Pervasive Computing, Internet of Things, and Autonomous Vehicles

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***Abstract*—Pervasive computing (also known as ubiquitous computing) is the integration of computing and the surrounding environments, being able to seamlessly implement technology to the point where the individual mechanisms are invisible to the user. This integration of computing and the surrounding environment evolves how people live. There are many applications of pervasive computing, ranging from smart watches to autonomous vehicles. Autonomous vehicles are a large part of modern-day research, large companies investing heavily in being able to produce these vehicles whilst overcoming the challenges that arise. Furthermore, implementing the concept of Internet of Things to be able to allow communication between objects can be used in cohesion with pervasive computing in order to help develop the technology surrounding our everyday lives. The aim of this research paper is to outline the importance of pervasive computing, how this links with large concepts such as Internet of Things and cloud computing, in particular, vehicular cloud computing. In addition to this, looking at early, modern day, and future applications of pervasive computing, specifically within the automobile industry.**

***Index Terms*—Pervasive Computing, Autonomous Vehicles, LiDAR, Internet of Things, Internet of Vehicles, Automotive Vehicular Computing, Intelligent Transport Systems, Cloud Computing, Vehicular Cloud Computing, Vehicular Clouds, Autonomous Vehicular Clouds.**

I. Introduction

Pervasive computing (also known as ubiquitous computing) is an important area of research within the world of computer science, implementing technology in any place at any given time. Pervasive computing tends to the combination of communications and technology in environments where they will be integrated with users. Pervasive computing can be intertwined with Internet of Things (IoT) to give these objects the ability to communicate with each other. Pervasive computing is growing as it is a relatively new area of research, the challenges involve implementing pervasive systems; combining technologies in order to solve a problem. Pervasive computing is used to a large extent in the vehicle industry, they utilise embedded computers for many different systems, for example, anti-lock braking system (ABS), central locking system, engine control unit (ECU), and many more. As technology evolves and computational power increases, vehicles will be more capable [1]. The automobile industry is using pervasive computing to lean towards 'smart cars' and autonomous vehicles. These vehicles have increased capabilities in respect to regular cars, providing more driver assistance and become more diverse in its abilities. This leads onto the development of concepts such as vehicular clouds and vehicular cloud computing, using communication between nodes to exchange various different types of information such as traffic information or guidance on possible dangers ahead.

II. Pervasive Computing

Pervasive computing can be defined as elegant implementation of computing and communications in environments that tends to be integrated with users [2], also referred to as ubiquitous computing. In simpler terms, the implementation of computing everywhere. Mark Weiser published a journal article in 1991 discussing about how "the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it." [3]. Weiser mentioned the idea of integrating computers into the world "seamlessly". This was deemed to be the initial introduction of pervasive (or ubiquitous) computing. The idea of pervasive computing was not simply making computers portable as this still emphasises on the technology being confined to a box, without seamlessly disappearing into the world. An early example mentioned by Weiser is the use of electric motors in a larger single unit machine found in factories. These smaller individual motors make it possible for the larger machine to work, where the human user would only interact with the larger machine itself, with the smaller electrical motors implemented "invisibly". Weiser and his colleagues developed something they call "tabs, pads and boards". These consisted of inch-scale machines that mimic post it notes. This is an example implemented by Weiser and his colleagues as an early form of pervasive computing.

III. Internet of Things (IoT)

The Internet of Things (IoT) is the concept of allowing 'things' or objects to interact and communicate with each other in order to complete a certain task [4]. IoT is deemed to be similar yet different to pervasive computing. Pervasive (or ubiquitous) computing is implementing some sort of computational ability to everyday objects seamlessly; IoT is the concept of connecting these objects with computational power to the internet allowing the further development of technology and how it impacts our lives daily. There are many examples of modern day IoT, some examples are smart watches (Apple Watch, Samsung Galaxy Watch, Tag Heuer

Connected), vehicle communications (Autonomous vehicles, GPS systems communicating), smart cities (Managing congestion, waste management, energy consumption, smart parking), smart lightbulbs (Phillips Hue, Auraglow), and smart audio devices (Google Home, Amazon Echo, Sonos One, Apple HomePod).

IoT initially started as a network of computers, exchanging information between one and another. The concept of the internet changed over the years to transform the concept into a social web, where the users were the target audience for content. As technology evolved, computational power became more powerful, devices were able to store more data, and the devices themselves were decreasing in size. These devices eventually were easily communicate with surrounding devices, combining physical hardware with the internet to give the concept of IoT [5]. IoT is an important concept as connecting devices allows the collection of large amounts of data. These devices exchanging data allows them to learn from each other and allows the device to provide more information to the user.

IV. Internet of Vehicles (IoV)

The Internet of Vehicles (IoV) is an application of IoT, the connection of these smart objects over the internet regarding vehicles [6]. An increased number of vehicles are used to communicate from one place to another, as we evolve, we demand greater things from these vehicles. A large application of IoV is a traffic management system. Vehicles communicating with each other, sharing data between each other to inform about traffic situations. This data can be used with the application of smart cities in order to improve congestion and reduce carbon emissions, keeping the city running efficiently and effectively. Manufacturers in the automotive industry can also utilise IoT for vehicle diagnostics. This can be used to check any failures that may occur to the vehicle. This information can be extracted, providing an insight to any malfunctions and allowing the manufacturer to pinpoint the problems with the vehicle. This in turn can help diagnose any safety issues with the vehicle, provide an improved driving experience, and assess the quality of their vehicles [7].

