Enabling and supporting car-as-a-service by digital twin modeling and deployment

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***Abstract*—Smart City is one area of application for the Internet of Things (IoT) and it has been attracting attention from both academia and industry. Cities will be composed by autonomous parts that communicate and provide services to each other. For instance, cars (autonomous or not) may be seen as a service that transports people from one point to another. Interactions between users and these kinds of services will grow, making it necessary to have digitization of all these parts of the Smart City. The Digital Twin (DT) concept proposes that real-world assets have a virtual representation connecting the physical world with the cyber world. This allows to track the whole life-cycle of this object as well as perform simulations with current or previously stored data. In this context, this work proposes the use of Digital Twin for enabling and supporting car-as-a-service (CaaS). A case study has been developed to demonstrate the modeling and the deployment of the Digital Twin, highlighting how this concept can be one of the key enablers for CaaS.**

***Index Terms*—car as a service, digital twin, modeling and deployment, smart city**

I. Introduction

A Smart City [1] uses different types of electronic sensors to collect data and process them to efficiently manage resources and assets. Data can be collected from many different sources such as transportation systems, power plants, water supply networks, sanitation systems, cameras for crime detection, information system in general, schools, stores, hospitals and even from citizens via wearables or smartphones.

In this context, the need for mobility in the cities is a source of investigation. The population continues to rise and research on how to manage transportation for the environment and economy needs to be addressed. The applications of smart vehicles such as connected vehicles [2], autonomous vehicles (AVs) [3], as well as connected and autonomous vehicles in the smart cities, will help to minimize the costs and improve resources efficiency.

As cited in [4] the challenge in smart mobility is to accomplish an inclusive, sustainable and efficient transportation system of people and products. This could be achieved with the introduction of connected vehicles that will allow improvement of connectivity, reduction of congestion and pollution in cities [5].

A smart city relies on a collection of smart Information and Communication Technologies (ICT) applied to critical infrastructure components and services. Emerging ICT paradigms such as Big Data, Distributed Systems, Internet of Things, Cyber Physical Systems, and Digital Twins are essential to the realization of the vision of Smart Cities. The creation of innovative applications and services for Smart Cities in mobility and transportation, like Car-as-a-Service (CaaS) is crucial to their success.

CaaS is becoming reality in most of the big cities, however, it is still not clear how to enable and support this new way of using cars. Therefore, new digitalization approaches are needed for connecting cars and users. In this context, DT can be a suitable solution of digitalization, since it provides a virtual representation of an asset of the real world. The DT can monitor and control the physical part through the connection established between them. This connection allows the extraction of information generated by the sensors. For instance, in Smart Factories, digital twins are being used to optimize the operation and maintenance of physical assets, systems and manufacturing processes.

DT is being used in industries as a technology that provides a precise way of simulation from the concept to the real-world scenario. For instance, the DT can be used in for healthcare field [6] where simulations can be performed based on vital signs provided by sensors connected to users, such as wearables, and treatments with better accuracy can be provided.

In this context, this paper proposes a concept for enabling and supporting CaaS by DT in Smart Cities.

The paper is organized as follows: section II brings a review of the state of the art; in section III it is presented how to realize CaaS by DT; in section IV a case study used to validate the proposed approach is implemented; in section V the results

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are presented and finally, in section VI conclusions are drawn and future research directions are signaled.

II. Literature review

A. Car-as-a-Service

Pana [7] introduces the concept of Car-as-a-Service as a way to provide multiple services with the use of sensors, actuators and radio-devices. The authors recommend the concept of using connected vehicles as service providers for passengers in the context of the smart city. For them, the CaaS's principal components are: Global Navigation Satellite System; High precision distance estimation; Radio connectivity; environmental sensors for assessing temperature, humidity pressure, etc; motion sensors, i.e. Inertial Measurement Unit (IMU) for assessing the traffic flow, the heading and roll of the vehicle, and quality of the road; a central cloud processing unit; social Networks; analytics.

One type of CaaS is car-sharing. Basically, in this kind of service, the user pays to use a car with other people. The main advantages of this service are: it can reduce the number of cars on the roads; it can save money for people that use a car only a few hours a week and decide to not own a car.

Archer [8] assumes that car-sharing schemes lead to reduced car ownership, with studies indicating that 5-15 cars are replaced for each shared car added to the fleet.

Ferrero [9] introduces a taxonomy and analyze the different aspects of car-sharing. Basically, most of the analyzed researches focuses on two groups: a) reviews considering the technical and modeling aspects; and b) surveys that deal with the business perspectives of car-sharing. There are also challenges related to the acceptance of this kind of service by the final user.

