Vehicular Sensing System for CO_2 Monitoring Applications

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***Abstract*—We are interested in monitoring the concentration of carbon dioxide (CO_2) gas in a large field such as an urban area. Although wireless sensor networks have been widely deployed to monitor environments, it has not been well addressed to use a small number of sensor nodes to monitor dynamic factors such as CO_2 concentration in a large field. We thus propose a *vehicular sensing system* to collect CO_2 concentration in large areas of interest. Our system is realized based on GSM short messages and geographic information of vehicles. Using vehicles as the carriers of sensing devices provides a flexible and economic solution to monitor a large field. We demonstrate our prototype of a ZigBee-based intra-vehicle network to monitor CO_2 concentration in Hsin-Chu city, Taiwan. The collected data is reported to a remote server, which is integrated with Google Maps as our user interface.**

***Index Terms*—CO_2 concentration, environmental monitoring, mobile sensor, vehicular sensing system, wireless sensor network.**

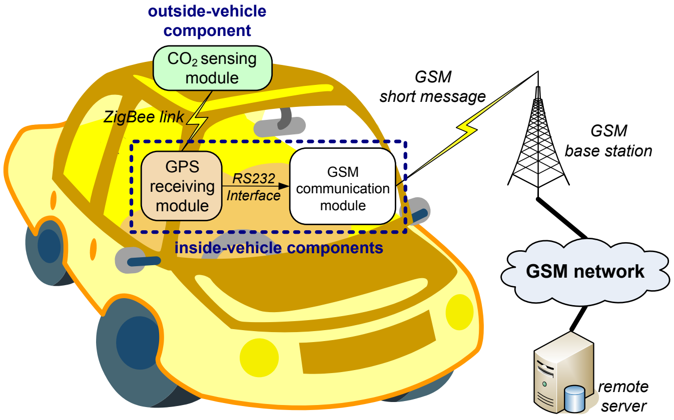


Fig. 1. The concept of our proposed vehicular sensing system.

I. INTRODUCTION

Carbon dioxide (CO_2) gas has been proven to be one of the most significant gases that will cause global warming. How to efficiently monitor CO_2 concentration in a large field such as an urban area is an interesting research topic. On the other hand, wireless sensor networks for environmental monitoring have been widely researched [1]–[3] . However, it has not been well addressed to use a small number of sensor nodes to monitor dynamic factors such as CO_2 concentration in a large field. Using vehicles equipped with sensing devices to collect environmental data would thus be an attractive solution. We refer to such a system as the *vehicular sensing system*.

This paper proposes the architecture of a vehicular sensing system for CO_2 monitoring applications, as shown in Fig. 1. Our system relies on GSM short messages and geographic locations of vehicles. In particular, we equip several vehicles with CO_2 sensing devices, GPS receivers, and GSM communication modules. These vehicles can be buses or taxies and they will roam inside the monitoring area. Each of the vehicles will continuously collect CO_2 concentration in its surroundings and periodically report the concentration together with its current location to a remote server, through GSM short messages. In this way, we can use only a small number of vehicles to conduct CO_2 monitoring in a large urban area. In addition, since vehicles possess high mobility, our vehicular sensing system can be easily applied to other monitoring regions.

In the literature, the issues of node deployment, network repairing, and sensor dispatch by mobile sensors have been intensively studied [4], [5]. The work in [6] proposes a hybrid sensor network for surveillance applications, where mobile sensors equipped with richer resources will visit those static sensors that have reported abnormal events to conduct a more advanced analysis. Several studies consider carrying sensing devices by vehicles to conduct various monitoring applications. For example, In [7], cars are equipped with vehicular sensors and GPS receivers to conduct car-health monitoring and driver characterization. The work in [8] equips multiple types of sensing devices such as microphones and cameras on bicycles, and cyclists will ride these bicycles to collect road information along several predefined routes. Reference [9] adopts cameras and chemical sensors on vehicles to monitor pollution from streets, and vehicles may exchange their monitoring data when they meet each other.

As can be seen, using vehicles as the carries of sensing devices to conduct environmental monitoring is quite promising. This motivates us to develop a vehicular sensing system for CO_2 monitoring applications in a large field. We demonstrate our prototype of a ZigBee-based intra-vehicle wireless network to monitor CO_2 concentration in Hsin-Chu city, Taiwan, and the results are displayed on Google Maps.

