GRPS-Based Distributed Home-Monitoring Using Internet-Based Geographical Information System

A. R. Al-Ali, Imran A. Zualkernan, Assia Lasfer, Alaa Chreide, and Hadel Abu Ouda

**Abstract — ***Recent developments in publically available web-based Geographical Information Systems (GIS) and the availability of low-cost integrated General Packet Radio Service (GPRS)/Global Positioning Systems (GPS) modem have enabled the development of embedded stand-alone home monitoring systems. This paper presents the design, implementation and testing of a home-monitoring system that utilizes online Map from a GIS in conjunction with the readily available public satellite-based GPS, and GPRS mobile networks. In addition to detecting intruders, the system allows a home owner to remotely monitor various critical home sensors status including those tied to fire, flooding, and gas leaks. Home owners can monitor their homes via their mobile phone or by using the Internet. This system can also be utilized by security firms, civil defense organizations and municipalities to continuously monitor and locate troublesome spots in residential neighborhoods and compounds using free GIS Maps*[1].

Index Terms — GPRS, GIS, Smart Home, Security, Embedded Systems, Remote Monitoring.

I. INTRODUCTION

World Wide Web, wireless communication tools and gadgets are being extensively utilized by the youth via social networks, smart phone and GPS technologies. While on the move, young home owners are utilizing GPS and GIS technologies for road and personal navigation, texting each other using smart mobile devices, using social media to communicate and follow each others' news instantaneously. The wide-spread popularity, acceptance and usage of these technologies has presented an opportunity to research and development engineers as well as information technology service providers to develop and provide value-added services. One such value-added service can enable the digital native generation to access and interact with their home appliances and to monitor and control their home systems in addition to smart energy conservation while on the move.

Several systems using Bluetooth, Infrared (IR), Zigbee and Radio Frequency Identification System (RFID) based communication protocols have already been utilized to wirelessly monitor homes within a short range. For example, the Bluetooth technology was utilized to build an intelligent home-security system [1]. In addition, remote-controllable power outlet system for home power management [2], a networked monitoring system for home automation [3] and intelligent home appliance control system [4] have also been proposed. An IR interactive remote control of legacy home appliances through a virtually wired sensor network were also described [5].

Zigbee–based technology has been used in local monitoring and controlling of home appliances within homes. For example, Zigbee-based remote information monitoring devices for smart-homes and home automation systems were developed and reported [6,7,8]. Monitoring and protection building electrical safety system utilizing ZigBee was also presented [9].

RFID technology has also been utilized in home automations [10], homes safety [11, 12] and health monitoring systems for elderly in nursing homes [13].

The above wireless local range monitoring systems have been extended to a wider remote range using GSM/GPRS networks [8] and wireless TCP/IP based communications [13]. In addition, a low cost wireless gateway utilizing a GSM/GPRS based system to monitor fire and door knobs were reported [14] and many others to mention.

The above mentioned systems are utilized for local monitoring or remote monitoring using wireless components like wireless access points and GSM/GPRS modems. Typically, such systems have been implemented using two or three hardware boards to perform the monitoring and control task. However, advances in technology have enabled the design and development of integrated monitoring and control systems that are cheaper, smaller, consume less power, have enhanced functionality and utilize publicly available GIS navigation services such as online maps. Using publicly available networks enhances and extends the monitoring and control beyond the home to include additional service providers like security firms, fire departments, civil defense, police, home insurance, municipalities, and others. In turn, such services enhance the quality of life aspects related to safety and comfort of a homeowner.

This paper presents the design and implementation of a compact wireless home monitoring system using a microcontroller and GPRS modem that are integrated on a single board (Micro-GPRS) unit [15]. The Micro-GPRS unit is an off-the-shelf board and has several built-in analog inputs and digital input/output (I/O) ports as well as a GPRS-GPS modem. Since Micro-GPRS unit has a built-in data acquisition unit, there is no need for programming the I/O ports; only threshold of parameters require configuration. The unit is interfaced with external sensors via its analog and digital inputs. The Micro-GPRS unit and the associated sensors are installed in a home. The threshold for the each analog input is configured via the unit's serial port using a host PC. If an abnormality is sensed, the Micro-GPRS transmits an

[1] The research was supported by the Computer Science and Engineering Department at the American University of Sharjah, P. O. B. 26666, U.A.E.

