Towards a Fully Automated Monitoring System for Manhole Cover

Smart Cities and IOT applications

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***Abstract*—Nowadays Manhole Cover (MC) failure is on the rise and generally affects the safety, security and economy of the society. This is why the need for a fully automated monitoring system has become very essential. Automated monitoring of MC is part of the development of Smart Cities (SC) and Internet of Things (IOT) which are the targets for modern governments to control and monitor the resources in cities. This paper is a survey study on the MC issues, presenting a complete classification with analysis for these issues based on the environmental effect and including the available current monitoring techniques used. It also evaluates the use of the automated and non-automated monitoring systems and the effect of the type of the underground on the MC structure. It is shown from the study the current automated monitoring systems do not cover all the MC issues, and most of these systems are not taking into considerations all of the issues ,therefore, misleading data may be found from these systems which is considered as a problem which this study contributes to overcome this problem. The classification in this paper is the first step towards design a fully automated monitoring system for MC taking into consideration the development in the SC and IOT solutions.**

Keywords— Manhole Cover; Smart Cities; Internet of Things (IOT); Smart Infrastructure, automated monitoring systems

I. INTRODUCTION

Modern governments have started to use the concepts of smart cities and the internet of things (IOT) to control and monitor the cities' utilities. Gerhard P. Hankeys et al [1]define a smart city "is a city which functions in a sustainable and intelligent way, by integrating all its infrastructures and services into a cohesive whole and using intelligent devices for monitoring and control, to ensure sustainability and efficiency" while CISCO defines the IOT [2] as " a system where items in the physical world, and sensors within or attached to these items, are connected to the Internet via wireless and wired Internet connections". This requires a big development in the monitoring systems especially for the underground infrastructure.

From these definitions, it can be shown that smart cities concept means monitoring the cities' infrastructure in an intelligent way and the IOT is the communication system used for this monitoring via the internet. By increased the population in urban cities, the failure and the aging of the cities infrastructure and the resources consumption both increase. The population growth problem is one of the motivating reasons for the modern governments to use the smart cities and IOT to control and monitor the cities' infrastructure and resources.

Road and underground infrastructures are the main cities' infrastructures affected dangerously by the population growth. Manhole cover (MC) is one of the road infrastructure and the same time is the door to access the underground infrastructure. By increased the failure of the MC, the road and the underground infrastructures are dramatically affected and its influence rises on the security, safety and economy of the society as it will be shown later.

From smart cities view, a fully automated monitoring systems for MC is needed to reduce the impact of the increasing MC failure. The available monitoring systems for MC are not all automated and the automated types are not monitoring all the MC issues. Most of the current monitoring systems monitor one or more of MC issues and are based on partial classification or study. The partial study of the MC issues has limited capabilities to address the wider automation problems and this leads to high probability of inaccurate monitoring. For example in [3] authors designed an automated monitoring system that monitors the security of the MC by monitoring the tilting of the MC; this system is very sufficient but the data from their proposed system can be misleading because MC structure can be tilted because of several sources like the soil moving or traffic pressure and not only because of unauthorised intrusion. Another example, in [4] authors used high resolution images to identify the location of the MC and their methods detect only 40% of MC while their study did not concern about the MC structural degradation issue which may affect their results.

This paper brings together all the issues related automated monitoring of MC issues and classifies these issues through a comprehensive survey of the literature. The MC issues classification is based on the type of the environment (upperground and underground environments) affecting the MC structure showing the available automated/non-automated monitoring systems used.

The study in this paper is the first complete study on the MC issues, targeting to be the first step for the design of a fully automated monitoring system for MC taking into consideration the effect of the development of this system on the smart cities and IOT solutions.

It is shown from the analysis of this study that the monitoring system required to automatically monitor all the MC issues cannot be a universal design and it depends on the type of the underground utility beneath the MC. Also, this system needs to be reconfigurable to add more sensors for monitoring the underground utility which is required most of the time.