V. Modern Day Pervasive Computing

The idea of pervasive computing has largely evolved from the initial implementation suggested by Weiser, examples range from autonomous vehicles to something as small as a smart lightbulb. They all utilise electronic microprocessors, carrying out various tasks for the devices to work. Pervasive computing continuously promotes the use of computing all around us whilst maintaining an invisible presence of the system in front of the user [8]. Typically pervasive computing systems use wireless communication technologies such as RFID sensor technology, Bluetooth, and Wi-Fi. These communication technologies are combined with communication protocols (both pre-existing and newly designed ones) in order to develop and implement the pervasive system [8]. Large applications of pervasive computing are within the automotive industry, with the evolution of technology, there will be large improvements in user experience.

VI. Automotive Pervasive Computing

Automotive pervasive computing evolved massively in the past thirty years, drastically changing the ways that vehicles are perceived and used. The evolution of technology and the implementation of pervasive computing allows many new features to be presented. With large amounts of research and investment in technology, the computational power has significantly increased the possibilities of pervasive computing and IoT. The introduction of IoV allow car components to be connected, sharing information to improve user experience. Currently we have seen that automotive pervasive computing has been able to implement many different features that improve safety, travel efficiency, and driving simplicity (some examples of features include semi-autonomous driver assistance, lane assistance, adaptive cruise control, etc.) [9]. This advancement in technology is leading towards a world with fully autonomous vehicles.

Automotive pervasive computing aims to implement technology in all aspects of the automobile. This also involves supplying information to both the vehicle and the driver, whether it be traffic information (e.g. Intelligent Transport Systems), journey navigation (GPS systems), or vision enhancement technology (parking assistance cameras) [10]. Early developments of pervasive computing in the automotive industry involve the implementation of electronic windows. Implementing technology as trivial as this comes a long way, the concepts tend to aid the evolution of other aspects of the vehicle (such as the operation of doors and trunks with simple buttons).

VII. Autonomous Vehicles (AVs)

Autonomous vehicles (AVs) are also referred to as self-driving vehicles, requiring bare minimal or no input by the human user to drive the vehicle. AVs are emerging, large manufacturers such as Tesla, Audi, Mercedes-Benz (not limited to) are investing heavily in research and development of these vehicles. AVs present a beneficial yet disruptive change to the world of transportation and pervasive computing [11]. These vehicles have the possibility of benefiting the planet by reducing pollution and improving traffic efficiency [12]. Furthermore, human error accounts to roughly ninety percent of all accidents [13], this can be significantly reduced by introducing the non-human element of artificial intelligence. These vehicles utilise IoT technology. Sensors are used to collect data ranging from road conditions, GPS locations, traffic information, etc. IoT sensors can also be used to support autonomous vehicles.

LiDAR is a sensing method used to measure distances to a target. LiDAR stands for Light Detection and Ranging. LiDAR tends to be an essential to a company's AV technology. LiDAR fires laser beams at its surrounding, forming a three dimensional point cloud, thus acquiring a three dimensional representation of the surrounding environment [14]. The measurement of these distances from the three-dimensional LiDAR must be processed to gain information for pattern recognition and object classification. Pedestrian recognition is vital as the AV needs to be able to distinguish a pedestrian from another object. Furthermore, prediction of pedestrian movement is vital for on-demand path planning of AVs [15]. The IoT sensors used in AVs can be used for collision avoidance, they process huge amounts of data to ensure that the vehicle maintains a safe distance between itself and the other vehicles on the road, the vehicle remains on the roads safely, and the vehicle makes consistent checks all around itself.

Information is transacted within the large network of vehicles in order to supply information for various different reasons, but most importantly transporting the passenger safely to the destination [16]. It is essential that the autonomous vehicles communicate efficiently and cooperate successfully in order to manage traffic flow effectively and reduce emissions whilst tailoring to the passenger's needs. There is a long road ahead for autonomous vehicles to be implemented, a clear misconception is the fact that current car manufacturers such as Tesla are selling these AVs. Currently, AVs require clear road markings, clear road signs, perfect conditions in order to detect several different stimuli. As technology advances, the necessities for perfect conditions may fade away. The AV industry requires the governments to make changes to cities in order progress towards this future [17]. The modern-day vehicles have driverless capabilities such as lane assistance and adaptive cruise control in respect to other vehicles, but these still require the supervision of the driver.

Furthermore, AVs propose large social dilemmas regarding the safety of humans. A common problem is the choice between two evils [12], whether the vehicle run over a pedestrian to save the passenger or whether it should sacrifice the passengers in the vehicle to save the pedestrian. These hypothetical scenarios should be taken into consideration, regardless of whether the situation may arise or not. Moral principles must be embedded into the algorithms that control these vehicles in a situation with no positive outcomes in order to distribute the harm that may be caused [12] [18].

