ISSTA: An Integrated Sensing System for Transportation Applications

Ken Yeo-Moriuchi, Sandra Deepthy Siby, Zhengqing Hu, and Mehul Motani
Electrical and Computer Engineering, National University of Singapore
{ken.yeo.moriuchi, sandrasiby, zhengqing}@gmail.com, motani@nus.edu.sg

***Abstract*—Traffic congestion has become an increasingly important issue worldwide. One way to mitigate this problem is to provide real time traffic information to drivers to help them make better decisions. To achieve this, we propose an integrated sensing system for transportation applications (ISSTA), that includes traffic sensing, data aggregation and information delivery. This system consists of two parts. The front end is a mobile device (attached to a vehicle), which can support real time traffic and environment sensing, wireless information transmission, and interaction with drivers. The back end is a server, which stores the information collected and implements smart decision-making. In addition to this, the system supports plug-and-play for a list of sensing components. At the same time, the information collected and decisions made can be easily monitored in real time through web services. We have built a prototype system and applications like real time environment monitoring and lane sensing have been implemented and tested on this system. We have shown that the prototype system is reliable and can provide valuable information to drivers and useful data to researchers.**

I. Introduction

Traffic congestion, such as the situation shown in Fig. 1, is a common problem for both developing and developed nations. It is predicted that traffic congestion will substantially get worse by the end of decade, even on the very favorable assumption that all current government projects and policies are implemented in full, successfully, and on time [1]. One example is in Jakarta, where the number of vehicles on the road doubled in the preceding 10 years while roads only grew 10% [2]. It also estimated that the traffic delays cost Jakarta \$3.5 billion a year in terms of extra fuel costs and productivity loss. If things in Jakarta remain as they are, it is predicted in [2] that traffic will grind to a complete halt by 2014.

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Fig. 1. Severe congestion [3]

The efforts that have been taken to mitigate the traffic congestion problem can be generally categorized into three different approaches: infrastructure-based, policy-based, and technology-based. The first approach is based on upgrading and providing new infrastructure resources such as building more roads and widening existing roads. Railway based transportation systems are also deployed, as an alternative, to reduce the load of road traffic. The second approach is based on implementing transportation policies and aims to reduce the demand for the traffic resources. Normally, it uses a monetary mechanism to reward people for buying fewer cars, driving less, and avoiding congested hot spots while driving. The last approach is based on using technology to mitigate congestion and increase the efficiency of using the existing road resources. Examples include collection of real time traffic information, and radio broadcasting or the Internet alerting drivers of road disruptions, variable message signs [4], installed along the roadway, to advise road users, and etc.

Many of the currently implemented technologies are infrastructure-based, which means they often require dedicated infrastructure on the side of road. Information can only be collected where there is infrastructure present.

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Hence, they are inherently associated with high deployment and maintenance costs. This forces traffic authorities to make significant investments to render such systems useful on a large scale.

Through technology innovation and advancement in making smart cars, many cars have substantial capability to sense nearby environment and traffic conditions. For example, reversing radar (based on ultrasonic sensors), alcohol gas sensors, and video cameras are available on many cars. Hence, it may be a cheaper and finer fidelity alternative to enable distributed sensing (sensing by individual car) instead of a centralized (infrastructure based) approach. Of course, if the infrastructure is already available, we can also combine the information collected by both approaches to provide a clearer picture of traffic condition. However, since information is sensed at each mobile vehicle, it is a challenging task to transfer and aggregate the information in real time.

In this paper, we have designed and implemented an integrated system which combines the distributed information sensing and relaying component (front end) and the data aggregation and processing component (back end). Currently, our system supports a number of sensors like temperature, pressure, humidity, light, GPS, ultrasonic distance, infrared distance, gas emissions and etc. Once information is sensed, values are sent to a 3G-enabled cell phone via Bluetooth. On the cell phone, the collected information will be shown to users, and at the same time forwarded to a server. At the back end, the server will store and aggregate the collected information from different cars. Algorithms can be applied to detect high level traffic conditions, or answer other inquiries. Driver with supported cell phones will be automatically alerted about any change in road conditions. Other users can also access the traffic conditions through a web service. With this system, we are aiming to provide relevant real time traffic information to users to help them make better decisions.