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Contributed Paper
Manuscript received 09/15/11
Current version published 12/27/11
Electronic version published 12/27/11.

appropriate message indicating the status of monitored sensors to an Internet-based server using a static IP-address. The server then sends a Short Messaging Service(SMS) message and/or an email to the home owner about the abnormality. In addition to the single-board feature and no programming, the system also utilizes a widely available Internet-based GIS to display the exact location of the monitored house as well as the abnormality status level, time and date. This online map feature can also be utilized by security firms, civil defense organizations and municipalities to continuously monitor and locate troublesome spots in residential neighborhoods and housing compounds. Such feature will enable these public safety service providers to outreach the neediest homes in orderly manner during an emergency situation or a major disaster like New Orleans of USA (flooded in 2006) and Jeddah of Saudi Arabia (flooded in 2009 and 2011) cities during the flooding seasons.

II. SYSTEM REQUIREMENTS

With the ever increase world population, cities around the globe are expanding vertically with high rise buildings each has up to a few hundred apartments in one tower. Many of the residents of these towers are occupied by young working couples who are away from their home one third of the day time. Many of these homes are equipped with sensing devices that detect excessive smoke and flooding or theft. In such buildings, alarms are typically connected to the security office on the ground floor of the building indicating a problem. In the event of an emergency, the security guard on duty calls the civil defense and informs them about the nature of the emergency and the address of the building. In many situations, the monitoring process mostly relies on vigilance of security guards. This is inefficient in many ways because it requires the guard to be extremely attentive, good in communications, and to have a quick response time. This is not always the case. If separate sensors (fire, gas leak, etc.) and guards could be replaced with a low-cost single board computer system that can detect and immediately report an abnormal event and its accurate location, then not only the security will be greatly improved, but losses resulting from emergency will be minimized.

The functional and nonfunctional requirements for the proposed systems are as follows:

A. Functional Requirements:

- Monitor the house/apartment through detectors; fire detector, smoke detector and motion detector.
- Detect accident/abnormal behavior or event when the monitored physical phenomena exceed a certain threshold.
- Alert home owner through SMS when an accident/abnormal behavior occurs.
- Notify security service providers or the Civil Defense Department/Security firm with the emergency and its type so they can take immediate action; notification is done through generation of marker on the online Map embedded in a website.
- In addition to the Internet, home owners shall be able to check the status of the houses by sending an SMS to the modem, the modem shall reply by indicating the status of the house.

B. Non-functional requirements:

- Reliability of the system; the system should be highly reliable during the time of its functionality.
- High accuracy of the system; the system should provide an accurate status.
- Availability and accessibility: The system shall be able to function on a 24/7 basis.
- The system shall take a maximum of two hours to be installed.
- The system shall not take more than one minute to respond to the changes in surroundings.
- The system must be secure; only the home owner can get response from the modem at home or the security service providers or the Civil Defense and others.
- The system should only accept valid SMS messages from registered modems.
- Scalable: the system should be able to accept at least 200 houses/apartments which a standard number for a tower building.
- Expandable: the system should allow the integration of different sensors depending on the needs of the user without changing the architecture.
- User friendly: messages to home owners or authorized users should be in plain language. The web interface shall not take more than ten minutes to learn.
- Low power consumption: during the operation of modems at home, the modem should only be in high power modem when a valid trigger is received otherwise it is in the sleeping mode.
- The system as a whole should not cost more than USD 200 to buy and install, and should not take more than USD 20 to maintain and operate during one year of the time of its operation.

III. SYSTEM ARCHITECTURE

To satisfy the above requirements, the system is designed to have two subsystems; a Home Gateway (H-Gate), and Monitoring and Dispatch Server (MDSS) center.

The H-Gate consists of the TCP/IP enabled Micro-GPRS and set of sensors to monitor gas leaks, flooding and intruders. H-Gate is located at the monitored home. The MDSS center is located at the monitoring firm service provider center/s (e.g., Security firm or Civil Defense) and interacts with a Short Message Service Center (SMSC) located at premises of the local mobile network service provider. MDSS uses the SMSC to send SMS messages to home owners. In addition to SMSC, the MDSS uses the online Map Server's GIS capabilities to show live maps of homes and their status to either the home owners or the service providers like the police, security companies, civil defense or the municipality. Figure 1 shows the system hardware building blocks. The next two sections describe the hardware and software systems respectively.