This paper is organised as follows, second section is an overview of the MC and exploring the effect of the MC failure on the society. The third section reviews and classifies the MC issues and the available monitoring technique which will be discussed with statistical analysis in the fourth section.

II. Overview

MC is made from several types of materials. The type mostly used is cast iron which will be the focus of the paper. MC has several shapes like circular, rectangular, square, triangle and double triangle. The design and fabrication of MC must meet the requirement of the country standard. For example, in UK, BSI British Standards is the UK's national standards organisation that produces standards and information of products that promote and share best practice [5].

The MC failure impacts the society in three main areas: safety, security, and economy. As an example of the safety: bikes and motor bike riders claim that MC causes accidents because of the sliding or skid resistance of MC, as sometimes it is said 'MC is the biker's nightmare'. The Motorcycle Action Group (MAG) has mentioned on its website [6] several problems of MC structure like road hazard. MC structure defects can cause injuries and accidents.UK government reported in the statistical release for the road causalities for 10 years, beginning from 2002 till 2012 [7]; that for this period of time the motorcycle accidents approximately did not change when compared by the car accidents that was reduced rapidly in the same time period, which indicates that more efforts need to be done to reduce the motorcycle accidents like monitoring any road hazards like MC failure.

It is reported in [8] that MC is one of the common metal thefts that costs millions of pounds in UK every year beside the harm of the underground utilities like electrical cables and national heritage. On the other hand, the work in [9] mentioned that WRC (Water Research Centre) found that many Manhole Covers in UK have failed and caused hazards which cost almost 40 millions of pounds.

The reasons of the surge to find a fully automated monitoring system for MC can be summarised as follows:

- Reduce any delay that can happen after any failure of the MC that may harm pedestrians or traffic.
- Reduce the cost of using labours and protect the labours from being harmed from the harsh environment beneath the MC.
- Integrate with other infrastructures within a smart city.

III. MC Issues classification and the available monitoring techniques

In this section, MC issues are classified based on the environment that affects the MC structure and the available monitoring techniques found for each issue (automated or manual). The fully automated monitoring system for the MC is normally found beneath the MC to prevent any harm to pedestrians or the traffic, and is connected to base station (or by any communication technology). Information is then transferred to the organisation that is concerned about the manhole cover and the utilities under it as shown in Figure 1.

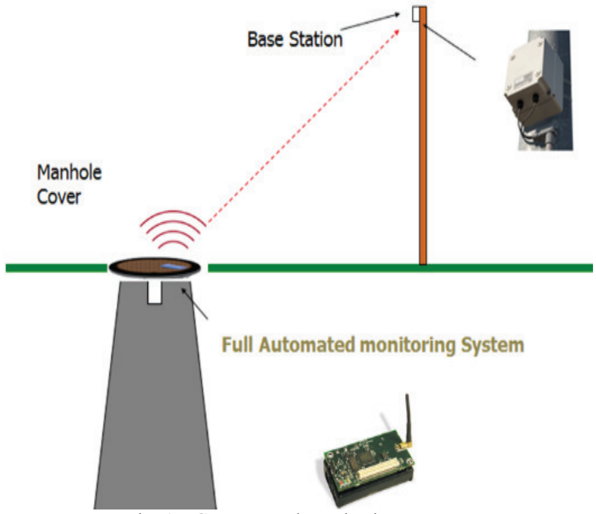

Fig. 1MC automated monitoring system

Generally, any automated monitoring system consists mainly of four modules as shown in Fig 2; the data acquisition (DAQ) module which consists of the sensors that measure the MC measuring properties followed by the signal conditioning circuit that reads the sensor measurement and then digitises the output of the signal conditioning circuit by means of the analogue to digital converter (ADC) [10]..

Data is then sent to the control unit module (CU) to control the monitoring systems and to save data given from the DAQ or the communication module. Communication module is responsible for transmitting and receiving the data from and to the monitoring system. The last module is the power subsystem which is responsible about feeding the monitoring subsystems with the needed power and can be controlled also from the CU module.