A. Related Work

An emerging example of utilizing vehicles for mobile sensing is the collection of road traffic data to permit better management of the transportation infrastructure and to permit navigation based on real-time congestion information. Work has been done in producing a platform for general collection of sensor data, such as the project of Floating car data [5] [6], which utilizes GPS embedded cell phones to sense the location and speed of cars;

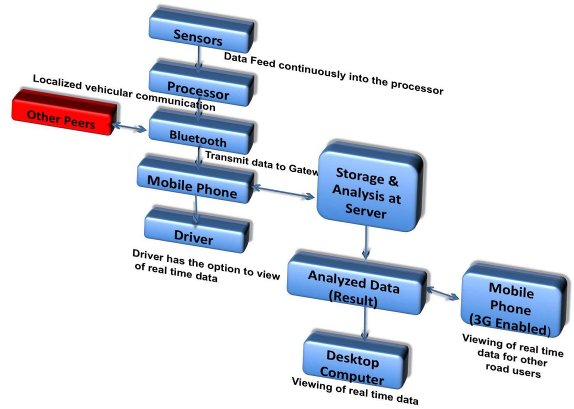

Fig. 2. ISSTA system architecture

project of CarTel [7], where individual cars are treated as sensor nodes and data is obtained about the driver and the environment. Our work builds upon and generalizes these ideas into a multi-purpose real time vehicular platform. We utilize the widely available 3G-enabled cell phone as relay node to provide real time connection and save cost. At the same time, extensibility, potability and plug-and-play technology is supported by our system.

II. System Architecture

The overall structure of ISSTA is shown in Fig. 2. ISSTA can be divided into two parts: the front end systems, which are attached to individual vehicles, and the back end system, which serves as a central server. In ISSTA, multiple front end devices collect and transmit sensing data to the back end server continuously. At the same time, the front end also serves as a user interface, through which queries are received and results are displayed. Once data reaches the back end system, it is stored, aggregated and analyzed. At the same time, a web service is available, which enable real time monitoring and updating.

A. Front End System

The front end system consists of a number of sensors collecting data like temperature, pressure, humidity, light, GPS coordinates, ultrasonic distance, gas emission etc. These values are forwarded and processed by a micro controller (Arduino Mega [8]) through standard digital I/O pins or serial ports. Then the micro controller will send data to an Android phone via Bluetooth. Finally, the phone sends the data to the central server via any available Internet connection, i.e. either through 3G cellular networks or WiFi wireless LANs. Meanwhile, the

Fig. 3. Hardware in the front end of ISSTA

Fig. 4. Illustration of the IO ports

phone serves as an interface to the driver, which displays information and collects instruction from drivers.

As shown in Fig. 3, the hardware components we used in the front system are:

- Top left corner: Arduino Mega micro controller board with BlueSmirf Bluetooth adapter, battery pack and multiple on/off switches for different sensors.
- Bottom right corner: Google Nexus One with Android 2.2 installed
- Remainders: Different sensors including Sparkfun Weather Board [9] (the board in red), Parallax GPS Receiver Module, Ultrasonic range sensors and etc.

B. Back End System

The back end system consists of a few modules including the module of authentication, web service, database, and the module of data aggregation and analysis. Once a front end device connects with the back end server, the user has to authenticate himself through his user name and password. The subsequent sensing data will be stored in the database where three fields (User Id, time and GPS location) are compulsory and the rest of the sensing data is optional. The web server, on the other hand, provides an interface to users for any queries. Once a queries is submitted, it will be passed to the data aggregation and analysis module to process. For example, if a user asks the average speed of a particular road in the past 30 mins, the web server will pass the query to the data aggregation and analysis module. This module will look for any matching data in the database, calculate the average speed and feedback to the web server and finally the result will be displayed to the user through cell phones or any web browsers.

C. Features

1) Plug-and-Play Technology: ISSTA supports plug-and-play technology for a list of sensors including sensors of GPS, temperature, pressure, humidity, ambient light, infrared, and ultrasonic distance. As shown in the Fig. 3, once any of the above-mentioned sensors are connected to the micro controller through any of the digital I/O ports or serial ports (shown in Fig. 4), they can be automatically detected and sensing data will be collected. From the raw data, the micro controller and cell phone will remove unnecessary information and re-format the data before forwarding it to the server.

ISSTA also supports other sensors, as long as they use standard digital I/O ports or serial ports. ISSTA will try to collect the information from these ports and relay whatever is collected to the server. At the server side, the unprocessed data are marked as ”others”. Hence, without changing the software program, people can use ISSTA to collect and relay sensing data for many sensors. We believe it will be a favorable feature for many small scale research projects, where developers may not want to touch the software codes on the front end devices.

