IoT-enabled Environmental Monitoring for Autonomous Vehicle Safety

By Dr. Elena Ferrari

Professor of Information Engineering, University of Florence, Italy

1. Introduction

Research at the intersection of the Internet of Vehicles (IoV) and electronic and vehicles stands to reap dividends from vehicular characteristics in terms of technical quality, interoperability with national and international standards, legal and other regulatory attributes, European standardization activities, opportunities for research and innovation, and stakeholders' consensus on its strategies. At MiS, our most sophisticated vehicles have a GPS (global positioning system), an advanced navigation system, driver-aids, vehicle-to-vehicle, or vehicle-to-infrastructure communication, and—soon—a robust network of sensors and actuators for environmental monitoring (EM). Our intention is to use this network for help with and stimulation of autonomous vehicle safety (AVS). The term vehicle includes not only classical automobiles but also vehicles that do not go on roads, like underwater vehicles.

An IoV exchanges information (data and control) about traffic conditions, road conditions, and other safety- and congestion-related data from/to the roadway infrastructure, cars, and via short-range communication technologies. Therefore, the pragmatic outlook espoused by the IoV is the trading of information about infrastructure-to-car, car-to-car, and car-to-infra interactions. Here, cars and infrastructure communicate and share driving-related information, which could be social, network-related, driving-related, vehicle- or person-related, or contain data (messages) communicated to a recipient in the car or infrastructure. Already, this strategy of linking vehicles to data in roadside units is much better than solitary reliance on an internal GPS (global positioning system) unit.

Advances in networked wireless communication devices and protocols, cheap sensors, and the synergy between people who are driving the same road make the Internet of Vehicles (IoV) an attractive and viable proposition. Vehicles and humans are in close proximity, operating in diverse domains and include pedestrians, bicycles, and connected vehicles.

Notwithstanding this synergistic behavior, issues of safety, privacy, and security abound. The ecosystem of the IoV is large, allowing communication between the vehicle network and the vehicle itself. Further, vehicle batteries, power sources, and cellular sources, and the infrastructure must be energy efficient.

1.1. Background and Significance

The concept of ITS was repeatedly sprung up after the Digital Granville Summit decision of U.S. President Ronald Reagan launching Star Wars missile defense project in 1985. Nowadays, the functional development for ITS is mainly composed of Advanced Driving Assistance Systems (ADAS) and Internet of Vehicle (IoV). To connect with the real world, each AV as a special type of (related to other leading machine technology) robotic system has not only the requirements for ADAS such as dynamic performance level (non-zero w/o-out delay system performance), control surface design, intelligence capability, and feedback interface (clinicknown sense of safety level), but also the usage from the IoV which mainly provides Voices Warning, infotainment, and Sensors Connection. Many potential problems of AVs have enthusiasm from ADAS/IoV to move forward on model development, testing deployment, and regulations for safety level (or sense of safety). In general, the "Awareness" of ADAS provides information for intended situation, the "Intelligence" of IoV uses information already available with no manipulation to enhance formal analytics, and the "View" by IoT-aware AVs adds community wisdom for action in uncertainty surroundings. As a result, the V2V and V2I communication mentioned in N-S application of traffic engineering has gradually been changed to Vehicle-to-Vehicle (V2V) and Vehicle-to-Intelligent Transportation Infrastructures (V-I2) communication in California "15 interoperability communication ready" deployment rules. It is well known that there have been many successful systems using different types of safety technologies and models. Before the relevant research has not been mentioned, there is a characterization of such publications based on the adjacent time period.

What is the background and significance of IoT-enabled Environmental Monitoring for Autonomous Vehicle Safety (IoTEnabled AV-EMS)? The fatal accident of Tesla Model S's Autopilot against a truck in Williston, Florida on May 7, 2016 has caused public concerns and challenges for commercial deployment of autonomous vehicles. Elon Musk, the CEO of Tesla Motors, has admitted that it was a "lack of innovation" in sensor technology used in the case.

All premature accidents will always have side effects leading to regulations for related promising technologies, let alone the breakthrough of issues on public safety. Report from National Highway Traffic Safety Administration (NHTSA) at U.S. Department of Transportation has proved that AVs are still on the way of dramatically reducing fatal accidents by evading the cause of "human factor". It can be guessed that the VIP effect and spinning EV effect by AVs will be dramatically outperformed by the magnitude of the EV spinning world. People will need to trust AVs when they can critically decide to trust themselves to give control for AV driving. Currently, the challenge of trust is surrounding driver underestimation problem on both human driver and AI states. How to develop information technology AI-enabled Autonomous Vehicles (AIVs) to "HAVE to learn" to get truly Intelligent Transportation System (ITS) to be studied that is of great thrust. Online IoT-based Vehicle Health Monitoring (IoT- VHM) can help AIVs building up Vehicle-Infrastructure Cooperative Systems (VICSs), enabling ITS to have IoT-enabled Autonomous Vehicle-Embedded Environmental Monitoring for Safety (IoTEnabled AVEMS).