The rest of this paper is organized as follows. Section II presents the architecture of our vehicular sensing system. In Section III, we give our prototyping experience. Section IV

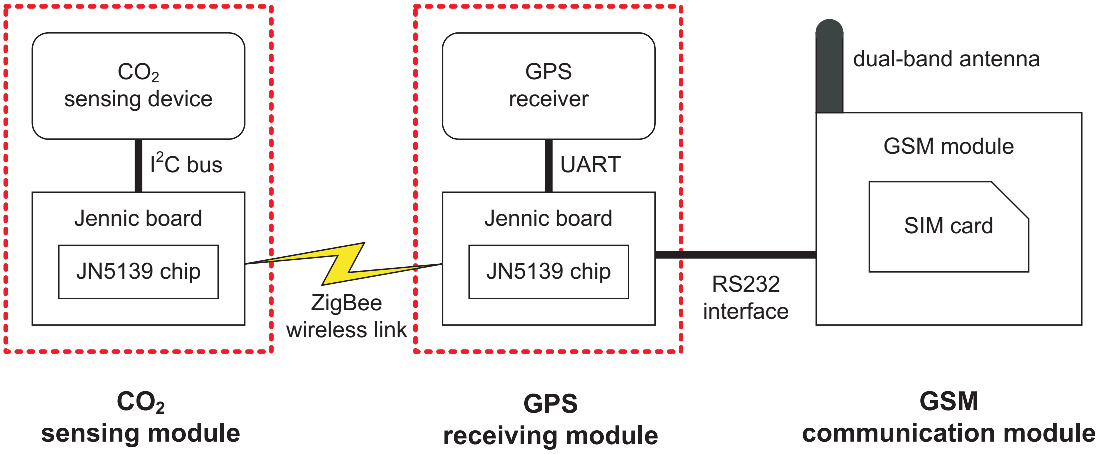


Fig. 2. The hardware architecture of our vehicular sensing system.

concludes this paper.

II. SYSTEM ARCHITECTURE

Fig. 1 illustrates the the concept of our vehicular sensing system. Each vehicle is equipped with three modules: *CO_2 sensing module*, *GPS receiving module*, and *GSM communication module*. The CO_2 sensing module is installed outside the vehicle to collect the surrounding CO_2 concentration. The other two modules are installed inside the vehicle. The GPS receiving module will periodically receive geographic data from the GPS satellites. The GSM communication module will then receive both the CO_2 concentration and the current location of the vehicle, and transmit these data to a remote server, through GSM short messages. Note that the communication between the CO_2 sensing module and the GPS receiving module is through a ZigBee wireless link.

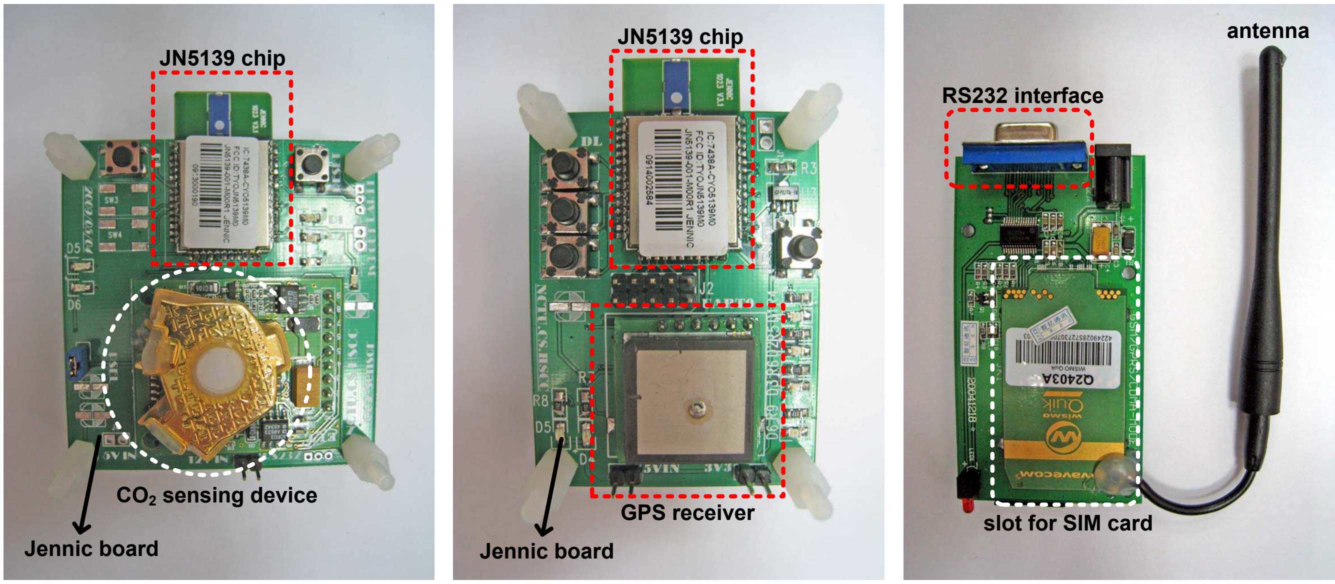
Each vehicle is assigned with a *reporting rate* to determine the interval between two successive GSM short messages (i.e., the reported data) that will send to the server. The default reporting rate of each vehicle is set to low (for example, 5 times per hour) to reduce the cost of sending GSM short messages. However, when users query more detailed CO_2 distribution in some regions, the server will notify the vehicles in these regions to increase their reporting rates. Such a notification is also through GSM short messages. On the other hand, when either the vehicle moves out of these regions or a predefined timer has expired, this vehicle will reset its reporting rate as the default one to reduce the message cost.

