Vehicle as a Mobile Sensor

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ABSTRACT

Automotive manufacturers are currently giving much interest to in-vehicle sensors and their relevant ITS applications. The number of in-vehicle sensors is in continuous increase for their proved benefits represented in avoided accidents, higher driving efficiencies, and ubiquitous sensing-based services. These benefits are not limited to only a vehicle's driver, but also to other vehicles and third parties. In this paper, we introduce Vehicle as a Mobile Sensor (VaaMS), a concept that shows how sensor-equipped vehicles can be considered a pivotal, mobile resource of sensory data and sensor-related applications/services. Besides, we present a new categorization of in-vehicle sensors along with a discussion of some representative sensors and some supported ITS applications.

I.   INTRODUCTION

The advances of the automotive industry are highly dependent on the deployed in-vehicle sensors which are currently considered essential components of any vehicle regardless of how luxury it is. Sensors improve a vehicle performance, monitor its operation and the status of its parts, and enhance the driving experience. As the demand for more automotive advances is increasing, the number of sensors in a vehicle is highly increasing too. According to the automotive sensors market growth in North America, the average number of sensors per vehicle has reached 70 in 2013 [1]. Currently, some luxury vehicles have an average of 100 sensors for supporting its operation and enhancing its in-vehicle services. Some of these sensors are added to vehicles and mandated under country regulations (ex. tire pressure sensors in U.S.), and others are added for providing higher efficiency and convenience.

Having that huge number of sensors, a vehicle can be considered a significant resource of sensory data that are hard to be all acquainted from a single sensory system or network. In this paper, we aim at clarifying the significance of in-vehicle sensors, the services they can introduce, and the systems/applications they can be part of by introducing the concept of Vehicle as a Mobile Sensor (VaaMS).

As well, a new categorization of the in-vehicle sensor is introduced with a discussion of some representative sensors.

The remainder of the paper is organized as follows. Section II introduces the new in-vehicle sensors categorization along with a discussion of some sensors and their applications. Section III introduces the concept of VaaMS with a discussion of some potential applications and existing platforms that adopt it. In Section IV, we touch upon some communication technologies that support VaaMS. Finally, Section V concludes the paper.

II.   IN-VEHICLE SENSORS

Sensors in a vehicle are of many different types. In [1], W. J. Fleming categorizes in-vehicle sensors into three categories according to their place of deployment in a vehicle: 1) powertrain sensors, 2) chassis sensors, and 3) body sensors. As the objective of the paper is shedding light on the potential services and systems that can utilize in-vehicle sensors, we categorize sensors in a vehicle according to their application domains; 1) Sensors for Safety, 2) Sensors for Diagnostics, 3) Sensors for Convenience, and 4) Sensors for Environment Monitoring, as shown in Figure 1.

A.   Sensors for Safety

With the increasing number of driving accidents and fatalities, automotive sensors have been added to the vehicle to form the basis of many safety-enhancing systems. These safety sensors can be further classified into many types as follows.
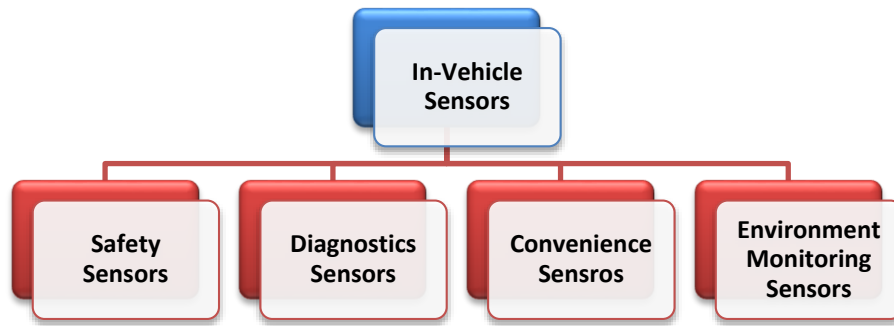
Figure 1 Categories of in-vehicle sensors.

1) *Distance Sensors*

Distance sensors are used for monitoring the area surrounding a vehicle to detect obstacles, hazards, or even other vehicles for the sake of avoiding collisions/crashes. There are two main categories of distance sensors as discussed in the following and shown in Figure 2.

-- *Long Range Distance Sensors*

These sensors look only forward with monitoring ranges between 30-120 m [1].

This category includes:

1. **Radar sensors** - operating in the 77 GHz band.
2. **Laser Scanners** - known as LIDARs (for Light Radars).