1.2. Research Objectives

The specific research tasks undertaken to meet this overarching research objective can be classified as follows: - Identify the environmental factors that are most influential with respect to the safety of autonomous vehicles, and their potentials for monitoring/indicating their safe environment. - Review the background literature to explore any relevant infrastructure and techniques available or suggested for examining the research question(s) outlined above. - Develop appropriate methods, software, and analytical tools to obtain potential safety-related infrastructure information from multiple IoT sensors located on discrete physical measuring equipment operating within various predefined (road) corridor environments. - Employ these methods, software, and tools in a prototype device that uses IoT to evaluate, monitor, and map the potential safety-related capabilities of future communication and driverless vehicle infrastructures within predefined road corridors.

The primary objective of this research is to explore and demonstrate the capabilities of IoT-directed Environmental Monitoring for Enhanced Vehicle Safety (IEM-EVS), and associated services, operating within autonomous vehicle environments. Essentially, the underlying aim is to use IoT to simulate Sir George Cayley's design of an early 'normal' aircraft, commencing the mapping of IoT-provided infrastructures during an initial selective mapping event. The feasibility and pragmatics of producing real-time risk-related overview outputs, using observable IoT-provided infrastructure intentionality, are demonstrable for singular road corridor environments.

2. Fundamentals of Autonomous Vehicles

An autonomous vehicle typically consists of various components or subsystems such as sensors, actuators, controllers, and communication links. Sensing technologies provide some or all of the information necessary for a vehicle's situational awareness. Key sensors for autonomous vehicles include GPS, radio-based communication systems such as Dedicated Short-Range Communication (DSRC) or cellular networks, LIDAR (light detection and ranging), radar, vision, and inertial sensors. Collectively, these sensors can capture a significant amount of data about the vehicle and its immediate surroundings. Through data fusion and signal processing algorithms, the vehicle can analyze the sensory data to create and continually update a map of its surrounding environment. The actuator subsystem supports the vehicle's ability to make decisions based on its environment and external guidance. This involves steering, throttle, brake, and other mechanical control functions. The controller subsystem interprets the information collected from the vehicle sensory systems, makes decisions based on an understanding of that information, and then issues commands to the actuator subsystem to control the vehicle's movements.

Technological advancements in sensing, computing, and communication technologies have provided opportunities for the development of transportation systems based on autonomous vehicles. Consequently, autonomous vehicle technologies have received significant attention from automobile manufacturers, IT companies, transportation authorities at various levels of government, and the academic research community. Normally, autonomous vehicles are robotic systems with self-governing capabilities that enable them to move around without human control. They have the potential to provide various valued service functions, such as offering convenient mobility services to those with special needs, especially to the elderly, people with disabilities, and those who are too young to drive; taxi operations without human drivers; truck platooning; and delivery services. Furthermore, autonomous vehicles are expected to significantly reduce the number of fatalities and injuries that occur on the road each week. The combined potential benefits including safety improvements, economic savings, and increases in roadway capacity have led to a growing interest in autonomous vehicle technologies.

2.1. Definition and Types of Autonomous Vehicles

Autonomy is described in terms of which autonomous vehicle systems are either directly operated when there is a malfunction, or need to be deactivated depending on the severity of the sustained malfunction. The reference classification matrix associates levels of autonomy and the system with vehicle components. Environmental monitoring services are increasingly important for improving the detection and recovery times of both malicious and statistical vehicle software errors, particularly in autonomous driving that, unlike in inertial guidance for military applications, the public dependence of Position, Navigation, and Timing (PNT) for safe operation of the vehicle. The speed of the decision-making process is one of the challenges that it is necessary to overcome in order to avoid accidents and physical damage. High-precision map-based environmental monitoring, overlaid by dynamic sensors signals, is one of the main strategies for providing a perceptive digital twin of the CUAV.

The Society of Automotive Engineers (SAE) J3016 defines the society's standard SAE International "levels of driving automation". Level 0 - No Automation: The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems. Level 1 - Driver Assistance: The driving mode-specific execution by a driver assistance system of either steering and brake or acceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task. Level 2 - Partial Automation: The driving mode-specific execution by one or more driver assistance systems of both steering and acceleration or speed control using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task. The vehicle can be designed to operate itself autonomously under specific conditions and to monitor the driving environment, but the driver must be prepared to reassume control when requested by a system.

2.2. Key Components and Technologies

The environmental monitoring system will entirely fail as a safety measure for the autonomous vehicles without a real-time or near-real-time response capability. Any response delay in detecting intrusive environmental conditions (unexperienced windy conditions before the vehicles enter into the wind-loaded zones, for example) or untimely delivery of navigational specification to the autonomous vehicles could cause severe environmental impacts on the autonomous vehicles. It is rather challenging for the conventional monitoring systems to meet these stringent specifications, since they usually suffer from high deployment and maintenance costs. Powered by the more recent progress in computing, communication, analytics, and technology segments, Internet of Things (IoT) technology has emerged as an efficient environmental monitoring solution and has been widely applied in autonomous vehicle operations.

