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Supporting Environmental Surveillance on Construction Sites using Mobile Environmental Information System

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***Abstract* — Data and data retrieval remain central to the challenge of environmental protection initiatives. Approaches such as walk-through inspections and environmental monitoring rely on environmental information that is concise, accurate, material timely and usable. However, current methods of collecting environmental data from the field are, on occasion, problematic in that they are labour-intensive and can take a considerable time to process between the point of collection and the period of analysis. These drawbacks create an obstacle for construction managers and can result in unnecessary environmental impacts, prosecutions and delays. Technological based surveillance has become an alternative in an attempt to overcome some of these disadvantages. But, in some circumstances it can be difficult to demonstrate a connection between the pollution detected and a specific source solely using these methods. Therefore, while physical environmental surveillance (observation/walk-through inspection) still remains important some improvements can be made through the application of Internet of Things technologies in order to accommodate the needs of both physical and technological based environmental surveillance in one system. This paper proposes a prototype of the Mobile Environmental Information System. This system is designed to assist construction environmental management teams to efficiently perform surveillance activities and make informed decisions in the light of a better awareness of the current status of environmental constraints and legislation. The user requirements, the conceptual model and the functional specifications as well as the system architecture for the prototype system presented in this paper will form the basis for the development of the prototype system.**

Keywords—Environmental Surveillance, Internet Of Things, Mobile Web, Wireless Sensor Networks, Mobile Environmental Information System

I. INTRODUCTION

The construction industry is vital in the achievement of the national socio-economic development goals but it can have negative impacts by causing environmental damage [1]. Over the years, the construction industry has been blamed for being a major cause of environmental degradation around the world [2] as the activities throughout a construction project's life cycle are not environmental friendly [3] and very often have had significant impacts on the environment. In general, environmental impacts caused by construction processes can be grouped into three categories including ecosystems' impacts, natural resources' impacts, and public impacts [4].

These adverse impacts have led to a growing realisation that there is a need for better implementation of environmental protection initiatives at construction sites [5-7].

Data and data retrieval remain central to the challenge of environmental protection [8] and any approach requires information that is concise, accurate, timely and usable [9]. Environmental surveillance on construction sites, in particular, requires accurate information from unique locations in space and time to be delivered to the right person, at the right time, and in the right place. It is because an environmental management team while performing the environmental surveillance confront issues that require prompt and decisive notifications, communications and responses [9]. Subsequently, by using that information, immediate sound decisions and reactions can be made by the right person in the same manner.

At this juncture, new Information and Communication Technologies (ICT) may present appropriate tools that can support environmental research and its transmission to policy-makers and construction industry players. Cheap and ubiquitous Internet connectivity, (the constantly enhanced technology of mobile communication devices) as well as the advancements in sensory technologies (e.g. wireless sensor networks, radio-frequency identification, Global Positioning System (GPS) etc.) all contribute to the expansion of the boundaries of the Internet. These advances help to link the physical world to cyberspace through smart devices which have resulted in more and more smart processes and services which can be deployed in the field of environmental protection. As a result, the reality of Internet connectivity has changed from "any-time, any-place" for "any-one" into "anytime, any-place" for "anything". Such connectivity matches with the need for the delivery of concise, accurate, material timely and usable environmental information.

This paper presents the work done as part of the Doctor of Philosophy research at the University of Salford, United Kingdom which aims at establishment of a conceptual framework and formulation of the system architecture of a mobile environmental information system for environmental surveillance on Malaysian construction sites. This paper is organised as follows. Section 2 introduces motivation for this paper. Section 3 presents the research methodology while

Section 4 discusses a scenario and requirements analysis.

Subsequently the proposed system architecture and functional specification (Section 5) are discussed. Finally, future works are discussed regarding the future development of the mobile environmental information system (Section 6).

