevention of collisions with pedestrians (saving lives) [9].
3. Prevention of collisions at intersections (a difficult task in terms of quantity of information).
4. Prevention of collisions with obstacles on the road.
5. Obstacle avoidance (not to stop, but get around; the questions of reliability, human error and responsibility) [10-11].

6. Adaptive cruise control (ACC, adapting the vehicle speed) [5-6,9].
7. Driving in traffic jams (slower version of the ACC) [12-13].

8. Intelligent parking assist system (for parallel parking, parking space measurement) [14-16].

Fig. 6. Ford’s Active Par Assist system employs ultrasonic and radar sensing to make parallel parking a breeze. The driver pulls alongside a parking spot and presses a button on the instrument panel, activating the ultrasonic sensors to measure and identify a feasible parking space (1). The system then prompts the driver to accept the system assistance to park. The system takes over and steers the car into the space hands-free. The driver still shifts the transmission and operates the gas and brake pedals with prompts from the system (2). A visual and/or audible driver interface advises the driver about the proximity of other cars, objects, and people and provides instructions (3). [17]

9. Lane keeping [18-19].

10. Lane changing (combination of lane keeping and ACC) [18,20].

Fig. 7. Lane-change warning system for the BMW 7 [20].

All these advanced assistance control systems have in common that they were first developed for robots. Therefore intelligent vehicles are considered as robotic applications. Applications developed for intelligent vehicles require:

1. Knowledge of vehicle state - position, kinematics and dynamics of the vehicle.
2. Knowledge of environment state.
3. Knowledge of driver and passengers’ state.
4. Communication with roadside infrastructure and other vehicles.
5. Access to digital maps and satellite data.
2. Knowledge of vehicle state

The most important task of intelligent vehicle is localization of the vehicle. The determination of vehicle position is important for control, because the vehicle is driven by a prescribed trajectory. Without knowing the exact current position, the position of the vehicle cannot be regulated to the desired values. For the control of intelligent vehicle it is necessary to know the kinematics and dynamics of the vehicle. Without this knowledge it is impossible to control the vehicle by means of obstacle avoidance or lane changing. Localization of the intelligent vehicle can be solved as:

- Tracking a device embedded in the road – particularly antenna, magnets or passive RFID transponders, bar codes, etc.
- Absolute positioning system in a vehicle – global navigation satellite systems (e.g. GPS, Glonass), inertial navigation systems, etc.
- Relative positioning system in a vehicle – visual marks in environment, etc.

For an intelligent control of the vehicle an electronic control unit capable of steering acceleration (engine torque, gearbox, clutch), braking (electric or electrohydraulic brake), and controlling the rotation (electric power steering), must be built in the vehicle.

3. Knowledge of environment state

Another critical area in the development of intelligent vehicles is the knowledge of environment. The most complex and most important function of this area is the interpretation of the scene around the vehicle. Solving this task requires usage of various sensors with intelligent evaluation of the situation, which gives a synthetic representation of the environment. The most commonly used sensors include infrared, ultrasonic, radar, laser and visual [1]. These sensors have to scan the environment continuously. Sensors have different characteristics, and therefore their use is specific. For example, radar sensors are able to detect obstacles in big distance, while infrared and ultrasonic sensors can be used as proximity safety sensors. Sensor position in a vehicle is determined by its properties.

The knowledge base, which was developed by the interpretation of the scene around the vehicle, is a key factor to preventing the emergence of false alarms and uncaught of the real alarms. Interpretation of the scene around the vehicle is a complex problem not only because of the complexity of the environment containing vehicles, but also due to frequently changing environmental parameters such as illumination, temperature, visibility, weather conditions etc., that cannot be controlled.

There are two approaches in development of perceptual systems for intelligent vehicles:

- Powerful on-board intelligent systems – vehicle itself is equipped with sensors and corresponding control systems, of which quality and quantity is increasing.
- Active communication components placed in the road – these components are able to communicate with all vehicles and they provide information in real time.