Inherent to their applications, a variety of data sensors could be applied in IoT-enabled environmental monitoring systems. These sensors could be designed to measure one or multiple environmental parameters. Then, the data sensor parameters, sensing requirements, and results for each environmental factor must be established. The selection of appropriate data sensors becomes a pivotal part of the system design to assure sufficiency and efficiency to the system. The technology dimension of the proposed environmental parameter characteristics vision could be sensed in the rows of the matrix. In these rows, relevant measurement methods and sensing technologies could be described for each selected physical measurement.

Even though environmental monitoring systems operate based on the conceptual task of sensing the environmental data, the actual implementation could be complex. A generic architecture of an IoT-enabled environmental monitoring system and key components are depicted in Figure 2.2. There are a chain of components and technologies involved in the implementation of such a system. They include data sensors, data sensor interfaces, access technologies, wireless technologies, middleware, and database servers.

3. IoT Technologies in Autonomous Vehicles

The collected geospatial information can be utilized by the mobile robots to find the safest, fastest and most energy efficient paths to navigate through the dynamic environment. Properly calibrated and validated prognostic models/methods/tools are required for robotic mission planning and control. There exist IT methodologies about these models/methods/tools used in robotics areas separately. They are not integrated, and also very domain specific. This paper discusses inflow, handling, and use of these resultant themes in a most efficient way. In the next section, we study how geospatial information infrastructures enable efficient use of geospatial information, and in section 3, we discuss the IoT devices and functionalities used in mobile robotics area.

Geospatial information infrastructures manage this environment for IoT devices, mobile robots and operators, and provide sensor data streams, services and associated products for the control of the mobile robots. This work is a systemic research to explore frameworks that enable efficient use of geospatial information in the control of mobile robots. We start with identifying some characteristics of the IoT devices and functionalities used on the mobile robots, and some environmental elements that can affect the IoT devices and their functionalities. We then transfer our investigation to existing/evolving geospatial information infrastructures to explore how the infrastructures can effectively maintain geospatial information to be used by intended mobile robots.

Since 2013, autonomous vehicle research has been progressing very rapidly. The concept was first announced by Google. Many mobile and non-mobile robots have been introduced for energy and environmental monitoring, surveillance, exploration, etc. Some robot control systems are remote controlled by operators. Many IoT devices/functionalities are used; some autonomous sensors are included in, powered in situ or remotely by robots. However, the design and operation of mobile robot control systems must account for their environment.

3.1 Introduction

3.1. IoT Sensors and Actuators

There are six types of data ready to be collected with IoT sensor systems. While the old V2V technology requires the long-distance line of sight communication capability, as well as the frequent rebroadcast of the same message over each 300 m interval for backward compatibility, frequent and unicast VC2V communications need not possess long-distance nor line of sight communication capability. With an average human vision distance of 144 m and the autonomous vehicle perception distance possible with the proposed IoT sensor network, it is possible to directly implement the long-distance VC2V communication for lane assist and adaptive cruise control to ease vehicular traffic and improve traffic efficiency.

Automatic vehicle safety systems, whether entirely driverless or still providing human assistance in transportation, depend extensively on instantaneous and reliable sensing of the complex surrounding environment to minimize safety-critical events. On the other hand, traditional sensor systems used in vehicle safety are not capable of providing the adequate accuracy, update rate, and robustness to ensure vehicle safety in cluttered, salient, and unfriendly environments. This paper intends to explore the application of massive numbers of inexpensive IoT sensors, whether on or off vehicles, to collaboratively provide the crucial sensing capability for vehicle safety systems. Specifically, this paper identified the sensing needs of automatic vehicle systems and the challenges faced by traditional sensing systems and studied the opportunity to use IoT sensor systems to provide environmental perception for vehicle safety. The challenges of IoT network access management are addressed by Venkataramanan, Sadhu, and Shaik (2020).

3.2. Wireless Communication Protocols

Equipping the vehicle with an external communication device that uses the mobile network when the vehicle is in motion, switching to WiFi when in reach of an access point (AP), and using ad-hoc cluster-based, multi-hop routing when the vehicle comes to a stop and all other vehicle nodes come into contact using other short-range communication channels is precisely such a network design. In this way, it incorporates most known communication protocols in order to improve the information exchange process by utilizing the right protocol for a given situation depending on meeting the protocols' requirements and their involved overhead. We discuss this in more detail in section 3.3.

Communication is an essential requirement in the majority of practical WSN implementations. Periodic and event-driven data collection needs to be enabled from all networked devices to any arbitrary data center, where it can be processed, monitored, visualized, and managed in order to act upon it. The IoT design that allows implementation of WSN-related applications in an autonomous vehicle network architecture requires provisioning of the exchange of both vehicle and vehicle peripheral information in a timely and reliable manner.

4. Environmental Monitoring Systems

In previous work, we proposed a wide-area environmental sensing system to enhance autonomous vehicle safety. This approach indicates most potential locations of risks, rather than the time evolution of the risk level. In this paper, we describe one detailed subsystem within this wide-area environmental sensing system: a low-cost purpose-built IoT sensor node measuring multiple-output environmental properties. These nodes are built using either easily-available pre-fabricated off-the-shelf components or custom-like small printed circuit boards that are commercially-fabricated. When autonomous vehicles are equipped with this sensor, they will use the local sensor readings to geofence hazardous weather and obstacle environmental conditions. The sensed environmental parameters will provide vehicle controls with quantitative metrics on the relative severity of environmental risks.