2) Portability: The front end of ISSTA is powered by battery and uses wireless communication to relay information. Its size and weight are equivalent to that of a book; hence it can be easily carried around. This means that our system can be easily used in many other ways besides vehicular applications. For example, it can be carried by humans to detect indoor environmental conditions, carried by any remote controlled vehicles

←T→	id	timestamp	latitude	longitude	humidity	light	pressure	temperature
	sj1234f	2011-03-20 21:08:18	117.9254	103.4632	73.67	1023	99903	29.3
	sj1234f	2011-03-20 21:08:19	117.9254	103.4632	73.67	1023	99905	29.3
	sj1234f	2011-03-20 21:08:20	117.9254	103.4632	73.67	1023	99903	29.3
	sj1234f	2011-03-20 21:08:21	117.9253	103.4632	73.67	1023	99907	29.3
	sj1234f	2011-03-20 21:08:22	117.9251	103.4632	73.64	1023	99906	29.3
	sj1234f	2011-03-20 21:08:23	117.9251	103.4632	73.67	1023	99905	29.3
	sj1234f	2011-03-20 21:08:25	117.9249	103.4632	73.67	1023	99907	29.3
	sj1234f	2011-03-20 21:08:26	117.9248	103.4632	73.67	1023	99904	29.3
	sj1234f	2011-03-20 21:08:27	117.9247	103.4632	73.67	1023	99905	29.3
	sj1234f	2011-03-20 21:08:28	117.9246	103.4632	73.67	1023	99907	29.3
	sj1234f	2011-03-20 21:08:29	117.9246	103.4632	73.64	1023	99905	29.3
	sj1234f	2011-03-20 21:08:30	117.9244	103.4632	73.64	1023	99905	29.3
	sj1234f	2011-03-20 21:08:31	117.9243	103.4632	73.64	1023	99905	29.3
	sj1234f	2011-03-20 21:08:32	117.9240	103.4632	73.64	1023	99907	29.4
	sj1234f	2011-03-20 21:08:33	117.9239	103.4632	73.67	1023	99905	29.3
	sj1234f	2011-03-20 21:08:34	117.9236	103.4632	73.67	1023	99905	29.3
	sj1234f	2011-03-20 21:08:36	117.9234	103.4632	73.64	1023	99907	29.3
	sj1234f	2011-03-20 21:08:37	117.9231	103.4632	73.64	1023	99904	29.3
	sj1234f	2011-03-20 21:08:38	117.9230	103.4632	73.67	1023	99905	29.4
	sj1234f	2011-03-20 21:08:39	117.9228	103.4632	73.67	1023	99903	29.3
	sj1234f	2011-03-20 21:08:40	117.9226	103.4632	73.64	1023	99903	29.3

Fig. 5. Illustrative data collected by the data logger application

to detect off-road information, or even a mobile sink in a wireless sensor network. Meanwhile, for the easy installation of different sensors on different cars, we have packaged sensors into standard box and attached magnets at the back of the box. With the help from magnets and simple wiring, sensors can be securely mounted outside the car and can sustain the vibration while the car is moving.

3) Open Source Platform: From the initial stage of this project development, we adopt the concept of Open Source in both the front end and back end of our system. This gives us the maximum flexibility and, at same time, much support from on-line resources. Since we have benefited from this feature, we want to enable others who use this system to customize it easily.

III. Applications

As we introduced earlier, we have successfully deployed and tested the following sensors with ISSTA: GPS, ultrasonic range sensor, infrared range sensor, temperature sensor, humidity sensor, lighting sensor, pressure sensor and gas emission sensor. Based on these sensors, we have built the following applications to test the ISSTA prototype: data logger and query and lane sensing.

A. Data Logger and Query

In this application, we installed the front end of ISSTA on a car. The information sensed, including GPS coordinates, temperature, humidity, lighting and pressure, is transmitted to the server and stored in an SQL database. The format of the data logger is shown in Fig. 5, where the environmental data are collected together with the GPS coordinates. Once the data are stored in server, we can either monitor all the updates in real time or send queries to the web server to get specific data. For example, we can query about the average speed in the past 5 minutes to know how fast the car has traveled or get an idea of local traffic conditions. We can also query about the weather in a particular area at different times to track the change in weather conditions.