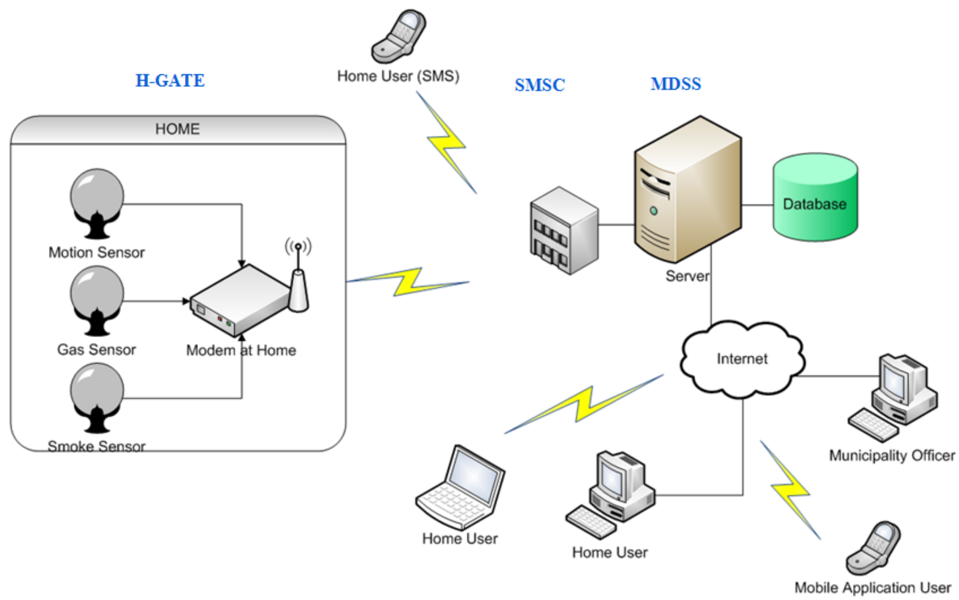

Fig1. Proposed system architecture

IV. SYSTEM HARWARE

The system hardware consists of a set of sensors for detecting environmental abnormalities, motions near the house main gate/windows and a Communication Module (CM) that are integrated into the H-Gate as shown in Figure 1. Description and function of each is described below.

A. Gas Sensor

A gas sensor being used has a high sensitivity to Liquefied Petroleum Gas (LPG), natural gas, town gas and smaller sensitivity to alcohol and smoke [16]. This makes the sensor appropriate for a kitchen. A signal conditioning circuit is design to interface the sensor to the one of the analog input of the Micro-GPRS. The sensor can detect the concentration of LPG that is between 300-10,000 ppm. Concentrations of gas above 1,000 ppm can be toxic [16]. When the value exceeds this threshold, the communication module sends an SMS alert to the MDSS through SMSC.

B. Smoke Sensor

A smoke sensor that has high sensitivity to detecting smoke is used [16]. A signal conditioning circuit is design to interface the sensor to the one of the analog input of the Micro-GPRS.

The smoke sensor can detect concentration of smoke between 300-10,000 ppm. Concentration above 5,000 ppm can be dangerous [16].

When the value exceeds this threshold, the communication module sends an SMS alert to the monitoring and MDSS through SMSC.

C. Motion Detection Sensor (MDS)

A motion detection sensor based on an infrared receiver is used [17]. For testing propose, it is assumed that the house has two doors and two windows that are to be monitored. As shown in Figure 2, the outputs from the four IR receivers are ORed to create an alert.

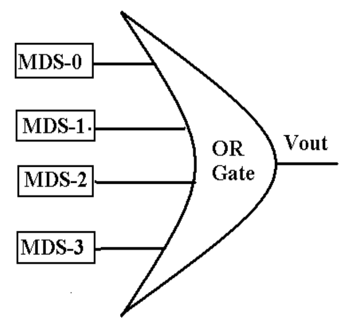

Fig 2. Motion Detection Sensor Circuit

D. Communication Module

The communication module (CM) is the Micro-GPRS board that is primarily used for machine-to-machine (M2M) communication [15]. The CM module is suitable for continuous monitoring activity on a 24/7. The CM module is IP-enabled and has a static IP address to communicate with a server through the public wireless mobile network. It supports SMS, SMTP, POP, and FTP protocols. The CM module has a built-in four analog inputs and two digital input/output ports in addition to an RS-232 port. These analog inputs and inputs/output ports are important because they eliminate the need for external microcontrollers for handling inputs and outputs. This feature makes the CM superior as compared to other home-monitoring systems that have utilized multiple microcontrollers or microprocessors in addition to a modem [8, 13-14]. In addition to lower cost, this module also has a smaller footprint and consumes less energy.