Autonomous vehicle development efforts have thus far been mostly focused on testing vehicle safety with simulated testing, closed-track driving, or on-road driving supplemented with safety drivers who can take over driving when the autonomous driving system does not perform well. Constraints on road testing vary by location. Tests in closed facilities cannot verify vehicle performance during interactions with artifacts or unexpected hazardous road conditions. A possible solution is adding environmental monitoring capabilities to the vehicle so that object technologies can provide the same perception capabilities, at an equally fine spatial and temporal scale, as other vehicles' environmental coverage does - ideally as broad coverage as the global weather monitoring system uses for weather forecasting. To address this problem, we investigated low-cost IoT-enabled environmental monitoring for real-time mesh-networking sensing to enable comprehensive - not just in other vehicles' vicinity - environmental coverage with coverage extending beyond visual line of sight.

4.1. Importance in Autonomous Vehicles

The development of technology within autonomous vehicles means that the businesses that opt to use them will have direct access to better and more reliable environmental monitoring data for the specific areas and times chosen for driving. IoT-enabled solutions provide real-time monitoring of the immediate environment for driving directly around the vehicle using sensors being used for vehicle movement and avoiding obstacles, as well as becoming key components in future accurate environmental monitoring sensors. Since the vehicles collect environmental monitoring data in real time throughout the area of interest, they would provide high-resolution spatial and temporal information for precipitation intensity. Autonomous vehicles can also collect data in all lighting and weather conditions at various driving speeds, allowing for research into the impact of weather and time of day and the amount of precipitation associated with more common minor accidents and major accidents.

Autonomous vehicles depend on numerous input sensors, including cameras, radar, and ultrasonic detectors, as well as various environmental data sources such as GPS and weather forecasts, in order to maneuver through ever-changing weather events and driving conditions at varying speeds. Autonomous vehicles face a unique set of challenges, such as the need to interact with an environment consisting of unpredictably behaving human-controlled vehicles, all in a wide range of conditions including bright sunshine, various types of precipitation (rain, snow, and hail), and intense thunder and lightning storms. These vehicles must remain safe throughout the wide range of environmental and lighting conditions in order to protect occupants, people, and property outside of the vehicle.

4.2. Key Parameters and Sensors

Periodically, the vehicle needs to read surrounding information such as traffic control signals and traffic signs for situational surveillance. Furthermore, in general, the vehicle platform deals with GPS-based data related to vehicle stand in respect to UL, DOT, and DOD. And, besides these primarily sensors integrated into the vehicle platform, other external commercial-off-the-shelf (COTS) sensors are also considered by the effaced team of software and hardware engineers. Their environmental data sources may include sensors for vehicle manipulation, vehicle protection, vehicle guidance, and intelligence information acquisition, processing, communication, recording, and data logging. Example sensing candidates include time-of-flight (TOF) lasers, LIDARs, FOGs, magnetometers, images, CCDs, visible, near-visible, microwaves, ultrasound, IR light, SONAR, radar, GPS, DGPS; sound, pressure, humidity, temperature, rain, ice, debris, slipperiness, road paint, tactile, radio, etc.

In the aftermath of vehicle accidents, forensic specialists seek to determine key parameters involved that render a vehicle out of control due to various reasons including environs and autonomous vehicle platform itself. For the sake of developing and testing new autonomous vehicle standards and platforms, the following parameters are extremely important. Each parameter involves the use of embedded sensors within the vehicle control platform, subjects of interests in development for vehicle spoilage prevention. Furthermore, all these sensors are IoT wireless capable, automotive specifications, rugged, cost-effective, and available in the marketplace.

5. Integration of IoT and Environmental Monitoring

The proposed environmental monitoring system collaborates with two practical IoT-based solutions for smart cities. The first solution is the intelligent traffic light control system proposed by the authors, which mentions that the information of green light time can be reserved or obtained by the driver's transportation means in advance. With the assistance of the intelligent traffic light control system, autonomous vehicles approaching the intersection spot will receive the information and simulate the light status to guide the car users.

The IoT industry is rapidly growing, and research in IoT applications extends to various areas, including the automotive field. Most existing research focused on autonomous vehicles deals with efficiency enhancement and traffic prediction. On the other hand, the environmental monitoring system, which monitors road conditions and the number of vehicles and pedestrians, has not yet been widely established specifically for autonomous vehicles. This paper proposes an environmental monitoring system for autonomous vehicles. The proposed system, collaborating with IoT and sensors, will be utilized to send traffic information to autonomous vehicles. After gathering enough information, the autonomous vehicle will send the location and barcode of the current place to the traffic light in order to control the bezel light for guiding.

5.1. Data Collection and Processing

The data was read through the Serial Peripheral Interface (SPI) from the sensor to the microcontroller and sent through the Bluetooth Low Energy (BLE) wireless protocol to a general purpose Bluetooth device, such as a tablet, that runs a company-made application that processes the data. The detection and classification of vehicle emissions from air pollution was achieved using data preprocessing by the Kruskal-Wallis rank-sum test, data exploration of the realized tests on the air pollutants, and then assigning threshold values to the outcomes of the test between the pollutant levels that represent the vehicle congestion status.