Lidars have an advantage that they are cheaper than the radar ones[1]; however, they do not function well in some weather conditions (do not penetrate fog, rain, or snow).
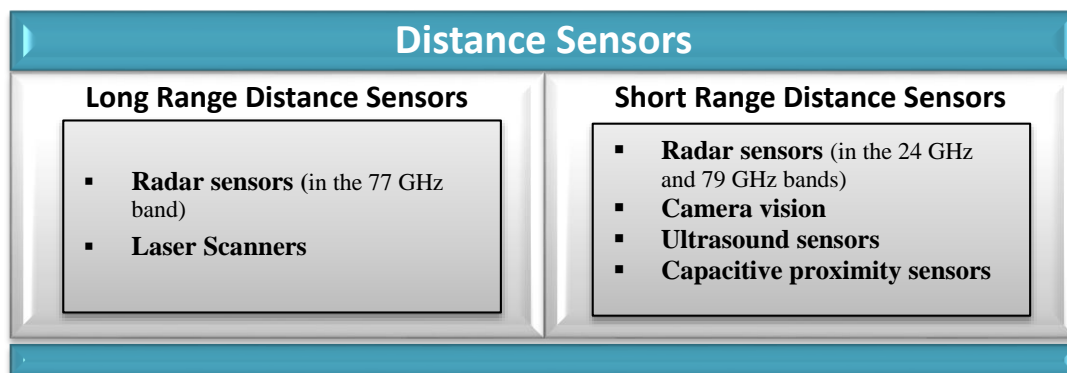

Figure 2 Categories of distance sensors.

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[1] The cost of a lidar is said to be 1/3 the cost of a mm-wave radar [1].

An example of the applications that made possible by the use of long-range sensors is the **Adaptive Cruise Control (ACC)** for detecting the speed of the vehicle ahead and adjusting the vehicle's own speed accordingly. In addition, the distance to the vehicle ahead can be measured and a guard distance can be kept between the vehicles to avoid crashes.

Instead of only using laser scanners for detection and tracking, Nashashibi and Bargeton [2] proposed an approach that provides classifications of objects on the road using three laser scanners and based on objects' dimensions.

-- Short Range Distance Sensors

These sensors can look at all directions but with shorter monitoring ranges, 0-30 m. They include:

1. **Radar sensors** - operating in the 24 GHz and 79 GHz bands.

2. **Camera vision** - which can be deployed for two different purposes; either to provide a view of the vehicle's surrounding, or, for view analysis when no scenes are displayed, but warnings or messages can be displayed for the driver instead based on data extracted through scene analysis. A typical example is the use of a charge coupled device (CDD) camera that generates two-dimensional images in a form that can be easily stored, processed, displayed, and searched for objects [3].

3. **Ultrasonic sensors** – low cost sensors which have an average detection range of 2.5 meters.

4. **Capacitive proximity sensors** – used to detect the proximity of objects without direct contact to them. They sense the proximity of conductive objects or objects with dielectric properties different from those of air. Capacitive sensors can accurately measure distances up to 2 meters [3].

This category supports many systems which are considered the core of the ITS safety applications, for example:

- **Blind Spot Detection** – This system supports the driver vision and perception by monitoring areas that are out of his direct vision which are known as the "blind spots". It monitors both the rear left and right sides of the vehicle and alerts drivers about any detected objects. The output of this system can support other systems such as the **Lane Change Support** system which in addition to monitoring the blind spots, it monitors the rearward of the vehicle for a much safer lane change.

- **Lane Departure Warning** (LDW) – The aim of this system is detecting markings of the lane on which the vehicle is travelling by means of machine vision and generating warnings for the driver if the vehicle is about to cross the lane boundaries. A more advanced version of this system is the **Lane keeping Assistance** (LKA) system in which, instead of only giving warnings to drivers in case of unintended lane departure, the LKA system provides drivers with assisting steering torque for easier steering adjustments.

- **Forward Collision Warning** – This system works on detecting imminent crash conditions and informing drivers about them by means of audible alerts, visual on-screen warnings, or seat vibrations. Some of these systems try to reduce the level of fatality by supporting driver safety and not only depending on alerting them but also taking actions to enhance safety levels. Examples of such safety actions are seatbelt pre-tensioning, airbags pre-firing, and automatic braking.

- **Backup Crashes Warning** – This system makes use of sensors to detect objects behind the rearward of the vehicle. It assists in reducing the number of tragic fatalities that happen when backing vehicles hit children that cannot be seen by drivers. This system can as well be a part of the **Parking Assist** system.

