A software platform for smart data-driven intelligent transport applications

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A Software Platform for Smart Data-driven Intelligent Transport Applications

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***Abstract*—Intelligent Transport Systems (ITS) are vital to increase safety and reduce congestion problems. ITS can support several applications such as emergency management, automatic road enforcement, variable speed limits, collision avoidance systems, dynamic traffic light sequence and many more. These applications use heterogeneous technologies for sensing, communications, and computation. A number of sensing technologies have been used for the ITS applications such as cameras, sensors, inductive loop detection to know the contextual information of the given environment. These technologies are measuring almost the same information but in various formats. Similarly, several technologies are widely used for short and long range communications within ITS. Future, ITS will require wireless communication among vehicles and the road side infrastructure. Furthermore, most ITS applications require realtime computation due to critical functions that need to provide realtime feedback to the end-users. In this paper, we proposed and developed a software platform to solve the challenging issues that came from sensing, communication and computation within ITS applications. The platform can process data from heterogeneous sources and makes sure that data availability and quality is maintained. Moreover, the proposed software platform is able to analyze data from heterogeneous sources to find valuable insights accordingly. Finally, we designed and developed a visualization layer to communicate valuable insights with the end-users by exploiting various visualization techniques.**

I. Introduction

Intelligent Transport Systems (ITS) are innovative tools based on information and communications technologies (ICT) applied in the transport sector. These tools enable authorities, operators and travellers to make more informed and intelligent decisions. ITS contribute to improving transport management and increasing efficiency and safety such as speed limitation, safety distance between vehicles, traffic signal control, dynamic roadside message signs for drivers, automatic number plate recognition, speed cameras, speed alert, hazard and incident warning, assistance for emergency vehicles, etc. ITS contribute significantly to a cleaner, safer and more efficient transport system [1]. Furthermore, ITS aim is to reduce traffic accidents, energy consumption, CO_2 emission, traffic congestions as well as to provide better driving experience. ITS applications have generally been classified into three main categories with respect to their functionalities: safety, efficiency, and comfort applications [2]. These applications require realtime, meaningful and reliable data for efficient working. The foundation of ITS applications is based on the smart objects. A smart object is an autonomous physical/digital objects augmented with sensing, actuation, processing, connectivity and communication [3], [4]. The network of smart objects can also be referred as an Internet of Things (IoT).

Transport management is a key research area because the population and number of vehicles on the road are increasing dramatically worldwide. With the advent of modern communication, computational devices and inexpensive smart objects, it is possible to collect and process data from a number of sources. Communications technologies can enable active safety in the following ways: (1) detecting and alerting drivers regarding potential hazardous conditions ahead, such as heavy fog, road construction work, or accidents; (2) Detecting and warning drivers of imminent dangers so that they can take immediate actions such as crashing with a nearby vehicle, running a red light; (3) Taking control over the vehicle (e.g., slowing down or completely stopping) proactively to prevent an imminent crash in case the driver fails to act [5]. To support all these smart ITS applications the underlying system needs to ensure stable communication between system entities. Mostly, ITS rely on GPS and mobile data for localization among other services. However, traditional technologies such as WiFi, Bluetooth, Zigbee, are being used for ITS communication in the world, where GPS and mobile data are not available.

We envision that a large number of devices will be connected in the future to support various ITS applications in our daily life. As a result, heterogeneous data sources will be used to measure the lane occupancy, flow, speed, etc. to support various ITS applications. These devices measure information in different formats. Therefore, ITS tools need to support the data fusion by which information from multiple sources are combined in order to reach a better inference [6]. Furthermore, these connected devices will generate a huge amount of data in any given context. ITS tools must be able to process nearly incomprehensible amount of data and produce information which is useful to the vehicle users [7]. For example, this information can be used to guide vehicle users to their destinations in the most efficient way possible and interact with infrastructure to facilitate relief of traffic