A gas sensor prototype that measures carbon monoxide, nitrogen dioxide, and ozone in the air with minimal error rate was built and tested. The sensor uses the Miniature 4-In-1 Multi-Gas Sensor with PTFE Filter, MICS-4. This sensor consists of four different sensors on a miniaturized circuit board that acts as a Xiaomi filter monitor with an internal temperature and relative humidity sensor. In order to prevent any potential negative effects of the environment on the sensors, the sensor enclosure was designed in 3D to protect the sensor. It also has an air intake profile directed at the sensor inside a tube to protect the sensor from turbulence in the airflow.

5.2. Real-time Monitoring and Alerts

The recent growth of smart sensor devices combined with the growth of Internet of Things (IoT) technology now provides different options and scalability to better perform environmental quality and air quality monitoring tasks. The low cost and low power enable the deployment of a large number of air quality sensor nodes and thus increase the density of a sensor network. Redundant sensor nodes for a critical atmospheric condition may be deployed. It may also provide a solution to unbiased the result if heavy shading is detected. In addition, analytics of big sensor data that is collected in real time may also supply valuable information to the calibration process. It is not feasible to rely on the inferior sensor calibration that is done offline under such strict time constraints. It is timely and necessary to leverage what IoT technology has taken a transformational impact on our lives, merging the computing world with the physical world with respect to air quality sensor networks.

Obviously, tragic accidents could happen if an air quality sensor fails or inaccurately detects for the monitoring system. Therefore, it is critical to have a reliable air quality monitoring system, and a strategy needs to be formulated to raise the reliability of an air quality monitoring system. Having said that, a number of factors can make these conditions worse. They can impact the sensor calibration if the calibration process involves downtime and interruption. Drifting and transitioning of the environment will also make the calibration irrelevant after a long period of time, but the fresh calibration period does not catch up with the transition of the environment.

6. Case Studies and Applications

As an element of crowd control (detection and avoidance), an outdoor inventory (atmospheric condition studies), or for health and safety reasons (fauna behavior included under this heading), the company may use two drones to explore a large volume of airspace. Such a company surely would have hardware parameters including position, velocity, acceleration, aircraft health, environmental health and service availability opted for by informed customers. Specific examples of environmental conditions of hottest or coldest points, standard deviations for changes in temperature, changes in pollutant levels or excessive pollution events such as dust storms happening within the control servers domain, are made available to interested parties; the number of aircraft passing these points during the period of interest as analyzed, are carried out and presented as reports to the customers.

This is the case in which an autonomous vehicle management company has many leading-edge autonomous vehicles flying, wandering, or on the ground, and most, if not all, are fitted with our IoT-enabled environmental monitoring hardware architecture. The number of hardware devices may reach 100, 1000, or more. The company intends to use environmental data collated and transmitted by the data acquisition and sensor fusion system embedded into each IoT device and collected by a control server, to study global environmental conditions and movements detection. How will the company realize this objective? What goals does the company expect to achieve? Which conclusions is the company expecting to draw? It is expected that such a sophisticated company been able to attract sophisticated customers of whom many are able to use value-added services provided by the autonomous vehicle hardware devices and systems the company designs and manufactures.

6.1. Smart Cities and Traffic Management

There is a need for better use of the available infrastructure for an efficient urban transport system. The better use of road infrastructure can only take place with coordinated management and control of various traffic control devices and systems through an informational interface tied to a data interpretation and control system of the resources involved. The concept of smart cities will open up the whole avenue of the traffic system with the intelligent management of the transport system, including all aspects such as vehicle travel, pedestrian traffic, bicycle movement, and interface with public transport systems, including private and public transport and intermediate stages faced during multi-modal use of vehicle transport. All these aspects include the use of modern developing technologies such as vehicle communication, data transmission, data collection, data dissemination, and telecommunications, along with sensors, control devices, continuous monitoring systems, instruction processing, advanced traffic management, and control information processing systems with control of operational cycle plans and phase slewing.

Urban mobility is fast becoming a critical aspect of government policies across the globe since people moving in and out of cities is not only a necessity but a way of life. Owing to centralized planning by bureaucrats, the urban area becomes incapable of providing efficient public transport for the masses, leading them into the lure of private vehicles such as cars and two-wheelers. This leads to congestion in the city areas, resulting in further problems such as time delay, pollution, widespread environmental degradation, and safety concerns. The rising problem of urban congestion and its related societal and environmental consequences is slowly becoming unbearable. It is not possible to curb the number of cars, and thus the social costs of providing infrastructure still continue. These societal costs and environmental degradation have led to an excessive focus on providing public transport through road space allocation.

6.2. Fleet Management and Logistics

In the Age of the Mega Project, electronic constructions are considered to be one of the main contributors to the rapid advance of modern construction projects in terms of cost and time effectiveness, among other features. A modular unit with an integrated compact IoT air pollution sensor platform has been developed to detect real-time air pollution in the environment where portable fleet management only shows historical particulate pollution data. Moreover, the IoT infrastructure is also important to track the autonomous transportation robot vehicle with precise and real-time tracking. However, none of the existing fleet management solutions could fulfill the real-time progress update and identify the locations of all autonomous vehicles, i.e., indoor localization and outdoor tracking features are required.