- **Stop-and-Go** – Also known as low-speed ACC. In traffic congestions, stop-and-go systems automate driving with the sake of keeping a guard distance among the vehicles to reduce the number of congestion-related crashes. This system has some convenience-relevant goals as well by reducing the burden of throttling and braking for the driver and allowing him to do other things while keeping control of driving on his behalf. The early version of this system was a stop-and-wait system but later it evolved by including forwarding movement whenever possible [4].

Figure 3 shows the monitoring ranges of the different distance sensor types relative to one another.
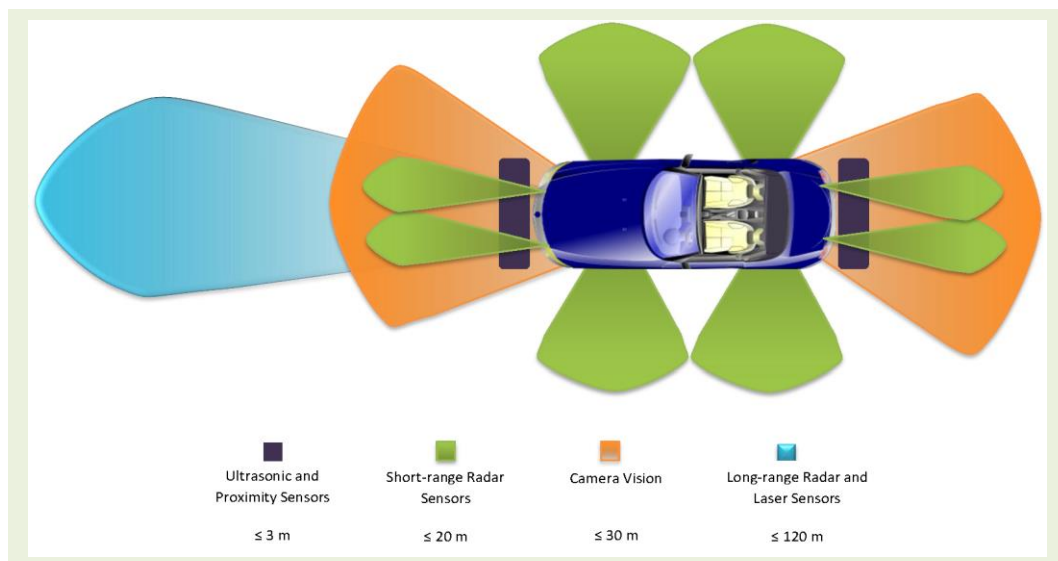

Figure 3 Distance sensors monitoring ranges.

2) Night Vision Sensors

Night vision sensors are used for assisting drivers' perception by viewing scenes for the road and roadside ahead beyond the illumination range of the vehicle's headlights. They can be either *active* or *passive* systems.

Active night vision systems use near-infrared systems which depend on the use of nonvisible infrared light sources directed to the road ahead and a camera to capture the reflected radiations. *Passive* night vision sensors use far-infrared systems which do not require use of light sources; instead, they depend on capturing the existing thermal radiations emitted by objects using thermographic cameras [5].

Some new versions of night vision systems have introduced more assistance by identifying objects and highlighting them on the displayed image.

3) Speed Sensors

Speed sensors are considered among the most significant in-vehicle sensors. They have been installed on vehicles for long time to support the operations of critical systems such as the **Antilock Brake System** and **Traction Control System.**

The **Antilock Brake System (ABS)** supports controlling the vehicle in cases of sudden stops. The speed sensors monitor the speed of wheels, and when they detect sudden braking; ABS releases braking pressure and provides optimum braking level for each wheel to prevent wheels from locking.

The **Traction Control System (TCS)** shares the wheel speed sensors with the ABS for a complementary, reverse function. When the sensors detect a wheel spin[2], the TCS helps in preventing losing control of the vehicle by applying brakes or slowing down the engine to regulate wheels speed.

4) Angular Rate/ Linear Acceleration Inertial Sensors

Utilizing wheel *speed sensors* along with *angular rate inertial sensors* and steering-wheel *angle sensor*, the **Electronic Stability Control (ESC)** system works on maintaining a vehicle's stability in cases of sudden turn for the steering wheel, taking a turn with high speed, or a side skid on slippery roads.