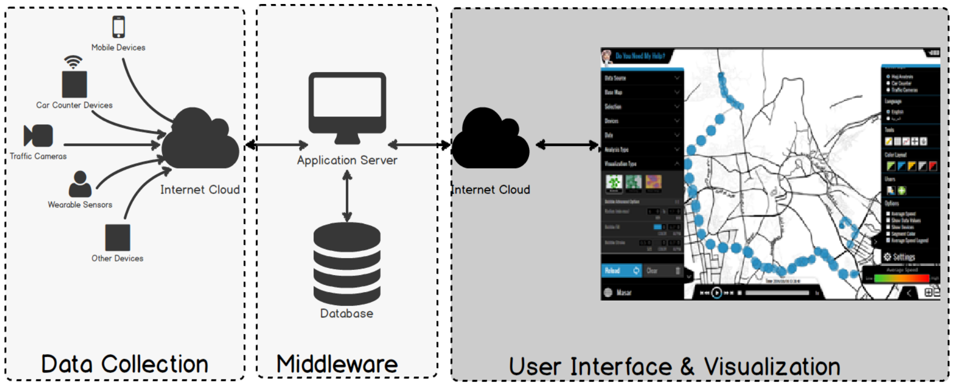


Figure 1: Masar platform abstract overview

congestion. ITS needs to do all these things in realtime. Mining useful information for vehicle users, traffic controllers, city planners and law enforcement personnel is another challenge.

To address the challenges described above, we proposed and implemented a software platform called *Masar* to support data-driven applications in ITS. For Masar platform, we follow a layered approach. It is based on three layers, as shown in Figure 1. One can distinguish three layers: the data collection layer, where the smart objects live, and are measuring the context in any given environment; the middleware layer, which is responsible for data management, fusion, storage, and analysis; and the visualization layer which facilitates the final users to easily understand processed data. It can collect data from heterogeneous sources such as cameras, traffic sensors, mobile devices, wearable sensors, social networks, etc.

This paper is structured as follows. The architecture of the proposed software platform is described in Section II. The experimental setup, performance metrics and results of the proposed strategy are discussed in Section III. We outlined the related work in Section IV. Finally, conclusion and future work are presented in Section V.

II. Proposed Software Platform - Masar

Masar is an online platform for ITS applications that helps to analyze data from the road traffic, and crowded areas using machine learning and statistical methods, and present the results to the end-users by using different visualization techniques. Figure 2 shows the proposed architecture of the Masar middleware layer.

A. Data Collection Layer

The role of the data collection layer is to interconnect heterogeneous devices such as mobile devices, wearable sensors, cameras, vehicle counting devices, and provides the contextual information of the given environments to upper layers of the Masar platform. Devices can be of various types, but in order to be considered IoT devices, they must have some ability of communication either directly or indirectly with Masar platform. The data collection layer is able to collect and combine data from various types of devices to support ITS applications, and perform both traditional and big data analytics on the collected data. The current implemented

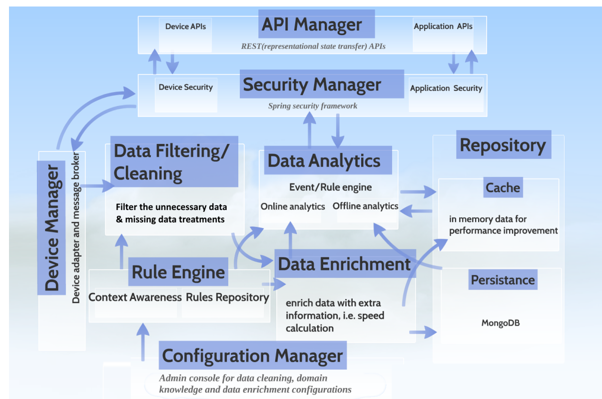


Figure 2: Middleware layer

data collection layer can collect data from various sources, which includes mobile applications for smart phones, different kind of wearable sensors such as Hexoskin [8], DigiAid [9] and wrist band (specially designed wearable sensor can be wear on wrist) etc. Another source is the video feeds form cameras which is processed using advanced image processing techniques.