The built-in embedded software on the CM Module allows automated functions to be configured and triggered based on the state of the various inputs thresholds. For example, if the voltage on the analog input connected to the

Gas Sensor exceeds a programmed threshold (1,000 ppm); the modem automatically sends a message to the programmed IP address of MDSS using GPRS. Figure 3 shows the message frame which consists of a unique source static IP address assigned to the modem. The destination address is the IP address of the Server. This is followed by the status of the various sensors.

Source Address (Home Add)	Destination Address (Server IP-Add)	Burglar Status	Gas Status	Smoke Status

Fig 3. SMS status frame contents

V. SYSTEM SOFTWARE

The software architecture for the system is described in two parts; the Home Gateway (H-Gate), Monitoring and Dispatch Server (MDSS) and Online Maps Server (OMS).

A. The Home Gateway (H-Gate):

The H-Gate does not require any programming. It only needs to be configured for the analog threshold for each sensor. This configuration must be done using the software driver that comes with the modem. The H-Gate hardware is configured via its RS-232 port before installation.

The module is normally in the sleep state to save power. The module goes into the wakeup status if one of the following four abnormal conditions is detected:

1. The pre-set threshold value from any of the sensors (e.g., Gas or Smoke sensor) has been exceeded.
2. The intruder alarm has been activated.
3. There is an incoming phone call from a pre-programmed telephone number which typically belongs to the home-owner's mobile phone.
4. An SMS with a pre-configured user name and password is received. This is also typically sent by the owner.

In other words, the software on the CM goes into a wakeup state either when a threat is present or when the home-owner or a monitoring agency like a security firm wants to check on the status of their home through either SMS and/or email.

The software on the communication module opens a TCP/IP client sockets connection to the server before going into the send state. In the send state, the communication module sends the data back to the server using the data packet format as shown in Figure 3. The data packet consists of sending the home location, followed by the intruder alarm and the values of the sensors (gas and smoke sensors). After the values are sent, the software closes the socket connection and goes back to the sleep mode. Figure 4 shows the flowchart diagram describing how the build-in software on the communication modules works [15].

B. Monitoring and Dispatch Server (MDSS)

The MDSS is built on top of the Windows Operating System and it uses multiple interacting servers to implement its functionality. The servers are HTTP, Database, Application and Socket Server. Figure 5 shows the MDSS software architecture.

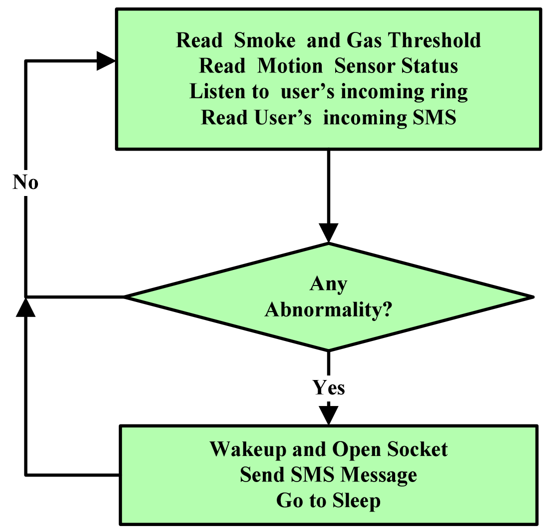

Fig 4. Communication module operation flowchart

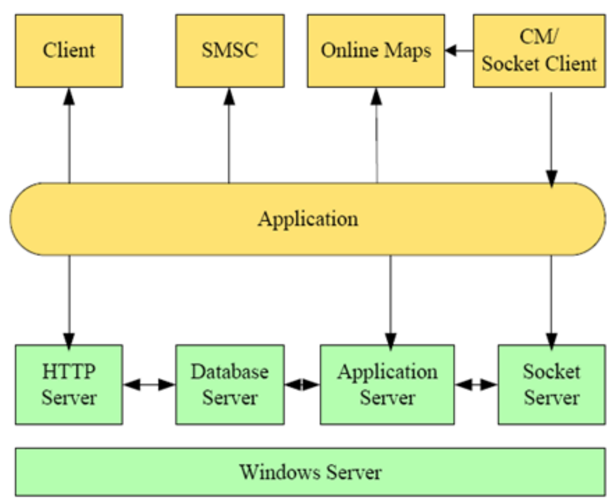

Fig 5. The MDSS Center Software Architecture

Each of these servers is briefly described below:

- HTTP Server: The HTTP server is a standard Web server that allows clients to connect over the Internet or through a GPRS network. The system is currently using an open-source server [18].
- Database Server: An open-source database server [19] is used to profile homes and record homes' statuses. Figure 6 shows the entity relationship (ER) diagram for the current database server.