When an accident or a crash is inevitable, the *acceleration sensors* (accelerometers) play a vital role in detecting the undesirable situation and triggering the passive safety equipment to reduce damage and injuries. These crash detectors are the activators for passive safety systems such as airbag inflation and motorized seat belt pre-tensioners.

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[2] A wheel spin may happen on starting the vehicle or at slippery roads

5) Passive Safety-Support Sensors

Although the passive safety systems were introduced long time ago, they are still getting improved to increase the safety level of passengers. For example, the airbag inflation system is enhanced by adding *seated weight sensors* as a means for occupant classification to distinguish a child from an adult. The airbag inflation level will be adjusted to provide softer triggering for children; hence, avoid injuries due to strong inflation of the airbag.

In addition to depending on *weight sensors* for adjusting airbag inflation, *seat position sensors* can also be used. A passenger's seat positioned far forward indicates that the person will be in a very close proximity to the airbag; hence, strong inflation may lead to severe injuries. These position sensors can be used to detect the position of the passenger's seat and adjust the airbag inflation accordingly.

6) Positioning/Navigation Systems

The **Global Positioning System (GPS)** can be considered an example of a source for data. It is a satellite-based navigation system that provides position and time information as long as there is an unobstructed line-of-sight with GPS satellites. GPS cannot be classified as a sensing element but it should be mentioned here as a source of measured data.

In addition to its navigational services, GPS readings can be utilized by other systems in a vehicle to support their operations. For example, the **Navigation-Brake Assist** system cooperates with the navigation system to get information about stop sign locations and assist in applying braking on time.

B. Sensors for Diagnostics

This category of in-vehicle sensors is used for providing on-board diagnostic services for drivers for detecting components malfunction and avoiding any further breakdowns or damages. In addition to displaying alerts for drivers, the on-board diagnosis system keeps track of these measures to use them in the next Diagnosis Service check to save time finding out the problems. As well, the diagnosis system can include a reporting capability for remote diagnosis.

Most of the in-vehicle diagnostic sensors are deployed in the powertrain area for monitoring the status and functioning of vehicles' mechanical parts and engine. As well, some of them can be used for diagnosing the chassis and body of the vehicle. The categories of diagnostic sensors are shown in Figure 4.

1) Sensors for Powertrain Diagnostics

A *position* sensor used for monitoring the fuel level is an example of this category of diagnostic sensors. Other examples are the *chemical* sensors used for checking fluids quality.

Temperature sensors as well can be used for the sake of diagnostics. They can be used for monitoring the temperature of fluids and air for handling over-temperature conditions either by electronics shutdown or triggering a coolant/conditioning system.

Gas composition sensors can be used for monitoring engine combustion and exhaust to make sure that vehicle-generated pollutants are as little as possible. Feedback is provided to the engine control system to adjust its performance if possible. As well, the driver will be informed that a service/repair is needed.

2)   Sensors for Chassis Diagnostics

An example of this category of sensors is the *speed* sensor used for monitoring the wheel speed. Such speed measurements can be used as inputs for monitoring the operation of the antilock brake and traction control systems.

Another example is the *pressure* sensor used for monitoring tires pressure. In 2007, the U.S. government obliged that each new car should have a Tire Pressure Monitoring System (TPMS) comprised of a pressure sensor mounted on each wheel. This regulation was issued as a safety standard and was driven by the non-negligible number of tire-caused vehicle fatalities [1].

In addition to monitoring a tire pressure, its temperature can be monitored too by a *temperature sensor* to avoid tires blowouts [3].

3)   Sensors for Body Diagnostics

Sensors can be used inside the vehicle's compartment (in-cabin sensors) for diagnosing the compartment's electronics and ambience.

An example is the sensor used for diagnosing the airbags malfunction to take actions to avoid any problems with its operation which may lead to severe fatalities.
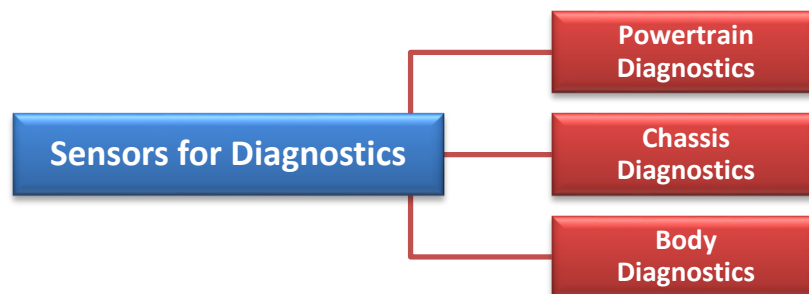

Figure 4 Categories of diagnostic sensors.