At first step, we designed and developed a smartphone application called *MapMyTrip* available online. MapMyTrip has been used to collect the following information as a background service: location, speed, network and its type, signal strength, operator (mobile service provider), sampling time stamp, accelerometer measurements, gyroscope measurements, magnetometer measurements, smartphone information (name, brand, model), and driver information (name, description of trip, age, ethnicity, driving experience, eye sightseeing level, education level, vehicle type {LTV, HTV}). Moreover, the data collection layer is able to collect data from three different wearable sensors. Firstly, Hexoskin [8] is used to collect the following data attributes such as GPS location, heart rate, breath rate, and activeness. Secondly, DigiAid [9] is used to collect the following data attributes such as GPS location, temperature, humidity, physical pressure, atmosphere pressure, oxygen sensor, and altitude. Thirdly, the wrist band is used to collect the following data attributes such as GPS location, heart rate, step count, calories burnt, and activeness. Our developed software platform is also able to collect the data from video cameras, which are deployed at different places on roads and piazzas that get live feeds of traffic and crowd. The following data attributes are collected through video cameras: vehicle incoming count (for each lane), vehicle outgoing count (for each lane), vehicle changing lanes (incoming/outgoing), vehicle classification (LTV/HTV), incoming vehicle/hour, outgoing vehicle/hour, number of people coming in and out from a certain region, and number of people in a certain region. The following standard data formats are supported by the Masar platform, to load, analyze and visualize the data on the fly: CSV file (Comma Separated Values), JSON (JavaScript Object Notation), GPX (GPS Exchange Format), Shapefile (geospatial vector data format), and KML (Keyhole Markup Language).

B. Middleware Layer

The middleware layer is the core layer of the software platform. It receives data from heterogeneous sources at data collection layer. It also receives visualization tasks either by the visualization layer or the rule engine, and fulfill them by computing the appropriate analytical results. Actual smartness of the system exists in the middleware layer. It exposes secured APIs for the inward and outward communication. These APIs provide the means of communication between internal and external system components. This communication requires access validation through a *security manager* for all the connected channels. The *API manager* and *security manager* components of the middleware layer work together in order to establish secure communication. The APIs can be categorized as data collection APIs (for data collection layer) and application APIs (for visualization layer). *API manager* is mainly responsible for two tasks: (1) Using data collection APIs, users can integrate their devices with the Masar platform. By integrating devices, user are able to submit the data to Masar platform. A unified data model is used to gather the data from connected devices. (2) Using application APIs, users extract stored data in the Masar platform database. These application APIs include access to raw data as well as processed data through analytics. The Masar platform dashboard interface also uses the same APIs for analysis and visualization. The *security manager* is responsible to handle the authentication and authorization of any connected client (device or application) to the middleware. Security manager will grant or revoke access to the clients depending upon the credentials.

The *device manager* is responsible for communication with the devices and provides both individual and bulk control of devices. It manages the device pooling to prevent the data lost in case of bulk load. Device manager stores the acquired data into the database. As the basic aim of the proposed software platform is to support heterogeneous data-driven ITS applications, we need to ensure the data quality at runtime before using it to take decision for certain applications. The *data filtering/cleansing* component is responsible to filter the redundant data, and interpolate the missing values to increase the quality of the collected data. The *data enrichment* component transforms, enhance and refines the raw data. It is a value addition process, where the raw collected data from multiple sources is enriched data from multiple sources to enhance the quality and richness of the data. For example, the speed of vehicles is calculated using distance between two deployed vehicle counting devices. When a car is detected by the first device, an entry is logged. Later, when the same vehicle is detected by the second device, then average speed of that vehicle is calculated by i.e., average speed = distance between counting devices/time difference of car detection between counting devices.

The *rule engine* carries out data filtering and enables data enrichment components in decision making capabilities. It consists of mainly two components *context rules repository* and *common rules repository*, where each having their unique purpose. Context rules repository consists of dynamic rules and provides domain specific contextual information. This contextual information helps different components of the system to tweak them for optimal performance based on the contextual information. Common rules repository contains the standard configurations and rules for all other components. It is responsible for static rules. For example the threshold speed value after which alert to be generated for the drivers. The *configuration manager* provides an abstraction over both rules repositories as a comprehensive solution for the system administrators to change and configure the various components of the proposed framework such as data filtering and data enrichment. Further, the configuration manager allows administrators to configure or update the domain knowledge for ITS applications according to the end-users requirements.