II. RESEARCH MOTIVATION

In the context of Malaysia, a recent study by Zolfagharian et al. [10] has investigated the frequency and severity of environmental impacts due to construction processes through structured interviews with a panel of experts which consisted of 15 construction professionals in Malaysia. The study found that, among the three environmental impacts of construction activities in Malaysia, 'Ecosystem Impacts' have the greatest impact (67.5% of total impacts), 'Natural Resources' Impacts' account for 21%, while 'Public Impacts' consist of only 11.5%. The results also demonstrate that 'Transportation Resources', 'Noise Pollution', and 'Dust Generation by Construction Machinery' are the most risky environmental impacts on construction sites in Malaysia. Such negative impacts can be controlled and reduced through the identification of environmental aspects and impacts of construction activities and the implementation of mitigation measures and site monitoring on a regular basis, e.g through the surveillance put forward by the framework for an Environmental Management System (EMS).

The Merriam-Webster Online Dictionary defines "surveillance" as a "close watch kept over someone or something" whereas Jenness et al. [11] give a more detailed definition. They define surveillance as "the process of collecting information through watching, monitoring, recording, and processing the behaviour of people, objects and events of interested targets in the sensing environment in order to govern activity". In addition, there is a definition of surveillance which is associated with techniques. Tasaki, Kawahata et al. [12] state that surveillance can be undertaken through routine physical inspection or patrolling, and/or through an established multi-media network on and around the surveillance's area. Similarly, according to Kirchner [13] surveillance is an organised assessment of aerospace, surfaces, or subsurface areas, places, persons, or things by "walk-through inspection", technological devices or other means.

Previous research [14-18] has pointed out that walkthrough inspections and environmental monitoring (measurement) have some drawbacks which relate to the poor delivery of environmental information. They are certainly challenging, time consuming, labour-intensive and can involve deficiencies and discrepancies [14-17] and these drawbacks create an obstacle to the efficient management of construction sites

In an attempt to overcome these disadvantages, technological based surveillance has become an alternative. Many researchers [15, 19-22] have shown that the use of mobile devices has significantly improved reporting and communication of site inspections while other researchers [23-27] have implemented technological based surveillance by using wireless sensors and the Web as an alternative to traditional environmental quality monitoring.

But, despite the improvements in environmental reporting and communication, in some circumstances it can be difficult to demonstrate a connection between the pollution detected and a specific source solely using the technological based surveillance [28]. It is possible to use audio-visual surveillance via live video streaming which would (to some extent) give the same effect as physical surveillance. However, a camera cannot cover the entire aspect of a construction site in a single view [29], hence requiring the deployment of many cameras with the functions of pan angle, tilt angle and zoom to ensure full coverage of a surveillance site. As a result, this might not be an attractive option due to the cost and maintenance of the cameras and the system.

Motivated by report of industry frustrations with existing methods of environmental surveillance on construction sites (particularly in Malaysia), the researchers proposed a prototype mobile web-based environmental information system with the aim of improving environmental checking and the correction process by providing a tool for environmental enforcement offices for managing their environmental surveillance activities and enhancing their decision-making capabilities. Better known as "ENSOCS", this prototype application should carry the vision of the "Internet of Things" where environmental and daily life items become part of the Internet. With the smartphone playing a role as intermediary between environmental management teams, 'things' (wireless sensor networks and a weather station) and the Internet, the interactions between them will be able to provide speedy information, enhanced delivery of reports, improved work performance and alerts of environmental non-compliances. ENSOCS is a mobile web that to be designed for internet browsing via a smartphone. It should works together with telemetry sensors to provide realtime environmental data monitoring while the officer carries out environmental surveillance. It is intended to demonstrate the interrelationship between activities and pollution in a new way as compared to the conventional paper-based method. While maintaining the concept of a checklist, users may take a note of their environmental observations using web forms in the ENSOCS. For certain environmental aspects such as air and noise pollution, users can confirm their observational findings by referring to data transmitted by telemetry sensors in real time.