C. Sensors for Convenience

For supporting comfort and convenience applications for drivers and passengers, a number of sensors of different types are installed in the vehicle for this regard. Most of these sensors are deployed inside the vehicle compartment to provide direct convenience services for its occupants, while others are deployed for providing driving assistance and efficiency for drivers. This categorization of convenience sensors is shown in Figure 5 and discussed as follows.

1) In-Cabin Convenience Sensors

A *gas composition* sensor can be used for checking in-cabin air quality. This sensor monitors the air intake of the HVAC system for detecting undesirable gases and adjusts the system accordingly by shutting off the intake and recirculating in-cabin air back to the outside [1].

Humidity sensors and *temperature* sensors can be used for measuring in-cabin humidity level and temperature, respectively, and adjusting the HVAC system settings.

2) Driving Convenience Sensors

A *position* sensor is used for measuring the angular position of the steering wheel. The feedback of this sensor can be used as an input to driving convenience systems like the **Parking Assist** and **Steerable Headlights** systems.

A *torque* sensor is used to measure the steering wheel torque and provide feedback to the **Electric Power Steering (EPS)** system. EPS was introduced to provide assistance to drivers by using an electric motor that reduces driving effort and provides steering assist.

In automatic dimming mirrors, *image sensors* are mounted on the rear-view mirror to detect light from approaching vehicles. When glare is detected, the mirror is automatically dimmed to a level suitable for glare elimination. This feature is introduced to the side-view mirrors as well.

Rain sensors can be used to detect rain, trigger windshield wipers, and adjust wipers' speed according to the amount of rainfall. *Fogging prevention* sensors are used to prevent fogging of the windshield glass. It consists of three sensing elements for sensing in-cabin temperature, windshield glass temperature, and cabin humidity. The fogging sensor feedback is used for adjusting the HVAC system to maintain the interior temperature higher than the windshield glass temperature; hence, prevent windshield fogging.

Distance sensors can support many applications that are considered for both safety and convenience. One of these applications is the stop-and-go system. In addition to maintaining a safety distance between a vehicle and the one ahead to avoid crashes, the stop-and-go system provides convenience for drivers by automating driving and controlling the vehicle in traffic jams and dense environments. ACC is another example of these applications. By automating braking and throttling, ACC reduces fatigue and stress imposed on drivers especially with long drives.
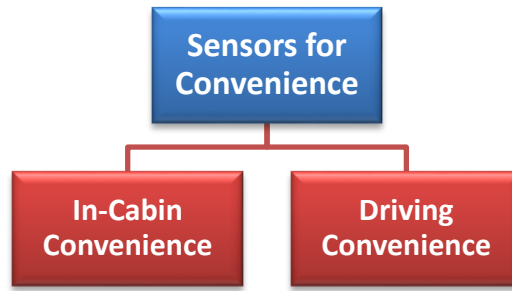
Figure 5 Categorization of convenience sensors.

D. Sensors for Environment Monitoring

This category of in-vehicle sensors is responsible for monitoring the surrounding environment and its conditions. It aims at providing ITS services in the form of alerts/warnings about hazards on roads or reported information about traffic, road and weather conditions. These services can be for the benefit of drivers only with the detected information displayed on the on-board unit (OBU) or, when possible, it can be reported to third parties, as discussed later.

Some of these sensors are deployed specifically for the sake of environment monitoring and others are sensors that are deployed for other applications but their reported data can be utilized to reflect some environmental conditions.

For example, a *pressure* sensor can be installed for measuring the ambient barometric pressure and report these data to weather centers. As well, readings of *temperature* sensors that may be already deployed for the sake of adjusting the HVAC system can be utilized and reported to weather centers for real-time weather reports.

Another example is the use of *distance* sensors to detect traffic conditions. A vehicle can detect the distance to its preceding vehicle which can be an indicator of the traffic congestion level at that road.

As well, in-vehicle *cameras* can be utilized for capturing street images that can be beneficial for many detection/tracking applications.

Yamada et al. [6] proposed a system for the detection of wet-road conditions based on images captured by *cameras* on the rear view mirror of a vehicle. Their proposed system employs image analysis for extracting features related to water and snow on the road. Water is recognized on the road based on polarization properties from images while snow is recognized by texture analysis.

Gailius et al. [7] proposed a system that detects ice on a road by analyzing tire-to-road friction ultrasonic noise. The system comprises a transducer installed to the front right wheel after the front bumper to record acoustic vibrations.