After data preprocessing, the refined and enriched data is stored in a repository having two levels of storage in order to ensure the efficiency and availability of the data. These includes the *Level-I* (in-memory cache) and *Level-II* (persistence storage). The cache storage is implemented using an in-memory database approach for faster and efficient access to the most recent information. In-memory databases dramatically improve the performance by eliminating most of the data access latencies associated with shuttling data back and forth between storage systems and server processors. In-memory databases are available to provide real-time performance for the most demanding applications. The persistence storage is implemented using a standard big data database in order to ensure the integrity and availability of the data for both current and future usage. To enable data-driven decision making in realtime applications, systems need efficient machine learning and statistical methods to turn high volumes of fast-moving and diverse data into meaningful insights. The *data analytics* component of the proposed framework consists of two subcomponents, namely, offline analytics and online analytics. In general, analytics refers to techniques used to analyze and acquire intelligence from big data [7].

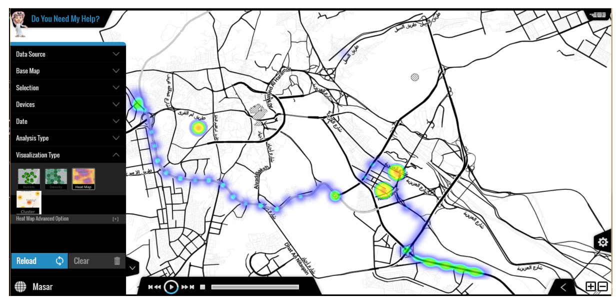
C. Visualization Layer

The visualization layer (user interface) provides the means to the end-users to interact with the developed analytical tools for ITS applications. It provides an option to visualize the collected raw data from heterogeneous sources for various types of ITS applications. Further, the visualization layer provides the means to visualize the results from the processed data. Those visualizations help to see the usable and meaningful data. The basic purpose of the Masar platform is to provide analytics and visualization on the raw data collected from heterogeneous sources. The proposed and implemented user interfaces are supporting various types of visualizations: (1) *Segment coloring* visualization is used to represent the road speed. Three colors have been used (slow = red, average = orange, high = green). (2) *Bubble map* is used to represent the values on map in different sizes, big bubble means higher values, whereas small bubble means lower values 3(a). (3) *Density map* is the representation in which areas are shaded in proportion to the measurement of the statistical variable being displayed on the map, such as speed (see Figure 3(b)). (4) *Heat map* is used to indicate the number of sensors data in a geographical area during the selected period of time 3(c). A color scheme is used to graphically represent the collected data to indicate the level of data samples collected. Dark colors are used to indicate low numbers, and bright colors are used to indicate high numbers.

Currently, the Masar platform supports three ITS applications, which require different types of analysis and visualizations. Firstly, the *Pilgrim Analysis Layer* uses the data collected from mobile devices [10] using MapMyTrip android application during Hajj event in Makkah, Saudi Arabia. This dataset contains a rich and diverse set of data samples, which we mentioned earlier in the data collection section4(a). Secondly, the *vehicle counter layer* includes the number of vehicles counted at different locations inside Umm Al Qura University campus using wireless sniffing devices. Speed analysis 4(b) on the roads inside the university was also carried out. Thirdly, the *traffic cameras layer* includes the vehicle and people counting data from both directions (incoming/outgoing) 4(c). Further, it also includes the vehicle classification, vehicle speeds and traffic density. The user can see the results of processed data by using the following visualization types such as tabular, graphs/charts, segment coloring, bubbles representation, density, and heat map representation (see Figure 3).