III. METHODOLOGY

In order to establish user needs, the research methodology adopted the use of "Scenario-based User Needs Analysis" [3032]. For this research, scenarios (Section IV) were developed and were discussed with the environmental experts during the semi-structured interview sessions. In all of the scenarios, the experts were told to imagine that they were using a smartphone to browse the mobile web while experiencing these scenarios at a construction site. Basically, the scenarios were representative of a task which the researcher believed the typical environmental inspector might perform on the website based on the findings in the literature review. After exposure to each scenario, the experts were asked a series of questions designed to assess whether the proposed prototype is suitable to be used for environmental surveillance and to confirm the features and functions of the mobile web that they required. They were then shown some images of screens on papers to represent the proposed layout of the prototype mobile web showing the proposed web pages containing the real-time environmental quality monitoring data and previous inspection reports.

These images of 320x480 pixels (which are equivalent to the screen size of an Apple iPhone) were designed in Adobe Photoshop CS6 by using the intended web colours and background, buttons, text forms, scroll down bar etc. Screens and contents were designed and implemented based on the core functionalities of an application. There were some screens that were not available due to their functions being less important compared to others. These categories were identified according to the major focus of the developed prototype application. The coloured images were then printed out and presented to the experts during the discussion of the web scenarios.

IV. IMPLEMENTATION SCENARIOS AND REQUIREMENTS ANALYSIS

For this research, the Malaysian environmental experts with a minimum of twelve (12) years experiences were given the scenarios and were asked to figure out what features were required in order to perform each scenario. The respondents then were asked to confirm the proposed potential applications through a discussion about the web-based scenarios.

In Scenario 1, the environmental experts were exposed to a scenario where they needed to carry out an environmental inspection on a selected construction site for the first time and, therefore, they needed to find the relevant environmentally sensitive receptors at the said construction site. They were told that the prototype was capable of providing them with Google Maps with tagging that showed the environmentally sensitive receptors in that particular construction project. They were then shown some images of screens on papers to represent the proposed layout of the prototype mobile web that allowed them to identify the environmentally sensitive receptors, and were also told about the sharing features on the prototype that allowed them to review the previous inspection reports so that they could obtain all the relevant information needed to set the inspection priorities.

In Scenario 2, the environmental experts were told to imagine that they had spotted that oil containers were placed on bare ground and that oil spill was spotted on the ground. Therefore, they had to imagine that they had to take a photo of this non-compliance as evidence by using the smartphone. Then by browsing the ENSOCS mobile web through the smartphone, they had to put this finding onto the Web, attach the photo, provide other relevant information to support this finding, submit the report, and share the findings on the Twitter. They were then shown some images of screens on papers to represent the proposed digital inspection checklist which was to be embedded into the ENSOCS mobile web. They were also told about the detailed contents of the checklist and the sharing of features on the prototype that allowed them to capitalise upon the technology of the smartphone itself (e.g. take a photograph and upload it into the system, auto-detection of the coordinates, etc.).

In Scenario 3, the environmental experts were told that the prototype was capable of containing and displaying environmental guidelines. This would create a Knowledge Base System within the website, hence contributing to the development of environmental management knowledge amongst the users. They were told that they should imagine themselves as a junior environmental officer and were using the prototype to find out the best practice for sedimentation control and to find the important areas upon which to focus during the site inspection particularly as regards sedimentation control. The proposed layout showing the best environmental practices as brought up on the ENSOCS mobile web were then presented to the interviewees.

In Scenario 4, the environmental experts were exposed to a scenario where they needed to pretend that they were attending an environmental meeting at a site office and were required to update their management on the status of the environmental checking and corrective action(s). They were told that the prototype was capable of displaying the status of environmental quality monitoring data in real-time and also could display the previous inspection reports. Such availability can enhance the real-time visibility of the status of the environmental checking and the corrective status of the projects and thus allow accurate judgement and effective reporting in the Environmental Checking and Corrective status. They were then shown some images of screens on papers to represent the proposed layout of the prototype mobile web showing the proposed web pages containing the real-time environmental quality monitoring data and previous inspection reports.

Based on the interviews and the scenario analysis with the environmental experts the following user needs were identified (Table I).