Car-sharing is practiced in almost all European countries, the USA, Japan, China, and Australia. Mattia [10] says that it is expected to be used by approximately 12 million people by 2021. Together with this sharing approach for using cars, new services will be created to bring more comfort and safety to users such as user preferences [11] and driver monitoring.

Concerning about driver monitoring, the authors in [12] reviewed Drive Monitoring Assistance Systems (DMAS) and it was figured out that the attention level of drivers is the main element for safe driving because fatigue and distraction are the dominant causes of road hazards.

B. Digital Twin

The term "Digital Twin" is widely used and tightly coupled with Cyber Physical Systems. Authors of [13] define the DT as a system that allows simulations of the physical device using physical models, sensor data, fleet history, in order to represent the lifecycle of its corresponding twin. For Rosen [14], the Digital Twin can be characterized as a virtual imitation of a physical asset facilitated through data and simulators for real-time forecast, controlling, optimization, monitoring and improved decision making.

The Digital Twin, through the Internet of Things, can provide many benefits as services such as simulations, devices monitoring and management since it can connect both the physical and the virtual worlds and it can store data of the whole life-cycle [15].

C. Digital Twin modeling and implementation

Regarding the modeling and deployment of DTs, there is a lack of standards. Nevertheless, there are several proposals for modeling and construction of DTs available in the literature.

A dynamic modeling approach of DT using ontologies is proposed in Xu [16] where the relationships between equipments are described by a combination of basic, functional and manufacturing process ontologies. The relation between parameters and the corresponding data stream of the real device is also mapped in the ontology.

Zhang [17] proposed a model of digital twin based on physical perception data. The model is composed of three parts: the plant physical model, digital model and 3D virtual model. The models are combined in real-time to form a basic digital twin model.

In [18] it is proposed a Reconfigurable Digital Twin (RTD). The RDT model is described from five dimensions including geometry, physics, capability, behavior, and rule. This approach is suitable for building DT systems with high fidelity since it is possible to describe the same asset with different perspectives/dimensions.

Ding [19] presents a reference architecture called "digital twin-based cyber-physical production system" (DT-CPPS).

Damjanovic-Behrendt and Behrendt [20] proposed a DT concept based on micro-services. However, no specific methodology for DT implementation and deployment was presented. Rovere also presents a reference architecture based on micro-services [21]. The main purpose is to allow the synchronization between physical and digital representations using a middleware where the communication between them is enabled by a WebSocket channel. The digital twin contains functional and behavioral models.

Schroeder [22] describe a methodology for modeling the interchange of information in a general digital twin system using AutomationML (Automation Markup Language). Also, [23] and [24] propose the use of AutomationML to create a model for the DT.

Summing up, the DT concept is still in its initial stages, and therefore no consensus has been reached concerning several issues. A variety of different approaches can be observed both at a conceptual level as well as at the implementation level.

D. Digital twin in the CaaS

Researches related to digital twins are primarily concerned with the product design and manufacturing industries. However, some works such as [25] propose the use of digital twins for vehicles and roads which can then be leveraged by machine learning-based approaches to predict and minimize congestion on roads. The authors of [26] also provide an interesting use-case for digital twins as digital behavioral twins designed to learn driver behavior through data accumulated from connected smart vehicles. The behavioral twins are utilized to compute the risk associated with surrounding cars and recommend (or autonomously take) preventive actions. [27] propose a fog