Fig. 2 shows the hardware architecture of our vehicular sensing system. The CO_2 sensing module is composed of a CO_2 sensing device and a Jennic board, where the latter is a small embedded computer that can conduct the operations of computation and wireless communication. Two Jennic boards can communicate with each other following the ZigBee standard [10]. The CO_2 sensing device will communicate with the Jennic board through an I^2C (I-squared-C) bus, which is a simple bi-directional 2-wire bus for efficient inter-IC control. The CO_2 sensing device will sample the surrounding CO_2 concentration and send the sampling data to the Jennic board, and the latter will further transmit them to the GPS receiving module, through a ZigBee wireless link. The GPS receiving module is composed of a GPS receiver and a Jennic board. The GPS receiver will synchronize with the GPS satellites and receive geographic locations from them, and then send the location information to the Jennic board through a UART (universal asynchronous receiver/transmitter) interface, which supports both serial and parallel communication of data. Note that the Jennic board in the GPS receiving module will combine the geographic location with the monitoring CO_2 concentration sent from the CO_2 sensing module, and then transmit these data to the GSM communication module through an RS232 interface. The GSM communication module containing a SIM card will then transfer the data sent from the GPS receiving module to fit the format of GSM short message, and send out the GSM short message to the remote server through its antenna.

III. PROTOTYPING EXPERIENCE

In this section, we present our prototyping experience. Fig. 3 illustrates our hardware implementation, which contains the following devices:

- **CO_2 sensing device:** We adopt the H-550EV CO_2 module [11] as our sensing device. The detectable range of CO_2 concentration is from 0 to 5,000 ppm (parts per million), with error range of ±30 ppm. H-550EV CO_2 module will sample its surrounding CO_2 concentration in every 3 seconds. Its response time is set to 30 seconds.
- **GPS receiver:** We adopt the uPatch300 GPS module [12] as our receiver. It can provide geographic location with accuracy small than or equal to 1.8 meters. Its reporting rate is set to 1 second.
- **GSM communication module:** We adopt the Siemens TC35 GSM module [13] as our communication module. It supports dual-band EGSM/GSM communication on frequency bands of 900 MHz and 1800 MHz.
- **Jennic board:** Recall that the CO_2 sensing module can communicate with the GPS receiving module through a ZigBee wireless link. This is realized by Jennic boards. Each Jennic board contains a Jennic JN5139 chip [14].



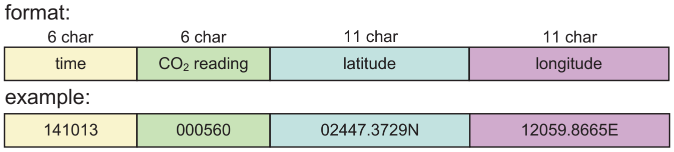
(a) CO_2 sensing module (b) GPS receiving module (c) GSM communication module

Fig. 3. The snapshots of our hardware components.