Research is focused on both approaches. In terms of safety and traffic flow the solution is in a hybrid system. Despite this fact, vehicles must be first focused on powerful intelligent board systems to guarantee the basic security of driving such vehicles. Communication components (road or other vehicles) are not the primary sources of information, but they can provide useful additional information such as road conditions, road geometry, number of lanes, visibility or traffic sign. In the future, application of active communication systems is expected in all vehicles. Pedestrians and cyclists will not have to carry any electronics in order to be detected. Intelligent vehicles will be able to detect the presence of these road users on their own.

The basic tasks of scene recognition are detection of road, other vehicles, and pedestrians, identification of road signs and other unstructured objects. Intelligent vehicle should not only detect these objects and situations, but also predict them. Example of sensors used for environment state sensing can be seen in figure 8.

Many vehicles are already equipped with a system for detection of lines on the road, and thus the identification of lanes [18]. These systems are based on vision systems [32-35]. Most of these systems work with simplified assumptions, such as parallelism of the left and right line, constant width of the roadway or the assumption of smooth road surface. These assumptions have been introduced due to the usage of simple and inexpensive vision systems. Some more expensive systems are using stereovision and may not work with these restrictions. Typical reliability of systems for detecting lanes on the road varies from 95% to 99% [25]. It should be noted that these systems are only support systems and they cannot be used for fully autonomous vehicles. In the autonomous vehicles it is necessary to develop and use algorithms and sensors that are able to ensure 100% detection of lanes under any conditions.
Another task of interpretation of the scene around the vehicle is the identification of the road signs [24,26]. Road signs help to coordinate the traffic. Road signs have known shapes, colors, and patterns. They are located at a constant height and position with regard to the road. For these reasons, their detection is considerably simplified. Identification of the signs is usually performed within the systems that can detect the shape and color. Identification of the sign shall be carried out in three steps: detection, position and recognition. As the set of tags is well-defined and the number of signs is limited, it is possible to use the principles of mutual correlation of the images.

Systems that can recognize the shape and color can also be used for the detection of traffic lights [24, 27]. However, it should be noted that despite the relative simplicity of this task, it should be taken into account that the detected signals from the traffic lights do not belong to the vehicle (e.g. traffic light for another lane etc.). For this reason an intelligent vehicle must be able to identify the corresponding signals of traffic lights. The position of traffic lights can be detected with using a
lane detection system. Another support system based on vision system is detection of reduced visibility, e.g. in fog. Detection of such feature requires a specific reference point or object, so the development of these systems is still in its inception.

Intelligent vehicle should be able to detect another vehicle as well. The detection of other vehicles can use a variety of visual sensory systems, or laser to ultrasonic [28-29]. Even though the vehicles have different shapes and colors, they usually have the same characteristics, properties, and are made mostly of reflective material. Detection and prediction of the positions of vehicles on the road is clear, if the lanes detection system is fully operational. Despite the fact that the detection of vehicles may use many different sensors, the most successful solution is to use several of these sensors and apply the information fusion. The visual system can fail in low visibility conditions, in low illumination environments or in heavy traffics. Thermal imagers are capable of detecting moving vehicles with high reliability (wheels and exhausts are generating heat), but fail to stationary vehicles or carts. The principle of laser sensors is generally robust, but they have reduced sensitivity in bad weather conditions. Radars are cheap, but may fail in the presence of nearby reflective objects. Ultrasonic sensors can be used only at short distances and due to their measurement characteristics; they may fail in some cases (e.g. narrow objects).