III. VEHICLE AS A MOBILE SENSOR (VAAMS) – CONCEPT, APPLICATIONS, AND PLATFORMS

Urban/public sensing is currently gaining more interest with the benefits it provides represented in global information sharing and access. For many years, the focus in public sensing was on making use of sensors available in mobile phones and handheld devices for sensing the surroundings and making use of the communication interfaces in these devices for sharing data of interest with others, which has opened doors to many new application domains.

With the increasing number of sensors in a vehicle and the inclusion of communication interfaces that supported vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, vehicles have become data resource candidates for the outside world, not only for the use of vehicles' occupants. Vehicle as a resource of sensory data has more advantages than the other mobile devices that have been utilized for the sake of urban sensing: 1) vehicles have no constraints with their power source which has been considered a major obstacle for the wide use of mobile devices, 2) vehicles can be easily equipped with powerful processing capabilities which widen the scope of supported applications, 3) sufficient data storage units can be installed on vehicles, on the contrary to the limited data storage in mobile devices [8]. All these features can enhance the use of a vehicle as a mobile sensor and formulate the concept of **VaaMS**.

Lots of applications and platforms are being proposed to make use of the advantages of using vehicles as data resources. In these applications, vehicles are used to sense/monitor the surrounding environment, generate data, and store them for further relaying- either without processing or after processing to search for certain data of interest. Sensed data, or processed sensed data, can be reported to third parties through the Internet or vehicle-to-any (V2X) communications. These third parties can be data servers for data centres that can publish/offer these data for public or commercial services, or they can be other mobile users/drivers.

Some of these services can be provided by street/highway sensors, but measuring them by vehicles is more advantageous. Instead of wasting money and time deploying such specifically-installed sensors, in-vehicle sensors can provide the same services with no extra deployment or maintenance cost, saving time of deployment, and provide a great level of convenience for interested data retrievers. In addition, use of already-there in-vehicle sensors has an extra advantage on their street/highway counterparts; vehicles are mobile, thus, they can cover greater areas of interest compared to the other fixed sensors. Therefore, even if the data collectors will pay for vehicles' owners to make use of their vehicles' sensors, the number of cooperating vehicles can be limited and vehicles can be efficiently chosen to cover the intended area based on their headings.

Examples of some potential applications of the use of a vehicle as a resource of sensing are the aforementioned environment monitoring applications. Weather status, street images, and road

and traffic conditions can be detected by the use of in-vehicle sensors and then they can be relayed to third parties as mentioned earlier. These sensed data can be processed locally by each vehicle (distributed processing) or at the collecting centre premise (central processing), then, they can be published by means of radio broadcasts, internet-based applications, street/highway displays, or micro-blogging.

Figure 6 summarizes the concept of **VaaMS** along with its involved components.

An example of proposed urban vehicular sensing platforms is the **MobEyes** platform [9]. **MobEyes** aims at utilizing vehicles for urban sensing by monitoring their surroundings, recognizing objects, storing data about them, and advertising their data by generating representative meta-data and periodically sharing them with vehicles in their vicinity. If other vehicles are interested in the advertised data, they can send queries to the data-holding vehicles to get their stored data. An example of the use of **MobEyes** is having vehicles recognize others' license plate numbers, storing them, and broadcasting representing meta-data. Other mobile agents (ex. police patrol cars) can harvest the sensed data by sending queries to retrieve the recognized numbers for the sake of, for example, finding stolen vehicles.