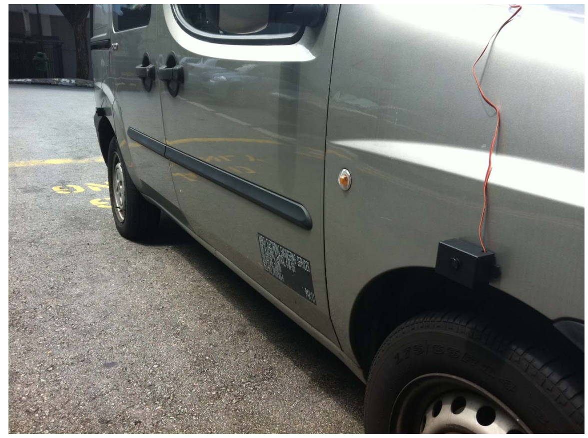

Fig. 6. The mounting of 2 UDSs on one side of vehicle

B. Lane Sensing

Lane detection is one of the primary research topics in advanced driving assistance systems. It also plays an important role in alerting of road disruptions. We propose a lane detection method with the assistance of four ultrasonic distance sensors (UDS) and GPS. Compared to the conventional vision based approaches, the ultrasonic based system is more robust under different environmental conditions (e.g. lighting, meteorological, and road condition). However, since the information collected by UDSs cannot tell the lane directly, it is challenging in terms of interpreting the data to get accurate lane detection. In this application the hardware includes 4 UDSs, mounted above the 4 wheels of a car. Each UDS has a maximum transmission range of about 6.2 m and has a maximum detection rate of 20 times per second. The distance between the front UDS and the rear UDS is about 2.5 m. Please refer to the Fig. 6 for the mounting of the UDSs. At the same time, the GPS can give the information of the car's speed and location.

We propose an algorithm which detects the lanes by performing two tasks: detect the reference distance and detect any other moving cars on the nearby lanes. The reference distance is the long time average distance a

UDS detects. This value is normally the distance from the car to the side of the road if there are solid boundaries (walls) on the road side; it will give the maximum range (6.2 m) in the case there are no boundaries. If the car detects some distance value, which is significantly different from the reference value, we know the car is passing by some objects, either on the road or on the roadside. Then we perform the second task: motion detection with length estimation of the object. If the object is moving and its length is longer than 3 meters, the object is most probably another car. This further implies there is a lane associated with the detected car. For example, if we pass a car or are passed by a car on the left hand side with a distance detected as 4 m, we know there is a lane 4 m away on the left. Hence, we are at least on the third left lane. By combining the data from both sides of the car, we can estimate which lane we are on.

Since the car is not always passing other cars, we need to make the decision based on the historical data (currently we use the data of the past 30 seconds). A potential problem with this method is that it may not react as quickly as a car changes lanes. It starts reporting lane changing after the car passes two or more cars. We find that it may not be a big problem when the car density is high e.g. during a peak hour where the traffic alerts with details to each lane is much appreciated. Another problem is related with the accuracy of the speed detection and length detection. This detection is based on the time gap of the report of the two sensors. For example, at the speed of 10 m/s, if the front sensor gets a hit at time 0 s and the rear sensor gets the hit at 1 s later, then we know the car we pass by has the speed about 7.5 m/s (since the distance between the two sensors is 2.5 m). However, this value may have an error due to inaccurate measurement of the time. For example, it may happen that the rear sensor actually crosses over the other car at time 0.96 s. However due to the fixed updating time, we only detect the cross over after the 0.04 s delay. This implies that the lower the updating rate, the larger the error is. Similarly the larger the speed difference of the two cars is, the larger the error is. With our current updating speed of 0.05 s, we can have a relative accurate estimation (1 m/s) if the speed difference is within 20 km/h.

In our application, we have applied this algorithm on the cell phone, which received the distance data from the four Maxbotix LV-EZ1 range sensors. Experiments have shown that we can, most of the time, get an accurate lane detection result approximately 10 s after we change lanes.

IV. Conclusion

With the current trend of building smart automobiles and popularity of 3G-enabled smart phones, large scale vehicular sensor networks will be a reality in near future. We have developed an integrated sensing system for transportation applications, called ISSTA, to provide a general purpose platform according to this vision. It provides the software system as well as the hardware platform to sense, transmit, store, process and display data for mobile vehicles in real time. Applications like environment sensing, speed sensing, and lane sensing, have been successfully tested on this system. We hope that ISSTA can serve as a test bed for research on vehicular networks and intelligent transportation systems, as well as a provide an understanding of how to design such systems in the future.

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