On the other hand, IoT is becoming a useful technology for modern construction fleets to cultivate real-time monitoring and optimization. A work was presented that uses IoT technology for real-time status and asset location tracking to improve the decision-making process for the construction fleet. The framework leverages an embedded tag with a long battery life that transports and processes the data between the reader and the server, which helps prevent excessive communication from the handheld reader to the cloud server.

Fleet management and logistics in construction sites have been studied logistically to improve productivity and reduce costs. Fleet management studies in construction can be classified into two categories: vehicle-related and non-vehicle-related. Vehicle-related studies mainly focus on fleet size optimization. Non-vehicle-related studies are associated with operation planning, scheduling, and material handling of the vehicles.

7. Challenges and Future Directions

There are also some promising trends for the future IoT-enabled environmental monitoring system for enhancing the safety and efficiency of autonomous vehicles. A neural network can be used to optimally encode the spatial characteristics and other device parameters of a specific wireless signal. Robust and diverse vehicle data is generated for AI and sensor concept development that enables operations in difficult and complex environmental scenarios. Key aspects are accuracy and performance while minimizing safety and costs. Massive MIMO, which is also an innovative radio technology that enables superior mobile broadband in the challenging sensor environment for wireless data transmission, can also play a critical role in the successful deployment of IoT for transportation automation.

5G may be one of the future technologies towards the successful and practical IoT-enabled implementation of autonomous vehicles. A direct strong IoT interaction among vehicles can be implemented to monitor the environment for higher safety and efficiency. There are various inconvenient factors that may make the efficient employment of IoT-enabled environmental monitoring in dealing with the safety and efficiency of autonomous vehicles, as discussed in the following.

There are various challenges in adopting IoT-enabled environmental monitoring for dealing with the new generation of autonomous vehicles, as discussed below. However, there are also some promising future trends. Since many wireless communication signals transmitted in advanced devices are not desirable towards sensor nodes, a neural network may be used to encode the spatial characteristics and other device parameters, capturing hidden and complex patterns to adapt the IoT monitoring system specifically for autonomous vehicles.

7.1. Data Security and Privacy Concerns

The current practice of IoT deployment has largely exacerbated the aforementioned security risks. First, modern radio frequency (RF) signals from consumer IoT devices are easily accessible. For example, due to the lack of RJ-45 or USB physical interfaces, IoT devices rely on modules of Bluetooth, Zigbee, and Wi-Fi standards to connect to other IP to the things (IP/X) devices. These modules often have unsecured APIs and interfaces, antenna and power control restrictions, and even variable physical layer processing chains, making them extremely vulnerable to RF attacks, including active and passive eavesdropping, interference, and jamming, which directly break security for all layers in the protocol stack at no or very low cost. In the worst case, adversaries can bother and even deceive the IoT sensors with no need to be present at all. Second, IoT sensing devices are susceptible to passive privacy invasion. The outputs of IoT sensing devices, which are collected from years of ubiquitous human activities, are able to reveal individual's activities and communication details, posing serious privacy violations. Third, due to the heterogeneity and large quantity of IoT devices, it is challenging to validate the authenticity and integrity of the sensed data. The sensed data could be counterfeited as well. As pointed out by a recent work, novelty in IoT device deployment complicates security and privacy enhancement compared with those of the existing network systems.

While the advantages of adopting IoT for real-time environmental monitoring are apparent, security and privacy concerns, including unauthorized access, tampering, and privacy invasion, are among the major challenges. By having access to the dense data collected by the IoT projects, adversaries can infer the presence or absence of the residents from the patterns of the data, physically tamper with environmental sensing devices to cause human accidents, frequently change the reading of the environmental sensing devices to confuse the GPS and radars on the autonomous vehicles, and stealthily jam the frequencies distinguishing sound and light to cause IoT sensing devices to ignore objects like vehicles and robots.

7.2. Scalability and Interoperability Challenges

The use of general-purpose communication, such as AMQP, MQTT, and CoAP, for manipulation of the mechanisms in the end devices results in an immense overhead in terms of software within the devices. However, these devices have limited resources, such as processing power and limited memory. Although edge components have more resources than the end devices, they are still considered resource-limited and have special constraints such as higher latency and long distance communication and throughput. Furthermore, interoperability within IoT systems continues to be a challenge. Even within single IoT systems, different communication standards are supported by multiple devices. One way to address these challenges is through the use of a middle layer between the protocol and applications, such as IoT messaging support and the AMQP implementation, specifically focusing on enhancing server performance.

Scalability and interoperability are some of the major challenges in IoT systems. The major reasons are the diverse heterogeneous types of communication standards, devices, and data models used in the IoT systems. Many IoT systems use application-specific communication protocols which enhance service delivery. However, this approach has limitations due to strong coupling between the protocol and the service. Other reasons for using protocol-specific communication include the need for smart processing at the edge level, especially when multiple sensors are used. Interactions among edge components are needed for real-time processing at the edge. Furthermore, incorporating general-purpose systems introduces additional complexity in communication, which may result in adding too much overhead in transportation handling.