Another example is the Vehicular Information Transport Protocol (**VITP**) [10] that supports location-aware services utilizing in-vehicle sensors. In **VITP**, vehicles can send queries to retrieve information from areas of interest and replies can be routed back from vehicles in these areas. Both queries and replies delivery are done via intermediate vehicles. An example of a **VITP** operation is when a vehicle needs to know the average vehicles' speed near a gas station.
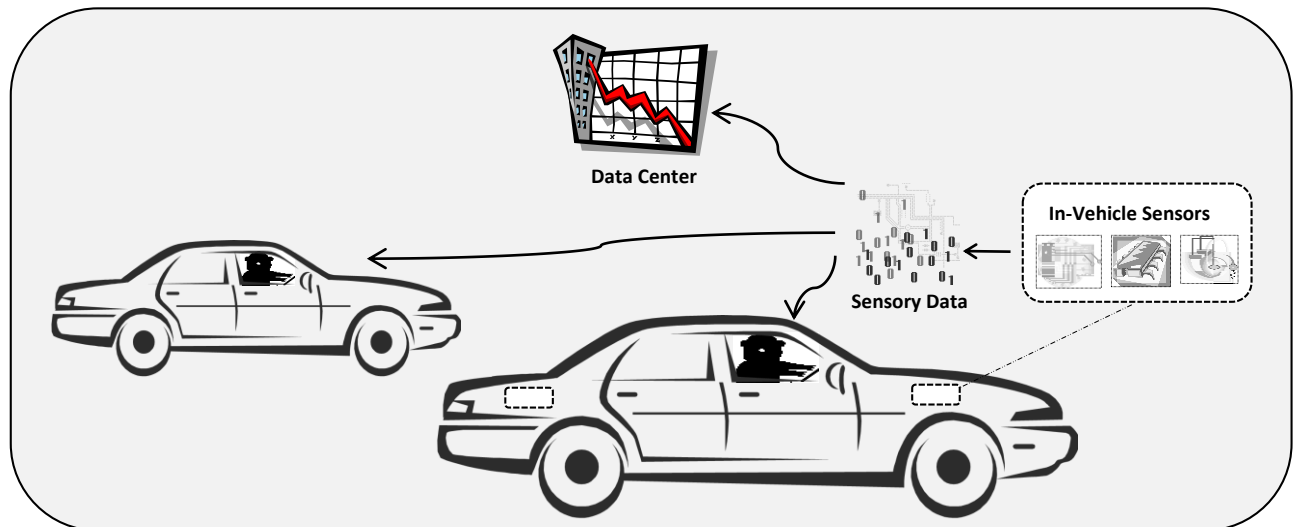

Figure 6 The concept of VaaMS. The sensory data obtained from in-vehicle sensors can be of benefit to the vehicle's driver, other vehicles on road, or to a third party (ex. a data center).

Unlike the above-mentioned platforms which depend on V2V communication for their operations, **CarTel** [11] is an Internet-based one. In **CarTel**, vehicles collect sensor data, process it locally, and send it to database servers through the Internet for further analysis and publishing. **CarTel** is considered a delay-tolerant platform as it depends on opportunistic connectivity for data delivery.

Similar to **CarTel** in delivering data through the Internet and depending on opportunistic connectivity, the Pothole Patrol (**P^2**) system [12] aims at monitoring road surfaces to detect potholes. It consists of three-axis acceleration sensors and a GPS device to assess vibrations caused by potholes and report the specific locations of these potholes. **P^2** is one of the earliest systems targeting road condition monitoring and, with the high benefits of these systems; many other platforms are proposed for this regard. CarMote [13] is a more recent example that supports a variety of techniques to extract road features.

IV. Supporting Communication Technologies

A. Intra-Vehicle Communication Technologies

To provide its functions as a resource of sensing, a vehicle needs to have the sensed data generated by its in-vehicle sensors accessible and utilized by the aforementioned systems/applications, the on-board unit, and the inter-vehicle communication interfaces.

Each of the in-vehicle automotive systems is implemented as an embedded system with a controller and a number of sensors and actuators that support the required operation of the system. This controller is known as the Electronic Control Unit (ECU). Each ECU consists of a processor[3], memory, and communication interfaces. An ECU is considered a closed-loop system that manages data retrieved by sensors, processes and analyzes thid data, outputs signals based on decisions to be taken, and activates actuators to adjust the operation of the corresponding automotive system.

For connecting such sensors and actuators to ECUs, a vehicle adopts four automotive communication protocols; the Local Interconnect Network (LIN), Controller Area Network (CAN), Media Oriented Systems Transport (MOST), and the most recent FlexRay.

1) Local Interconnect Network (LIN)

The LIN bus standard was introduced in 1999 by the LIN-consortium. LIN is a slow serial bus system that is used to integrate sensors and actuators and connect them to ECUs in automotive systems. It supports speeds up to 20 Kbps [14].

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[3] It is usually a microcontroller.

LIN is considered a gateway to a CAN bus. Each vehicle may have many LIN buses that support the different automotive systems. These LIN buses are independent with no direct interconnection among them [15].

2) Controller Area Network (CAN)

In 1983, Bosch started working on the development of the CAN standard that was officially released in 1986 [16]. The goal for developing CAN was having a robust serial bus for connecting devices in real-time control systems [15]. Later, CAN was widely deployed to support the implementation of the in-vehicle automotive systems.