TABLE I. REQUIREMENTS' SPECIFICATION FOR ENSOCS

Identified needs and problems	Brief description	Derived user requirements
Environmental requirements /approval conditions	Environmental surveillance is carried out to ensure compliance against the stated approval conditions.	Environmental requirements/approval conditions should be made available as a part of project information.
Surrounding environmentally sensitive areas	Information about surrounding areas and activities would help in the process of setting the priorities in environmental surveillance. For example, information about environmentally sensitive receptors would indicate an area of importance that needs to be highlighted during the surveillance.	The system should be able to provide information about the sensitive receptors surrounding the project area.
Access to project and contractors' information	Information pertaining to the project location and descriptions as well as the relevant contacts is important for site familiarization and communication.	The system should be able to provide project and contractors' information to the users.
Tools/equipment for	Paper-based	Environmental surveillance

Identified needs and problems

inspection and measurement

Photograph of incidents/noncompliances

Need for EQM realtime data

Alert on any occurrence of noncompliance

Effective communication between parties involved in the environmental management of the project.

Brief description

checklists and notes are the main instrument for environmental walk-through inspections; additionally traditional grab sampling methods for environmental monitoring are currently being used. The data can only be updated when the officers return to the office. It is time

consuming and labour intensive.

Photographs are one source of evidence to show environmental noncompliance. Currently, inspectors are using a conventional camera to take a photograph(s) which they need to carry along with them and then upload into a computer at a later stage.

The time required to obtain environmental monitoring data under current approaches may take a minimum of ½ day up to maximum 14 days. This discourages immediate action against noncompliance.

Alert for each measurement reading exceeding the threshold allows for immediate action. Under current approaches, sample results are only ready at least 12 hours after the fieldwork sampling.

Current approaches use paper-based documentation. A long period is required for the authorities to receive, and take action on, the report.

Derived user requirements

data for both walk-through inspections and environmental monitoring captured from a site should be communicated in realtime up the information chain.

The system should enable a photograph(s) to be taken using the smartphone and upload it into the ENSOCS.

Deployment of technological based surveillance and real-time data streaming are needed.

Ability to send an alert to the users in the event of exceeding the threshold.

Environmental monitoring data captured from a site should be displayed on the ENSOCS and any latest inspection report will be emailed to the respective parties immediately upon completion.

Identified needs and problems Access information when needed (especially when out of the project office)

System to support continuous learning.

Ease of integration with other applications

Portability

User-friendly system

Brief description

Some organisations use intranet systems (system works on a private network) or even implement paper-based documentation and manual record keeping. Accessing and updating data can be difficult, especially when the person is out of the office.

The prevention of, and the resolution of, impacts and unconfirmed practices which are derived from the practical experience of experts and

professionals in the field should be shared, especially with junior environmental staff as part of their onjob training.

Interoperability with other applications

The traditional paper based methods have some drawbacks as they are certainly challenging, time consuming, labourintensive, etc. The ability of the mobile web to provide a digital checklist and to integrate sensory technologies as well as the features of the mobile devices themselves would improve field data collection.

Some of the environmental managers and officers are senior and are accustomed to using paperbased records for their day-to-day activities. Thus, they need a system that is easy to use and learn so that it is easier for them to adopt the system Derived user requirements

The system should be designed as a web-based system that will be accessible via mobile devices and internet-ready desktop computers.

The system should provide information on environmental management best practices as a part of the contents.

The technology used should be interoperable and able to integrate well with existing web systems in the market. The system should also be scalable so that it can be iteratively improved.

The system must support the data requirements of both fixed and mobile network clients.

The system should offer a very clear and straightforward interface and include consideration of the limited screen size, the input and output capabilities and the limitations of a mobile device.

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Identified needs and problems	Brief description	Derived user requirements
	more effectively. A complicated system would create resistance to change.	
Services (community news, weather information, traffic information)	The effectiveness of environmental mitigations is closely linked to weather conditions and human activities. For example, there is a high probability of dust pollution occurring during the dry season and in the case of heavy traffic, whereas a siltation problem might occur during the rainy season. For these reasons, the system should be capable of providing valueadded services (that include community news, weather and traffic information) to let the inspectors have knowledge of the on-going situation on the construction site so that they can come up with informed decisions.	The system should include potential services as valueadded services for the mobile web system.