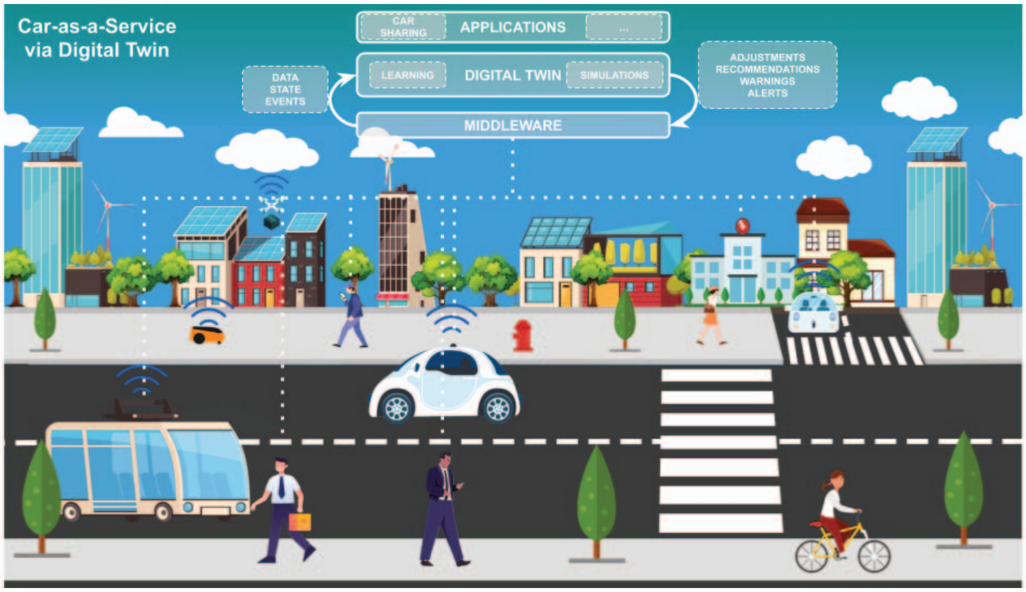

Fig. 1. Concept of Digital Twin applied to Smart Cities

computing-based framework to assist autonomous driving. The framework relies on overhead views from cameras and data streams from vehicle sensors to create a network of distributed digital twins, called an edge twin. Venkatesan [28] uses Digital twin for health monitoring and prognosis of electrical vehicles using an intelligent digital twin approach.

After reviewing the state of the art, the conclusion is that Digital Twin and Car as a Service may change future intelligent transportation in smart cities. None of the works mentioned above takes into consideration the user preferences, and there is a need for new approaches that use digitalization in the context of CaaS.

III. Realizing Car-as-a-Service by DT

Together with this new way of using cars comes also a need of having new approaches of digitalization. In this context, DT can be a suitable solution for digitalization, since it provides a virtual representation of a real-world asset.

Figure 1 illustrates a scenario of a Smart City with some main elements of this context. People, cars, robots and other devices that may exist are connected via the internet to an IoT middleware [29]. This middleware supports the main available standards and protocols which makes it possible to connect devices of different brands or generations.

The Digital Twin is a virtual representation of an asset of the real world. It mirrors the real-world objects into the cyber world, providing a virtual environment where it is possible to perform simulations and learn from historical data.

A DT can be composed of the following elements:

- **Storage**: for storing historical data, a DT must have access to storage, usually a database or a file record. Historical data can be essential in some applications that have big data analysis or predictive maintenance.
- **Methods**: thought the methods it is possible to access functionalities of the DT by users or other applications. They are used to control devices, run diagnostics or execute simulations.
- **Access Control**: security measures are needed in some applications to avoid unauthorized access. This is an essential part of the DT in the sense of providing mechanisms for security or identification.
- **Communication Interfaces**: details like protocols, address, and port, for the communication between the real device and its DT must be defined.
- **Events**: a DT can trigger events based on predefined conditions. This can be used, for instance, to trigger an alarm when the temperature of a device is too high.
- **Human Machine Interface (HMI)**: user interfaces may be part of a DT allowing users to interact with the virtual representation. It can be a simple dashboard or even a complex application with augmented reality.
- **Application Programming Interface (API)**: through the API it is possible to access methods by external applications.
- **Physical Model**: different models can be used to represent the same DT or parts of it. In other words, a DT can be composed by a set of different models, each describing the asset from a different perspective.

Data, states and events flow from the real world asset into the virtual world to the respective twin. Triggers can be executed every time new data is received and after processing this data, the DT can send adjustments/recommendations or alerts to the real world. By using this approach it is also possible to store all lifecycle of each individual element as well as data related to the interaction between two or more objects. This allows the system to evaluate and improve future relationships between

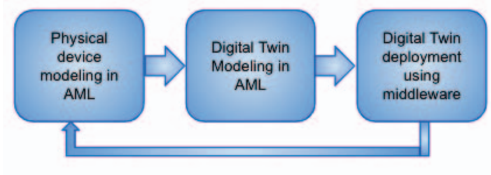

Fig. 2. Steps to create a DT

the entities of the system.

Different approaches related to modeling DT can be found in the literature [30] [31]. It is possible to identify similarities in the way these works understand the modeling and deployment of a DT. Figure 2 shows the main steps and a description is given as follow:

- **Physical device modeling**: first step is to model the elements of the real world with their attributes and the relations between them.
- **Digital Twin modeling**: the Digital Twin is created based on the model of the physical devices from the previous step. Data source (e.g. IP and port) and a target database are defined in this step. Methods (behaviours), events, and triggers can also be modeled to enable the DT to send feedback to the real-world device.
- **Deployment**: The deployment is based on already created models. It is possible to extract information automatically from the models [22] [32], and create communication interfaces for the integration between the physical device and its DT.