CAN connects the different ECUs in a vehicle to provide interaction among them and integrate their outputs. Since it supports many LIN buses (each ECU has its own LIN bus), it has higher data rate than the LIN bus system. It can support up to 1 Mbps.

3) FlexRay

As the number of automotive systems in a vehicle is growing, the number of supporting ECUs is increasing too. The CAN communication capabilities and the 1 Mbps bit rate is getting not adequate for supporting communications of such growing number of ECUs. Hence, there was a need to come up a with a more advanced communication solution to support and enable the implementation of highly demanding automotive systems [17].

FlexRay [18] has been developed by the FlexRay Consortium, a cooperation of leading companies in the automotive industry, to be a high-speed serial bus that provides fault-tolerance and adequate bit rates for the advanced automotive systems such as X-by-Wire[4] systems [19]. It supports data rates up to 10 Mbps. FlexRay has been designed not to replace the old communication buses, but to work in conjunction with them [15].

4) Media Oriented Systems Transport (MOST)

With the high demands for in-vehicle infotainment, there was a need for a higher speed technology to support such real-time systems requirements. MOST [20] was initiated in 1998 with expected speeds of 150 Mbps that was achieved by the MOST150 version in 2007. The first version was MOST25 which had a maximum data rate of 25 Mbps. MOST is considered the key enabler for multimedia and infotainment systems.

Unlike the aforementioned communication technologies, MOST is using plastic optical fibers to provide the higher speeds but with higher costs.

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[4] X-by-Wire systems replace the automotive mechanical control systems with electronic control systems with interfaces to the drivers. Examples are the steer-by-wire and brake-by-wire systems.

5) Intra-vehicle Wireless Communication

Although wireless communication usually comes with great advantages represented in reduced cost[5] and ease of deployment and use, it is so far not proved to be an efficient communication means for intra-vehicle communications. One of the most important reasons for this inefficiency is the broadcast nature of wireless communication. Exchanging data wirelessly in a vehicle may make the vehicle vulnerable to security attacks especially for those technologies that make use of the ISM band. As well, wireless communication is subject to high interference levels and long set-up delays which are not suitable for the critical safety applications. For these reasons, the wireline communication technologies are the dominant ones for intra-vehicle communications.

Although wireless communication is not suitable for the critical applications, there were some trials to use it for some other in-vehicle applications. In [21], Y. Chen and L. Chen demonstrated that the Bluetooth technology can be a possible candidate for the non-safety-critical applications such as vehicle diagnosis and software updates.

As a dominant technology for the wireless sensor networks applications, many experiments are being conducted to test the viability of the use of Zigbee for intra-vehicle sensor networks [22]. Zigbee is expected to be a good candidate for the non-critical monitoring and control applications.

Finally, the IEEE 802.15.3a Ultra-Wide Band (UWB) emerging wireless technology can be a competitor to the MOST wireline counterpart for providing multimedia applications with its high speeds (can be hundreds of Mbps) [17].

B. Inter-Vehicle Communication Technologies

Many wireless communication technologies can be adopted for getting the data out of the vehicle and deliver it to other vehicles or third parties. Examples include the specially-developed Wireless Access for Vehicular Environment (WAVE) standard which is based on the IEEE 802.11p standard and the Dedicated Short Range Communication (DSRC). Another communication facility that is considered a bridge for anywhere connectivity for vehicles is the CALM technology standard which stands for Communication Access for Land Mobiles. CALM will support having an integrated communication unit that provides many air interfaces that include 2G/3G cellular technologies, Infrared, Millimeter-wave, Mobile wireless broadband (HC-SDMA, 802.16e, and 802.20), Satellite, and DSRC. In addition, some Zigbee communication modules are designed to support vehicular communication. As well, the use of Visible Light Communication (VLC) in the vehicular environment is now gaining high interest. Detailed discussions of these communication technologies are out of the paper scope but readers can refer to [23] for an overview.

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[5] No cables to be installed.

V.   CONCLUSIONS

In this paper, we introduced Vehicle as a Mobile Sensor (VaaMS) with the objective of providing a comprehensive view about how intelligent vehicles can be considered a significant resource of sensing data. A vehicle as a mobile sensor can be a major key enabler of urban sensing with great advantages on its counterparts. We showed that services provided by sensor-equipped vehicles can be of benefit not only to their drivers/occupants but also to other vehicles on the road and third parties. Besides, we presented a new categorization of in-vehicle sensors that categorizes them based on their application domains along with some representative sensors and their relative ITS applications.

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