In addition, it is important to highlight that with regards to the communication medium for conveying messages on environmental status, not all the experts were agreeable as to the use of social networking media like Facebook or Twitter for such a purpose. This was due to the reason that environmental data should be contained within the organisation and because some of data are classified as confidential. Additionally, the use of company assets for accessing social networking media like Facebook or Twitter during their working office hours is prohibited.

V. PROPOSED SYSTEM ARCHITECTURE AND FUNCTIONAL SPECIFICATION

The requirement specifications as discussed in Section IV have been translated into the conceptual model. The conceptual model shown in Fig. 1 presents the data flow between a user and the ENSOCS application. The user in the outer box of the diagram is the important component of the system. The numbered boxes (from 1 to 8) are the functions of the system (e.g. Login to ENSOCS) while the boxes with numbering from D1 to D19 are the items included in the class diagram (e.g. D1 – Contact Detail). The conceptual model also provides the guidelines for the development of the functional specifications as in Table II.

TABLE II. JUSTIFICATION FOR THE SELECTION OF THE FUNCTIONS OF ENSOCS

No.	ENSOCS' System Functions	Functional Requirements	Rationale
1.	Login	Only an authorized permitted to execute all the functions available within the application.	Information pertaining to user is the environmental management of a construction project is confidential. Thus, using a login page with a user ID and password is a simple and quick solution enabling restrictive access to files or directory structures of web sites which contain sensitive information [33].
2.	Contacts	Providing the contact details of the relevant parties. In addition to typical directory data (such as name, phone number and email address) the smartphone's capability to make a phone call will be capitalised through linking phone numbers with XHTML markup that invokes a phone call. This would enable the user to make a phone call by one click.	The environmental management team should be able to contact anyone who may have relevant information, e.g. to assist them in obtaining administrative clearances and to make necessary arrangements if samples need to be taken [28]. In addition, Standard Operating Procedures (SOP) especially on Emergency Response Plan (ERP) require that the respective parties should be informed in any case of non-compliance and emergency. In some cases, immediate telephone calls are urgently needed. Because the mobile web would enable a phone call, this feature will be incorporated into the ENSOCS system.
3.	Project Information Dashboard	This function should enable the Environmental Management Team to have an instant view of the progress status of the projects as well as the stakeholders of the project.	From the literature review, it was found that project dashboards in a mobile application were used for but not limited to: • A progress monitoring project information system [34]. • Construction information management [35]. • Construction project and programme management [36].

No.	ENSOCS' System Functions	Functional Requirements
4.	Maps	Google Maps to show the location of the project and directions to it, as well as showing the environmentally sensitive receptors surrounding the project site.
5.	Tasks	This function should enable an environmental management team to update the system with the findings of the environmental inspection through the online checklist (using web form handling). The environmental management team may use the mobile device's built-in camera to take a photograph of any non-compliance spotted on the site as evidence.
6.	Live Boards	This function should enable the Environmental Manager to have an instant view of the Air Pollution Index (API), the weather and traffic conditions. In addition, deployment of environmental monitoring sensors would enable the real-time streaming of data on air and noise quality monitoring on the web page.
7.	Events	Previous records on environmental surveillance and environmental monitoring data will be available through this function.
8.	Best Practices	This function contains intelligent searching for relevant information on environmental best management practices on construction sites that is based on contextual information.
9.	Generate Report	The environmental surveillance report will be automatically generated once the user updates the system. The photograph(s) taken by using the mobile device's built-in camera can be attached to the environmental surveillance report too. Then, the users would also have an option to send it to the respective parties through an email.
10.	Warning Alert	In the event where the reading of PM_{10} and Sound Levels exceed the thresholds, the system will send a Short Messaging System (SMS) to the users as a Warning Alert.

Rationale

Google Maps is used by 54% of the global smartphone population according to GlobalWebIndex from a survey undertaken in the month of August 2013 [37]. This makes it the most popular mobile app. Satellite images are one of the sources of information for environmental assessment activities [3839] and Google Maps offers satellite imagery, street maps and Street View perspectives, as well as functions such as a route planner, and supports the maps being embedded on third-party websites via Google Maps API.