Applications like Car-sharing can be created on top of the digital twins and they can take advantage of accessing high-level objects without handling low-level issues like different protocols for each device. The applications can also offer customized services based on the previous data from the DT that is stored during the whole lifecycle of the asset.

However, to have such a generic and compatible system it is necessary to model the elements in a common language that can be understood across the entire system.

IV. Use Case

A case study has been developed to demonstrate the proposed concept of this paper. It is composed by the main components of a CaaS system such as users, cars as well as the virtual representation of these elements (DT).

A. Description of the scenario

Figure 3 illustrates the elements which were considered for this case study and the relationship between them. There are two main parts in this kind of system: the real world which is in green and the cyber world which is in blue.

Users can keep their profiles updated with personal information through their smartphones. The main smartphone manufacturers already provide a platform to access fitness information about the device's owner. It is also possible to connect wearables to measure vital signs with more accuracy and be notified when any sign is out of range.

B. Physical and DT modeling

The first step of the implementation is to model all real-world elements in AutomationML, which is a neutral data format based on XML for the storage and exchange of plant engineering information. A user has been modeled with its attributes such as name, age, gender, height, weight, active (if the user does sports), alcohol (if the user drinks alcohol), and smoke (if the user smokes). There are also interfaces that can be connected to a stream of data for continuously measuring users' vitals signs such as heart rate. This vital sign can be measured by most wearables available in the market nowadays. Figure 4 shows part of the model which contains the user and its attributes.

C. Deployment

After users and cars are modeled, communication interfaces are generated automatically via a script written in Python. This script extracts all entities from the model with their attributes and configures the communication which in this case study is made through a middleware IoT called FIWARE [33].

All elements from the real-world are connected via FIWARE and each element is represented as an entity which can be manipulated via HTTP requests.

- POST: used to create a new entity.
- PUT & PATCH: used to update an existing entity.
- GET: used to retrieve an entity.
- DELETE: used to delete a specific entity.

An important feature of FIWARE is the possibility of subscribing to updates on a specific entity. Using this functionality, a script for keeping the Digital Twins updated was implemented. Every time that a new update on the user's data was received, this data was evaluated and a prediction of heart attack was done via a neural network.

The implemented neural network was trained using the dataset Heart Disease and Stroke Prevention [34] and it has an accuracy of 85%. With this algorithm, it was intended to show the possibility to add machine learning-based algorithms directly into the DT. It receives as input the user's health data such as heart rate and predicts if the user is having a heart attack. If the chances of having a heart attack are greater than 70% and the user is driving a car, an alert message is sent to the car. This alert can be visualized on the display of the car and the user can observe if this situation gets better or not. This approach allows implementing more complex situations such as trigger a call to an ambulance or an autonomous response from the car.

A mobile application has been developed in Flutter/Dart to access the user's fitness data through the Google Fit platform. In this application, the user has to login with his/her Google account and grant access to the fitness data. It is also required that the user enter its personal information to keep the profile always updated. This app keeps the digital twin of the user updated with the most recent data available. Through an API, the app requests the health data to the Google Fit platform every period of time. This period can be configured based on the kind of user or on the information that is being requested.