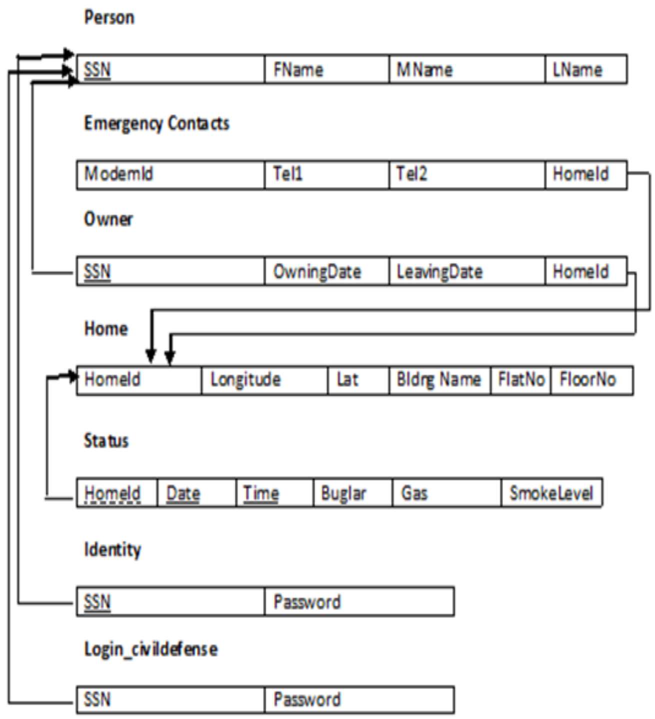

Fig 6. The ER diagram for the database server

- Application Server: The Application Server serves as the glue between the HTTP server and the other servers including the Database Server. The system used an open-source Application server [20].

- Sockets Server: The Sockets Server is a customized multi-threaded sockets server written in the Java language [21]. This server waits for the H-GATE to open a sockets connection. For each client socket connection, the server launches a thread that connects to the database server and updates the status of the particular home. In addition, it connects with the mobile networks service provider SMSC server and commands it to the send an appropriate SMS to the requesting party.

The primary logic sequences for MDSS are summarized in Figure 7.

An administrator is able to add, edit and delete various homes and home owners. Figure 8 shows a screenshot of creating a user portfolio. In addition, an administrator is able to conduct search and configure the online Maps server. The primary logic sequences for MDSS are summarized in Figure 9. After receiving an SMS and/or data frame, the system checks the validity of the abnormal values. If the values are valid, a corresponding event is added to a database and an SMS warning is sent to the home owner. In either case, the Map is updated with a status of the home. The Online Maps Server is described next.