Previous research [15, 1922] as well as commercial products e.g. Inspection, Checklist, Audit Mobile Apps by IMEC Technologies, IForm EHS by Zerion Software and many more, have demonstrated that the use of mobile devices and mobile web/apps with online checklists have significantly improved reporting and communication in site inspections.

Many researchers [23-27, 40] have implemented technological based surveillance by using wireless sensor and the Web due to the ability of such systems to disseminate data within a short period of time.

The above mentioned studies have shown that a project dashboard enhanced the visibility of the project as well as the stakeholder's information.

The environmental management system (EMS) is a process of continual improvement by which an organization constantly reviews and revises the system [41-42]. Therefore, Rationale

previous records are important in order to gauge performance against the mitigation measures in place.

A key problem facing the construction industry is that all work is undertaken by transient project teams and, in the past, there has been no structured approach to learning from projects once they are completed [43]. The prevention of, and resolution of, impacts and unconfirmed practices which are derived from the practical experience of experts and professionals in the field together with rules, guidelines, best practices, etc. within an exclusive Web Knowledge Base would allow for knowledge sharing and junior environmental staff in particular would benefit from this Knowledge Base for their on-job training [44].

Under the current traditional approach, the delivery of necessary information to the construction site or the collected data back to the office has been problematic and slow [45] but the mobile application will enable the user to communicate the information in real-time up the information chain [46].

The warning alert system is acknowledged to be a good prevention mechanism. Thresholds set for abundances/ magnitudes, when crossed, trigger set responses so that rapid action can be taken accordingly [47]. SMS is one way of alerting users via a warning alert system [48].

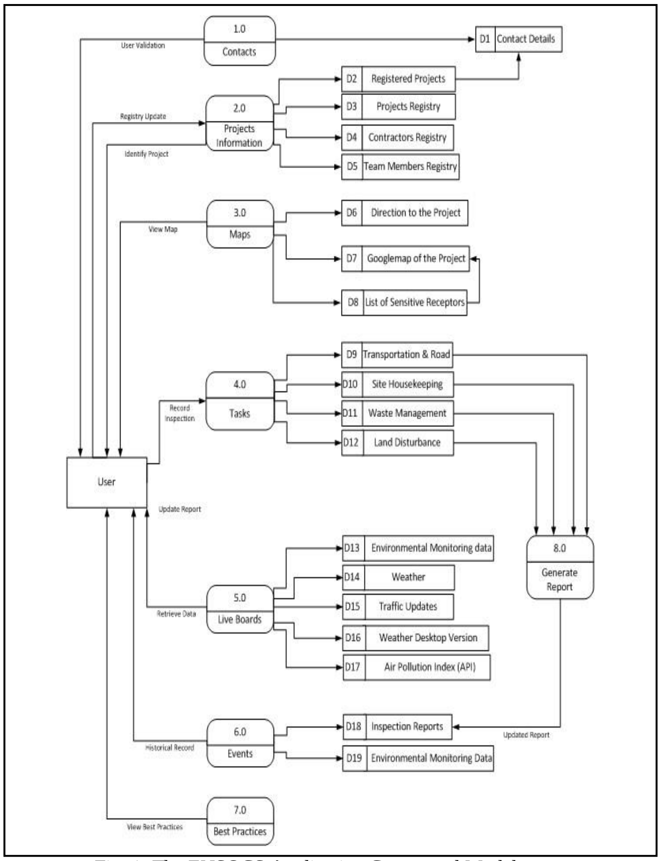

Fig. 1. The ENSOCS Application Conceptual Model

Fig. 1. The ENSOCS Application Conceptual Model

Further to the functional specifications and conceptual model, this research continued with the development of the system model or the software architecture for the design of the Environmental Surveillance on Construction Sites (ENSOCS) mobile web system. A review on the previous works by Fang et al. [49], Jian et al. [50], Sarma and Girão [51], Freeman and Simi [52] and Castell et al. [53], concluded that the architecture of the IoT should be a fourlayer structure. It should contain a sensing and control layer, a networking layer, a middleware layer and an application layer as in Fig. 2.