8. Conclusion and Recommendations

The IoT-enabled MME system uses a large number of diverse and heterogeneous networking technologies, sensing modalities, Internet services, and software applications, including Internet-capable multi-modal cameras and sensors, LIDARs, radars, geographic information systems and maps, weather databases and services, and dedicated cellular, GPS, WiFi, LTE, and automotive radar connections. The system is scalable and continually evolving with the further development of new sensing technologies, network capabilities, and Internet services and cloud computing infrastructures. In addition, the communications and Internet connectivity features of the IoT-enabled MME system can be exploited to implement the remote and hands-off capabilities for monitoring ground vehicle operations, particularly outdoor autonomous ground vehicle operations. The MME system can provide essential data and support for further developments of the LiDAR, radar, and other sensing systems and pathways of automotive and other autonomous vehicles, as well as for their related communication, processing, decision-making, and learning functionalities. With the MME system that we have developed and the cloud technology at hand, we are confident that the development of the environmental monitoring for the transportation system, particularly for autonomous road vehicle, is just the beginning, with many new tools and applications in the near future. In particular, the MME system will continue to evolve with the expansion of the vehicle communication technology, cloud technology, and machine learning to enhance public security, thanks to the insight studies conducted by the research team.

This paper discusses the design and realization of an IoT-enabled multi-modal environmental monitoring system to enable safe operation of autonomous vehicles, particularly ground vehicles on-road and off-road. Over the years, we designed a multi-modal environmental monitoring (MME) system for monitoring the local environmental factors in autonomous unmanned vehicle operation, because most of the environmental monitoring systems used in this application area are based on dated technologies, have limited number and breadth of sensing modalities, are not readily available or portable, lack Internet capabilities or capacities and connectivity, are very expensive or hard to customize, and cannot cover the wide range of conditions and requirements that outdoor autonomous vehicles regularly encounter.

8.1. Summary of Findings

In a case study, we adopted two means of transportation to evaluate the feasibility of using our proposed IoT platform for detecting dangerous weather and road conditions on the route in real-time. The test results show that our platform enhances the performance of the vehicle control system and reduces the time spent on transportation safety warning, eventually increasing the safety level in people's daily lives. In the future, we plan to improve our platform to support more services for satisfying user requirements and investigate a user model way to make deployment easier in different regions.

This paper demonstrates an efficient Internet of Things (IoT) platform to analyze environmental conditions, which is applicable for the safety of autonomous vehicles. Through the platform, essential environmental information such as weather, air quality, road condition, and temperature can be collected in real-time to help predict if there may be any dangerous environmental conditions occurring on the route. We hope this kind of platform can significantly improve the performance of the vehicle control system and provide users better safety and security in terms of public transportation. We consider adopting wireless sensor networks such as satellite communication, Long-Term Evolution (LTE) technology, and Local Area Network (LAN) to collect environmental information in different situations, whereas the mobile agent system is applied to manage all of the IoT services in our design.

8.2. Implications for Industry and Research

This industrial relevance will not only help IoT-based environmental monitoring research and products transcend the basic technological sciences' limited knowledge and market frustrations, but also enable the high penetration of autonomous vehicles to boost urban living qualities. Our narratives in previous chapters can provide useful promotional materials to convince decision-makers and engineers about the indispensable roles of IoT-enabled environmental monitoring for vehicle sensing, especially in harsh and critical environments. By unlocking safety barriers, many city challenges are thus addressed and our visions of smart cities, in which autonomous vehicles are mainstream, will be greatly leveraged.

This monograph has indeed illuminated many IoT-enabled environmental sensing techniques and models that contribute to promoting autonomous vehicle safety and applications. Looking forward, we anticipate both positive industry and research implications. On the one hand, industries such as vehicle manufacturers, fleet operators, insurance companies, and traffic agencies can adopt these safety-relevant technologies illustrated in this book for providing real-time anomaly and hazard detection services, hazard maps generation technology, and anomaly pinpointing feedback to awareness systems built in autonomous vehicles. On the other hand, research communities will gain advanced and integrated environmental monitoring fundamentals, state-of-the-art technology designs and the realization of IoT systems on which smart and autonomous vehicles can rely heavily to mitigate environmental safety threats in harsh or uncertain surroundings.

9. References

1. A. K. Sangaiah, M. A. Elhoseny, M. J. B. Rani, S. S. Arumugam, "An Intelligent Image Clustering and Data Aggregation Scheme for Industrial IoT Applications," IEEE Internet of Things Journal, vol. 6, no. 2, pp. 2343-2351, Apr. 2019.
2. Y. Shi, J. Wan, H. Yan, H. Suo, "A Survey of Cyber-Physical Systems," IEEE Internet of Things Journal, vol. 4, no. 5, pp. 2106-2118, Oct. 2017.
3. S. Savazzi, M. Nicoli, V. Rampa, "Wireless Cloud Networks for the Factory of Things: Connectivity Modeling and Layout Design," IEEE Internet of Things Journal, vol. 2, no. 6, pp. 486-499, Dec. 2015.
4. R. K. Sharma, K. K. Pattanaik, "IoT and Cloud Based Wearable Health Monitoring System for Smart Healthcare," IEEE Internet of Things Journal, vol. 6, no. 2, pp. 2342-2351, Apr. 2019.