(a) Bubble map

(b) Density map



(c) Heat map

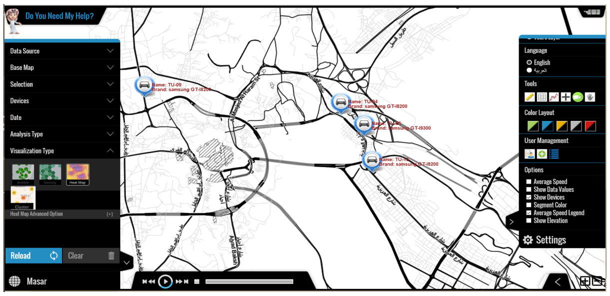
Figure 3: Visualization types

III. Performance Evaluation

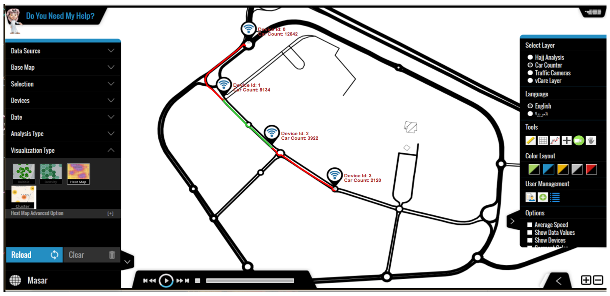
Traffic authorities can use Masar platform to monitor, control and manage the road traffic. It means that end-users should be encouraged to play active roles early in platform development. The users' opinions and expectations should be given detailed attention. Evaluation by end-users is particularly important for the development of systems with a multi-use perspective, which are designed to support customization for various uses, including unforeseen uses. Usability tests aim at examining how well the developed Masar platform meets the needs and objectives of its intended users. To this end, we performed the usability testing of the Masar platform for three ITS applications. The testing group consists of 10 people with the mean age of this group is 25, with a standard deviation of 3 years. 50% of them are female and 50% are male. Not surprisingly, all members of this group are advanced users of latest ICT technologies, and have driving experience. The user interacts to the visualization tool via the web interface. The instructions are passed to the lower levels of the Masar platform, and the results are reflected at the visualization layer, while the web interface view is updated accordingly. The user is asked to fill out the usability evaluation questionnaire. The focus of the testing methodology is to assess whether the architectural design and implementation of the Masar platform is useful and usable for users.

A. Usability Testing Approach and Metrics

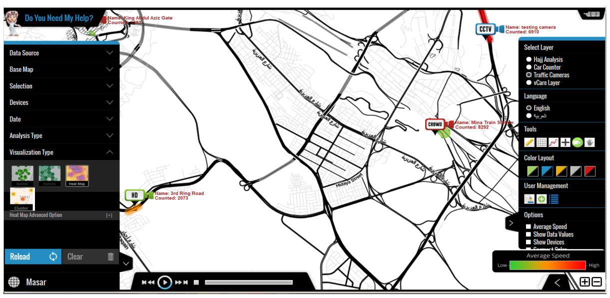
According to the ISO 9241-11 standard, usability refers to "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use". The evaluation of the system is two-fold: a quantitative analysis seeks to collect the users' assessment on a number of measurable parameters ranging over a given scale, while a qualitative



(a) Hajj analysis



(b) Car counter



(c) Traffic cameras

Figure 4: ITS applications

analysis aims at identifying users' difficulties, feelings, and wishes, so that these are taken into account in the future during the system improvement and extension. Data referring both to the quantitative and qualitative aspects of usability tests are gathered in terms of a questionnaire that is given to the users. In the followings, we explain the main usability features along with their relevant metric components: (1) *Acceptability* of Masar visualization platform in general captures the opinion of users towards the importance of ITS technology, their eagerness to delegate tasks to an analytical software to give them useful information on the road. (2) *Learnability* assesses how easy it is for the user to get familiarized with the system. It refers to the amount of effort the users have to make in order to understand the functionalities of the ITS tool. (3) *Aggregate system effectiveness* measures how satisfied the users are from the ITS tool, by taking into account a number of aspects referring to different components. For example, a metric is used with respect to the control panel's usability, assessing how clear and attractive the Web Interface is, and how convenient to use. (4) Finally, *efficiency* is concerned with the speed at which the system performs certain tasks.