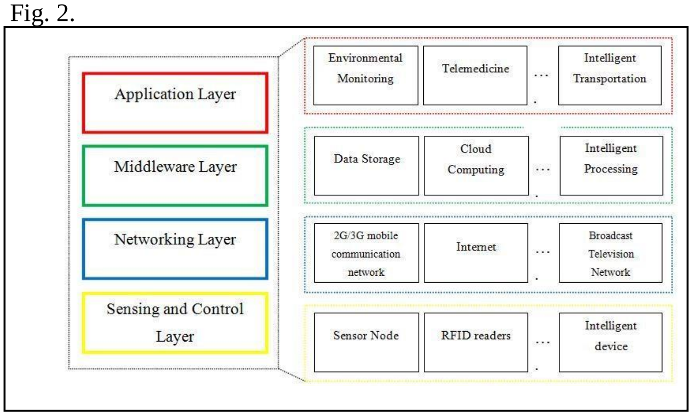

Fig. 2. Four-layer System Architecture of IoT

Similarly, the ENSOCS architecture follows the same four-layer structure of the Internet of Things (IoT) (see Fig. 3). The details for each layer are as below:

a) Sensing and Control Layer - The Wireless Sensor Networks for capturing the reading of PM_{10} concentrations and noise levels, and the weather station to obtain weather conditions' data. GPS and WLAN are also being used for the determination of the current location of the user;

b) Networking Layer – Wireless Local Area Network (WLAN) and Local Area Network (LAN);

c) Middleware Layer – The server system that will process location data gathered from the built-in smartphone, the sensor data, the data input from the user and the weather data. The server will then intelligently choose the right information and services from the servers available in the system. The server systems of the ENSOCS prototype consist of the MySQL Database server and the web server.

d) Application Layer – The Mobile Client – a mobile device that is able to deliver the inputs from the user and, at the same time, receive the Short Messaging System (SMS), location coordinates, sensor and weather data from the built-in GPS, the wireless sensor network (WSN) and the weather station.

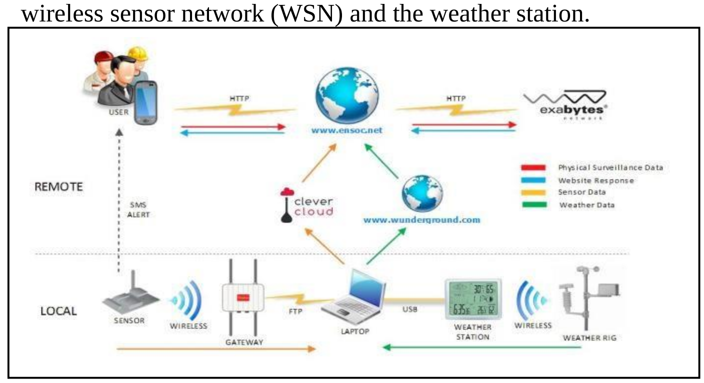

Fig. 3. System Architecture of ENSOCS

VI. DISCUSSION AND FUTURE WORK

Within this research a user requirements for the proposed prototype of a mobile environmental information system (MEIS) were identified and subsequently, the conceptual model, functional specifications and system architecture were prepared. The user requirements, the conceptual model and the functional specifications as well as the system architecture for the prototype system presented in this paper form the basis for the development of the prototype system.

Thus, our future work involves the study and development of prototype to support the environmental surveillance by environmental enforcement officers. It is also important to note that the researcher must achieve some level of confidence that the prototype is not only technically feasible but that the concept is also acceptable to the industry. Thus, later in the next stage the researcher will adopt an iterative approach whereby the targeted users will be involved in the prototype evaluation in order to ensure that the prototype can gradually be developed to become a robust system.

Therefore, the focus of the other research papers would emphasis the prototype development, the evaluation of the prototype system and presents the results from the prototype evaluation. The evaluation is made to prove the concept, to strengthen the user requirements and to see whether the application can provide efficient information and services. The results from the evaluation and the refined prototype can be used to help in developing and applying the ENSOCS prototype to real applications.

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