The most complicated task is the detection of other road users (e.g. pedestrians or cyclists). In vision system the shape of a pedestrian can change within a few milliseconds, there is no invariance in color, texture, or size [30]. Estimates of position, velocity or visible parts of the human body cannot be done. Currently, despite the many existing technologies, there is no reliable system to detect pedestrians. Radars are not able to detect pedestrians when there is a large number of them in one place, vision systems are limited to optical properties and thermal imagers fail in environments with higher temperature.
4. Knowledge of driver and passengers’ state

Intelligent vehicle should not only sense the state of environment, but it should scan the conditions inside the vehicle, especially the state of driver and passengers. Solution of this task is usually based on a vision system, that monitors driver’s fatigue and attentiveness on the basis of driver’s sight and eyelid movement [31]. Statistics show that 92% of accidents are caused by driver’s mistake [1]. However, the driver cannot be excluded from driving. Therefore, intelligent vehicle acts according to this scenario:

- The vehicle will monitor the scene using advanced assistance system, which interprets state of the environment and warns the driver about dangerous situations.
- The vehicle will monitor the state of the driver using a vision system. This system will determine the status of the driver. If the driver is tired, sleepy, distracted, confused, or intoxicated, the vehicle will warn him of corresponding risks.
- For legal reasons, the vehicle cannot take control of the vehicle itself, so the driver is alerted with audio-visual or tactile warnings. The vehicle will not perform obstacle avoidance, it will just slow down before them.
- If it is not possible to avoid an accident, the vehicle will brake automatically. To maximize the safety of passengers, safety belts will be tightened and airbags fired.
- After an accident it is important to know the state of passengers in the vehicle. If the passengers are injured, vehicle will perform an automatic emergency call. At the same time, the vehicle should provide information on its location and information about the injured persons to rescuers intervening at the place of accident.

In all the above mentioned points driver monitoring is important. Consider the example when the driver passes from one lane to another. If the monitoring detects that the driver falls asleep, the vehicle should not be allowed to carry out this maneuver. Driver state monitoring systems must be contactless and noninvasive. Therefore, the vision systems that are able to detect the driver’s state without dependence on gender, age, race, sunglasses, facial hair etc. are used. In addition, driver monitoring systems should not detect only the presence of the driver, but also his head position, viewing direction, rate of blinking etc. Despite the many advantages of intelligent assistance systems in vehicles, it should not be forgotten that too many electronics can dispel driver’s attention.

Fig. 12. Driver state detection [1].

5. Communication with roadside infrastructure and other vehicles

Technologies allowing vehicles to communicate with each other increase the safety and efficiency of road traffic. Such communication systems should take care of prevention of collisions, safety braking of the vehicles and sharing of road and traffic information with other vehicles. Basic communication modes of intelligent vehicles are:

- Communication vehicle - road infrastructure,
- Communication vehicle - vehicle.

For the communication over short distances, there is protocol DSRC (Dedicated Short Range Communication) that provides tourist, commercial and safety information. It uses short messages, and works up to 300 meters. For the communication between vehicles and road infrastructure CVIS protocol exists (Cooperative Vehicle Infrastructure System). It operates on base of IPv6. For the communication between the vehicles there are no standard solutions. The best known system in this area is a system called VANET (Vehicular Ad hoc NETwork) [1].
6. Access to digital maps and satellite data

The combination of global navigation satellite systems such as GPS with digital maps creates a wide range of applications for intelligent vehicles. Such systems help in interpreting the scene around the vehicle, navigate the vehicle in conditions where other sensors are not working (sun, dust), etc. Digital maps used for navigation are now commonly available. The enhancement of digital maps by real-time data about traffic can make traffic more effective. Other extensions of these digital maps are warning of curves, speed warnings, information signs, etc.

7. Conclusion

Though there already are first autonomous vehicles, there are still challenges in research of operational safety, condensed traffic solutions, reduction of pollution caused by cars, development of autonomous vehicles for mass transport, hybrid control of autonomous vehicles, communication modes and modules, and intelligent sensor systems. First of all it is needed to improve reliability of existing assistance systems. An appropriate combination of these systems will make a vehicle fully autonomous, so it will be able to handle any conditions that can occur in normal traffic. However, control loop of a human should never be removed.

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