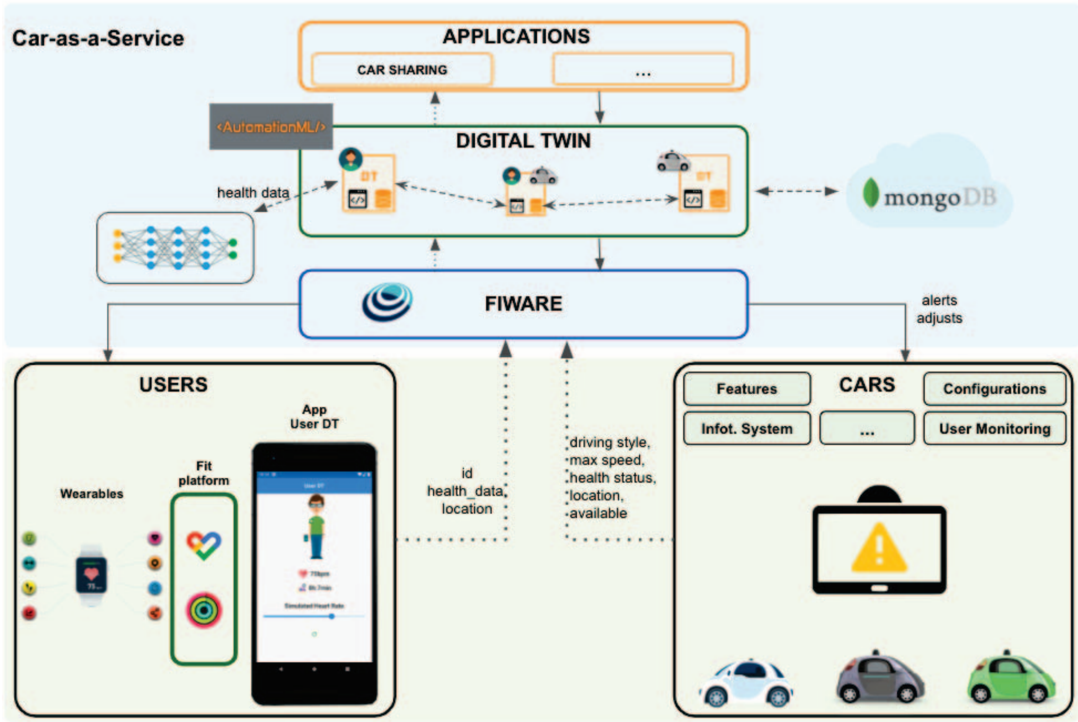

Fig. 3. Structure of the Use Case implementation

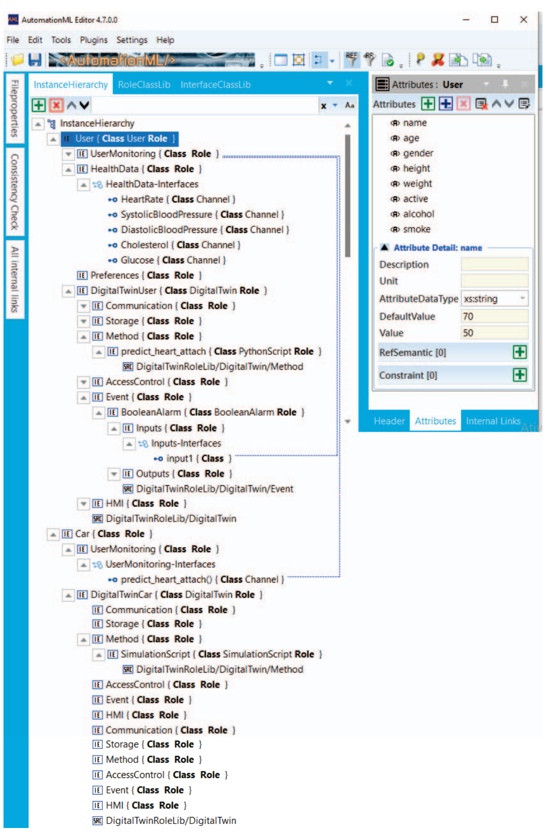

Fig. 4. Part of the Digital Twin model in AutomationML

For simulation purposes, an interface to external systems has been developed to allow the communication between the car and its digital twin. Through this interface it is possible to send alerts or change some configuration of the car such as the max speed limit.

This case study showed how the proposed concept can be applied to a real scenario and it was possible to identify the advantages of using the concept of Digital Twin to enable and support Car-as-a-Service. One important advantage is that all entities have a virtual representation that can be accessed via the middleware. Another benefit of using this approach is the possibility of tracking historical data from all entities such as cars, users and the relations between users and cars, making it possible to improve the user experience in futures rides.

V. Discussion

A concept of enabling and supporting CaaS by Digital Twin was proposed and a use case has been implemented to demonstrate how it can be applied in a real scenario.

It is possible to observe that having a virtual representation (DT) of all elements of the system brings benefits such as an easy way of integration or creation of applications that use these objects. Another advantage is that this approach permits to store the whole history of users and cars as well as the interaction between them. This can be useful for providing new services and making the existing ones better.

The AutomationML is a well-defined modeling tool and widely adopted by companies. It allows reusability and interoperability between different applications and languages.

VI. Conclusion

Thanks to the big business changes, cars are increasingly being used as services, especially in developed and big cities where traffic is crowded. In this context, this paper proposed the use of DT for enabling and supporting CaaS.

A concept is proposed with the key elements of this scenario such as the city itself, a middleware to connect all entities, the DTs models that run over the middleware, and on the top, applications like car-sharing can be implemented.

The case study demonstrated how it is possible to implement the proposed concept and it also pointed out some important improvements for future works.

A more detailed use case with autonomous agents is planned for future work. Safety and security are key aspects to consider before bringing this approach to production. Technologies based on blockchain is a possible way to try to handle these aspects.

Wearables can provide important data to implement reactive applications, however, there are still technical challenges on connecting directly to the device and retrieving data whenever it is needed. All brands have their own way of providing access to their Fit platform and it is not guaranteed that the data is updated.

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