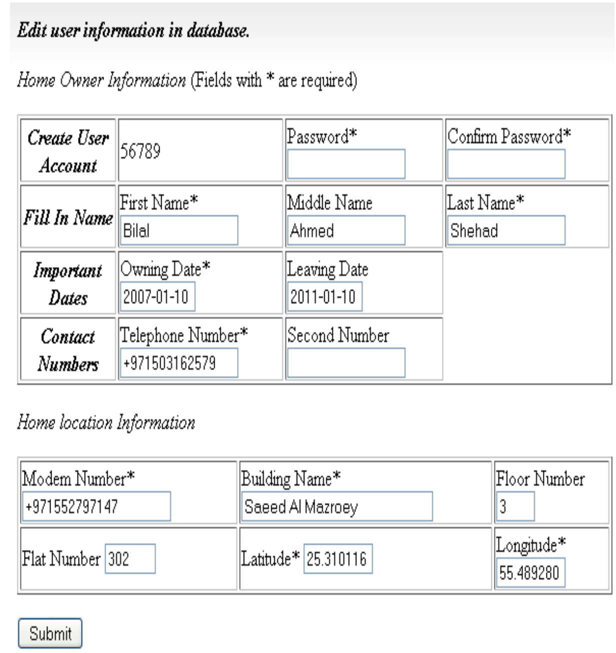

Fig 7. The MDSS primary functions

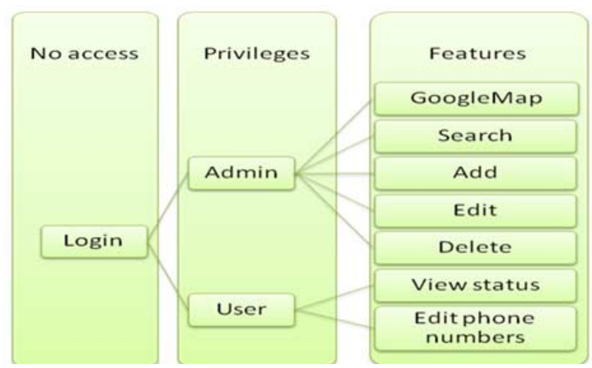

Fig 8. Creating and editing user's information screenshot

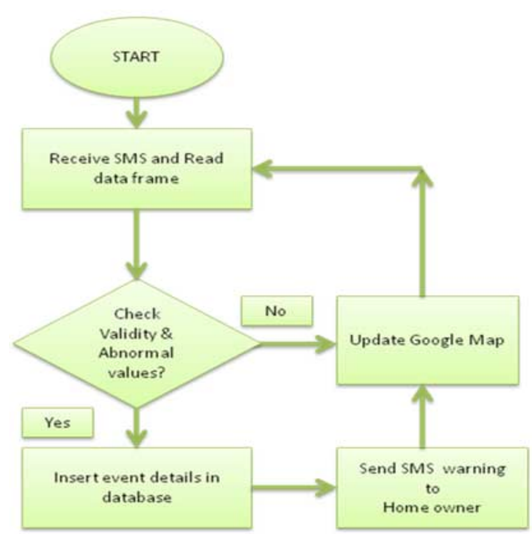

Fig 9. Main Algorithm for MDSS system operations

C. Online Maps

This server is developed using a published software interface from a freely available Internet-based GIS [21]. The Online Maps server dynamically show the status of any home in an Internet browser running either on a normal computer or a mobile phone.

Figure 10 the status of several homes using online Maps. Figure 11 shows detailed of a home using online Maps indicating the status of the various alarms as well as its address. When a home-owner requests the status of their home through the HTTP server, the Application Server instructs the SMSC server to send an SMS to H-GATE of the home-user using an appropriate user name and password. Upon receiving this information, the H-GATE opens a socket connection with the MDSS which receives and stores the most recent values into its database. These values are then displayed to the home owner.

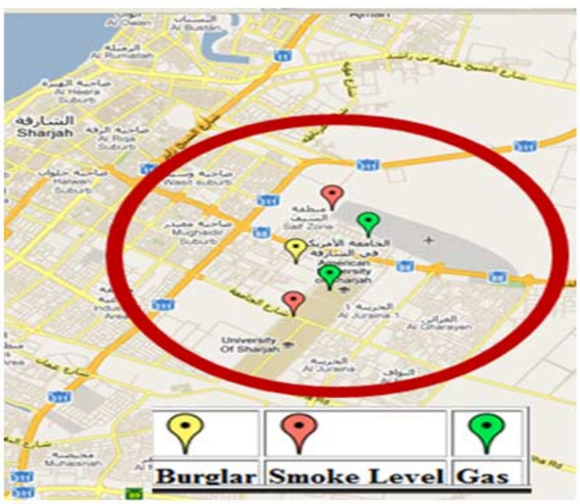

Fig 10. Several homes statues on the online Map

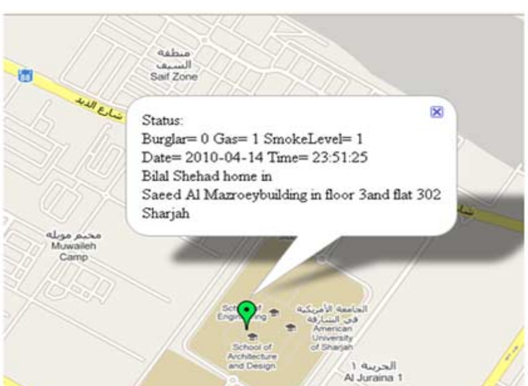

Fig 11. Detailed status for a home on the online map

A key feature of this system is that no special requirements are needed to be able to display maps on a typical mobile device. Figure 12 shows how a home owner can monitor his/her home status using his/her mobile phone.

Fig 12. Status of a home on a mobile device

VI. CONCLUSION

This paper has presented the design and implementation of a compact, low-cost, low-power single-board integrated home monitoring system that utilizes GPRS and the freely available public services like GIS Maps. The monitoring service is accessible through the mobile phone or through the Internet (using GIS Maps). In addition, database and convenient interfaces to services providers like home security firms and the municipality are also provided.

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