Usability feature	
Aggregate acceptance	0.95
Learnability effort	0.80
Aggregate system effectiveness	0.92
Efficiency	0.94

TABLE I: Aggregated results of the usability tests of the Masar platform

Table I summarizes the quantitative findings of the usability tests. All quantitative factors included in the questionnaires are mapped to a scale from 0 to 1. The findings indicate that the aggregate acceptance, aggregate system effectiveness and efficiency metrics values are particularly high. We also asked testing group to identify potential problems and recommendations to improve the current Masar platform. The findings conclude that the Masar platform together with the visualization layer is useful to the users.

IV. Related Work

An extensive literature study has been performed to know the challenging issues in transportation domain, and also reviewed the state of the art solutions to tackle these issues. CarWeb [11] traffic data collection platform depends on GPS data sharing for calculating road speeds. They propose two algorithms to calculate road speed. First one is based on averaging the speeds of all cars on the road and second one is based on the weighted average of moving cars and stopped cars waiting for green light at the signal. Zhang et al. [12] developed a system that can provide traffic congestion information to users. Zhang et al. [13] propose a method to process the GPS data by increasing weights of recent records and high velocity. They used weighted approach of aggregate-based and sampling-based ways to evaluate performance of the weighed method and the heuristic method for estimating traffic states using samples. Zhu et al. [14] claim that real-time traffic information system produces massive traffic data and that its reuse for history data mining implies massive storage and high performance processing requirements. They alleviate this by using a cloud computing and storage based infrastructure, and provide distributed data management service to support data storage and data mining. Iovanovici et al. [15] developed a traffic monitoring and data collection system using a custom designed java application running on smart phones. They also provide a web interface to query the data collected. Moreover, they proposed an algorithm called GIS Independent Location Algorithm (GILA) for collecting data in absence of GIS information. Main et al. [16] proposed a data platform that transforms collected traffic data into information.

Zhao et al. [17] describe DeCloud4SD, an integrated processing platform as a service for receiving, storing, acquiring and computing traffic sensor data in a scalable architecture with real-time guarantee. Their analysis shows that DeCloud4SD can ensure scalable and customizable traffic sensor data gathering and computing, rapid application development and deployment using a MapReduce-like model, and seamless integration with existing relational data sources and applications. Later, Zhao et al. [18] propose a system for traffic sensory data processing, which is designed to combine spatio-temporal data partition, parallel pipeline processing and stream computing to support traffic sensory data processing. Cui et al. [19] developed the GrandLand Traffic Data Processing Platform (GLPlatform) that uses data-driven model to provide distributed and scalable processing of traffic surveillance video data.

Hung and Peng [20] proposed a model-based data collection framework to reduce the amount of data transmission and the number of vehicles reporting their GPS data points. Using their framework, vehicles report some coefficients that describe its movements instead of reporting all position information. Our proposed Masar platform distinguishes itself from existing literature by supporting the data cleaning, data enrichment, smart data repository, data collection from heterogeneous sources, advance data analytics solutions to have real-time computation, and advanced visualization types.

V. Conclusion and Future Work

We proposed and implemented a prototype of the Masar platform that couples advanced research methods and technologies into the layered architecture of the Masar platform, in particular, data collection, data preprocessing, data enrichment, data analytics, data storage components at middleware layer, and advanced visualization techniques. It can support various ITS applications with a minimum effort. We used layered architectural pattern for more high-level abstractions, such as data collection layer, middleware layer, and visualization layer. We further decomposed the middleware layer into discrete components. This decomposition in turn makes our high-level design a highly cohesive solution, where each component has its well defined role in the overall system. This ensured the low coupling design principal in our high-level design. A useability study is performed to investigate the users' acceptance and suggestions to improve the Masar platform. In future, we planned to have usability testing with traffic control authorities. ITS applications infrastructure is generating a huge amount of real-time data from various sources. Therefore, the Masar platform will be extended with a unified data model to make the data collection process more easy and fast, and it will increase the scalability and resolve the interoperability issues. Further, the current implementation of the middleware layer components will be updated with the state of the art methods and technologies to support real-time ITS applications. Moreover, we will evaluate the performance of each individual component of the middleware layer using the relevant performance metrics.

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