This chip includes a 32-bit RISC processor, a fully compliant 2.4 GHz IEEE 802.15.4 transceiver [15], 192 KB of ROM, and 96 KB of RAM. We adopt the ZigBee protocol as the inter-board communication.

Each vehicle will report its current location and monitoring CO_2 concentration through a GSM short message, which follows the format of “time, CO_2 reading, latitude, longitude”, as shown in Fig. 4(a). For example, a string of “141013, 000560, 2447.3729N, 12059.8655E” indicates that a vehicle has detected the CO_2 concentration of 560 ppm on the location of 2447.3729 degrees north latitude and 12059.8655 degrees east longitude at time 14:10:13 (hour:minute:second). On the other hand, the server can adjust the reporting rates of vehicles in certain region by sending a GSM message with the format of “latitude and longitude of the top-left point, latitude and longitude of the bottom-right point, new reporting rate, expiration time”. For example, a string of “244728382N120595138E, 24408565N121591245E, 10, 150000” indicates that the reporting rates of vehicles inside the rectangle with the top-left point at location (2447.28382N, 1205.95138E) and the bottom-right point at location (2440.8565N, 1215.91245E) should be adjusted to 10 times per hour, and this command will expire at time 15:00:00. The message format of the server is shown in Fig. 4(b).

We have implemented a 16-node prototype to collect CO_2 concentration in Hsin-Chu city, Taiwan. Fig. 5 demonstrates our monitoring results at the National Chiao-Tung University (NCTU) campus. The monitoring region is approximately 80 hectares and we partition it into 5×4 grids. The range of monitoring CO_2 concentration is within [380, 429] ppm and is divided into 5 levels. The colored circles on the Google Maps indicate the CO_2 concentration on the corresponding locations. Different colors represent different levels of CO_2 concentration.



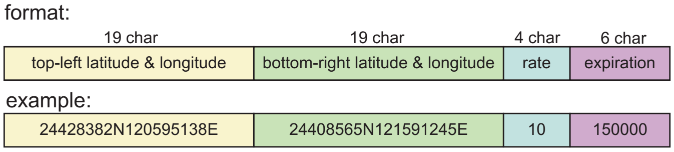
format:

6 char	6 char	11 char	11 char
time	CO_2 reading	latitude	longitude

example:

141013	000560	02447.3729N	12059.8665E

(a) message format of a vehicle



format:

19 char	19 char	4 char	6 char
top-left latitude & longitude	bottom-right latitude & longitude	rate	expiration

example:

24428382N120595138E	24408565N121591245E	10	150000

(b) message format of the server

Fig. 4. The formats of our GSM short messages.

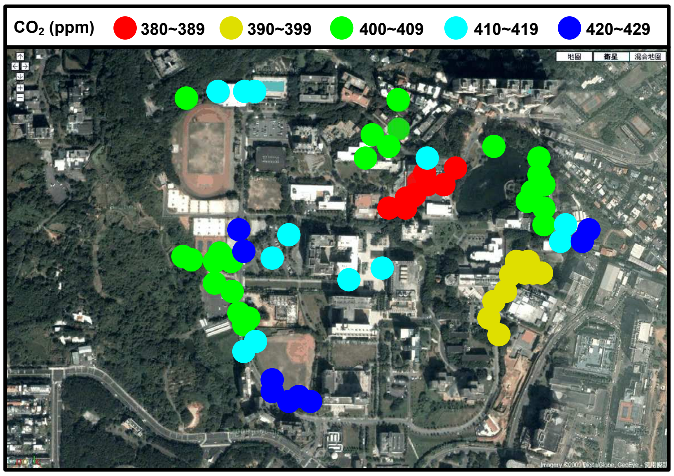


Fig. 5. User Interface on Google Maps.

IV. CONCLUSIONS

In this paper, we have proposed a vehicular sensing system to monitor CO_2 concentration in large areas of interest. The idea is to carry sensing devices by vehicles and make these vehicles roam inside the area of interest to collect CO_2 concentration. We have also implemented a 16-node prototype to monitor CO_2 concentration in Hsin-Chu city, Taiwan. The prototyping experience is reported in this paper.

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