The automotive industry aims to implement pervasive computing to all aspects of the automobile in order to be able to operate each feature of the car using technology to the point where it seems 'invisible' to the user.

VIII. Intelligent Transport Systems (ITS)

Intelligent Transport Systems (ITS) combine communication and technology to supply information to improve road transport efficiency and the safety of transportation, a key application of vehicular pervasive computing with the combination of IoT. Modern improvements in hardware, communication technology, and software allow the development of multiple different types of networks. A network used in conjunction with ITS is the Vehicular Ad-Hoc Network (VANET). VANET uses a wireless network consisting of a set of moving vehicles that utilised information communication technology (ICT) in order to provide various services regarding transport and traffic management [19]. This type of communication technology is a prime example of how IoT is used in the automotive industry.

IX. Cloud Computing (CC) and Vehicular Cloud Computing (VCC)

"Cloud computing is the on-demand delivery of IT resources over the Internet with pay-as-you-go pricing. Instead of buying, owning, and maintaining physical data centers and servers, you can access technology services, such as computing power, storage, and databases, on an as-needed basis from a cloud provider like Amazon Web Services (AWS)." [20]. Cloud computing has the responsibility of the computation and storage of data. There are three main types of cloud computing: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS).

IaaS consists of the elementary 'building blocks' for cloud information technology. It tends to entail the supplying of access to networking features, virtual or physical computers, and data storage [20]. PaaS contains the layer for distributing storage [19], removing need to manage the underlying infrastructure such as operating systems and hardware, thus improving efficiency for the user [20]. SaaS provides software and applications for the end users, allowing the user to use the internet to connect services from providers, this uses a pay-as-you-go-model for the transactions of data [19].

"Cloud computing utilises excess computing power" [19]. According to the United Kingdom Department for Transport, "there were 37.9 million licensed vehicles in Great Britain" [21]. Most of these vehicles tend to be left idling, this is simply an "unexploited resource" [19]. These vehicles could possibly be used in a cloud computing network as nodes in order to compute data and relay this information with the other nodes in the network.

Vehicular cloud computing (VCC) is a new concept in which vehicles will interact with each other; collaborating in order to detect the surrounding stimuli. In addition, these vehicles will process the data detected from the environment. The resultant information will be relayed between the vehicles. The transactions of data between vehicles introduce a paradigm known as the Vehicular Cloud (VC). The VC consists of large amounts of data, which is 'queried by the driver' in order to receive information. This query could be the latest traffic information, essentially providing as much relevant information as possible to aid the driver in reaching their destination safely. The vehicular cloud does not follow the norm in which the computation takes place on the cloud (internet cloud), but instead is computing on the onboard sensors of the vehicle [22]. A paper written by Eltoweissy et al. discusses the paradigm of the Autonomous Vehicular Cloud (AVC). The AVC refers to using "a group of largely autonomous vehicles whose corporate computing, sensing, communication and physical resources can be coordinated and dynamically allocated to authorized users" [23]. They discuss the importance of “seamless integration and decentralized management of cyber-physical resources”, furthermore, they mention the use of “on-demand solutions” meaning that the scenarios that occur cannot be planned for. The importance of seamless integration in AVC was also mentioned by Weiser to be a key part of pervasive computing [3], to ensure that implementation is as elegant as possible [2].

X. Conclusion

The paradigm of pervasive computing provides a promising future for technology, in conjunction with IoT, advancements can be made to existing technologies. However, challenges arise, which prove to be difficult in order to provide the developed technology to the customers. Weiser said that “The real power of the concept [pervasive computing] comes not from any one of these devices; it emerges from the interaction of all of them” [3]. This interaction using IoT will allow the development of our world, large projects such as smart cities and autonomous vehicles will transform the way people live. The area of research has come a long way since it began with Weiser’s (and his colleagues) tabs, pads, and boards; but there is still more research required to further develop the pervasive environment around us.

The concept of IoT has transformed our everyday lives, aiming to transform how the internet is used, furthering the pervasiveness of the internet. Autonomous vehicles have emerged and come a long way since it was first introduced. Years of innovation required in order to provide solutions to problems, yet there is still a large hurdle to come across. Tesla have developed technology which allows the vehicle to operate under “active driver supervision” [24], meaning that the technology implemented is still not fully autonomous. There is a long way until autonomous vehicles will be fully functional as they rely on a large amount of data in order to navigate around cities. These vehicles look for road markings and signs, these vehicles also require a consistent internet connection for information to be transmitted between vehicles via the vehicular cloud.

IoT systems prove to be a challenge in itself, the vast variety of applications along with the difficulty of implementing the IoT network requires practice and excellent execution in order for it to be a success [25]. Pervasive computing will always be expanding, finding new ways to improve user-facing applications [9]. All industries will face large hurdles, the attempt to overcome these challenges will prove to be difficult due to the capricious nature of technology and pervasive computing; finding solutions in order to seamlessly integrate technology into everyday objects.

XI. References

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