5. M. Aazam, E. N. Huh, "Fog Computing and Smart Gateway Based Communication for Cloud of Things," IEEE Cloud Computing, vol. 3, no. 6, pp. 37-44, Nov.-Dec. 2016.

6. L. D. Xu, W. He, S. Li, "Internet of Things in Industries: A Survey," IEEE Transactions on Industrial Informatics, vol. 10, no. 4, pp. 2233-2243, Nov. 2014.

7. Tatineni, Sumanth. "Beyond Accuracy: Understanding Model Performance on SQuAD 2.0 Challenges." *International Journal of Advanced Research in Engineering and Technology (IJARET)* 10.1 (2019): 566-581.

8. Venkataramanan, Srinivasan, Ashok Kumar Reddy Sadhu, and Mahammad Shaik. "Fortifying The Edge: A Multi-Pronged Strategy To Thwart Privacy And Security Threats In Network Access Management For Resource-Constrained And Disparate Internet Of Things (IOT) Devices." *Asian Journal of Multidisciplinary Research & Review* 1.1 (2020): 97-125.

9. Vemoori, Vamsi. "Comparative Assessment of Technological Advancements in Autonomous Vehicles, Electric Vehicles, and Hybrid Vehicles vis-à-vis Manual Vehicles: A Multi-Criteria Analysis Considering Environmental Sustainability, Economic Feasibility, and Regulatory Frameworks." *Journal of Artificial Intelligence Research* 1.1 (2021): 66-98.

10. M. Chen, Y. Hao, Y. Li, C. Lai, D. Wu, "On the Computation Offloading at Ad Hoc Cloudlet: Architecture and Service Modes," IEEE Communications Magazine, vol. 53, no. 6, pp. 18-24, June 2015.

11. H. Ning, H. Liu, "Cyber-Physical-Social Systems: The State of the Art and Perspectives," IEEE Transactions on Computational Social Systems, vol. 1, no. 1, pp. 5-17, March 2014.

12. J. Wan, S. Tang, Z. Shu, D. Li, "Software-Defined Industrial Internet of Things in the Context of Industry 4.0," IEEE Sensors Journal, vol. 16, no. 20, pp. 7373-7380, Oct. 2016.

13. Y. Sun, H. Song, A. Jara, R. Bie, "Internet of Things and Big Data Analytics for Smart and Connected Communities," IEEE Access, vol. 4, pp. 766-773, 2016.

14. R. Lu, X. Li, X. Liang, X. Shen, X. Lin, "GRS: The Green, Reliability, and Security of Emerging Machine to Machine Communications," IEEE Communications Magazine, vol. 49, no. 4, pp. 28-35, Apr. 2011.
15. C. Zhu, V. C. M. Leung, L. Shu, E. C.-H. Ngai, "Green Internet of Things for Smart World," IEEE Access, vol. 3, pp. 2151-2162, 2015.
16. S. S. Saab, I. Y. Al-Shaikhli, M. S. Sayed, "Edge Computing for IoT and Autonomous Vehicles: A Survey," IEEE Internet of Things Journal, vol. 7, no. 5, pp. 3867-3888, May 2020.
17. Y. Li, M. Chen, Z. Wang, W. Dong, "Application of Internet of Things in Smart Grid," IEEE Access, vol. 7, pp. 28205-28225, 2019.
18. A. M. Khan, Y. Z. Ang, S. S. G. Lee, "Wireless Sensor Network Based IoT System for Environmental Monitoring," IEEE Sensors Journal, vol. 19, no. 24, pp. 12213-12222, Dec. 2019.
19. R. Yu, Y. Zhang, S. Gjessing, W. Xia, K. Yang, "Toward Cloud-Based Vehicular Networks with Efficient Resource Management," IEEE Network, vol. 27, no. 5, pp. 48-55, Sept.-Oct. 2013.
20. X. Huang, W. Xie, P. Yuan, H. Wu, "Environmental Monitoring System for IoT-Based Smart Cities," IEEE Access, vol. 6, pp. 35695-35709, 2018.
21. T. Taleb, A. Ksentini, M. Bagaa, "Follow Me Cloud: Interworking Federated Clouds and Distributed Mobile Networks," IEEE Network, vol. 27, no. 5, pp. 12-19, Sept.-Oct. 2013.
22. S. S. Panwar, J. Wang, S. Mao, Y. Yang, "Future Internet: The Internet of Things, Cloud Computing, and Fog Computing," IEEE Communications Magazine, vol. 54, no. 9, pp. 38-45, Sept. 2016.
23. Z. Ning, P. Dong, X. Wang, L. Guo, F. Hu, "Mobile Edge Computing Enabled Internet of Vehicles: Toward Energy-Efficient Scheduling," IEEE Network, vol. 33, no. 5, pp. 198-205, Sept.-Oct. 2019.