Before starting the MC issues classification, first the definition of “MC issue” has to be cleared. MC issue can be defined as “the issue which causes MC structure failure or it is the issue resulting from the MC structure itself”. From the survey done by the authors, which is based on the effects of the upperground environment and the underground environment on the MC structure. MC issues can be classified into three types:

a- Upperground MC issues: MC issues based on the effect of the upperground environment only.

b- Underground MC issues: MC issues based on the effect of the underground environment only.

c- Common MC issues: which are common between the upperground environment and underground environment effects. However the influence of each environment on the MC structure may differ.

Table 1 shows the MC issues classifications based on the type of the environment. It is shown that each type of the environmental effect on the MC structure is responsible for three kinds of MC issues.

Table 1 MC Issues Classification

MC Issues	**Upperground MC Issues**	Security
		Detection
		Skid resistance
	Underground MC Issues	Stray/Contact
		Explosion
		Noise
	Common MC Issues	Corrosion
		Structure degradation
		Miss-Alignment/Moving

The available monitoring techniques for the upperground MC issues, underground MC issues, and the common MC issues are shown in Figures 2, 3, and 4 respectively. In these figures the automated monitoring systems are in dashed boxes while the manual monitoring systems are in regular boxes.

Figure 2 shows the available monitoring techniques for the Upperground MC issues which are:

1- Security: This issue arises by the increased number of the stolen MC and the fear of any terrorists attacking the underground utilities. Most of the available technique is based on automated monitoring systems[11], [12][13]. The automated monitoring systems used have different mechanisms. Mechanisms may be based on switching (mechanical, magnetic) or image processing (CCTV), or cutting the fibre cable (fibre method) or based on the MC orientation (accelerometer).

2- Detection: this issue takes place mainly after changing traffic road or developing the road maintenance and in some countries like Taiwan MC are buried and the detection method is using RFID. All types of monitoring this issue are based on manual monitoring techniques[4], [14]–[16].

3- Skid resistance: This issue affects especially the bike and motor bikes riders and causes several accidents. This issue is monitored most of the time manually by using the British Pendulum Tester [17]–[20].

Figure 3 shows the available monitoring systems for underground MC issues, which are:

1- Stray/Contact: This issue is based on electrical/communication underground utilities when the electrical wires are aged and the coating material are cutting down, this charges the metallic MC by electricity which is very dangerous for pedestrians and cars. This problem is monitored manually by using contact voltage meter[21][22].

2- Explosion: MC explosion takes place because of high pressure from ignition of explosive gas (flammable gas, natural gas, or the sewer gas) or fault in electrical cables. Gas pressure is monitored manually by gas detector while for electric fault smoke/fire detector are mainly used [23][24].

3- Noise: MC structure contains holes to reduce the pressure on the MC. By the presence of these holes and the pressure from the underground utility especially sewer system, a noisy sound is heard from MC. This issue is not monitored but it depends on the claims from the people only[25].

Figure 4 shows the available monitoring systems for the common MC issues, which are:

1- Corrosion: This issue is very common from the upperground especially at coastal areas and from the water/sewer underground utilities. This issue is monitored manually by using normal visual monitoring or recording by digital camera [26][27].

2- Structure degradation: This issue results from the stress of the traffic and the high pressure from the underground especially the water/sewer system. This issue results in cracked, shattered, or broken MC. While this issue has very dangerous effect on pedestrians, traffic and underground utilities, only manual monitoring systems are used to monitor this issues by means of normal visual inspection or recording by digital camera. Manual vacuum test can be used for the sewer system utilities and to measure the pressure on the MC.

3- Misalignment/movement: Due to wrong installation (upperground effect) or soil movement (underground effect), MC structure can be misaligned or moved from its original place which generates dangerous hazards on the road. This issue is only monitored manually by means of tape measurement [26].

Most of the MC issues are monitored manually and some are based on recording camera to capture an image of the MC to attach to the regular inspection report [26]. Regular manual inspection is mainly based on the underground utilities [23] and may take from several times per month to several times per year. However, long time without inspection and monitoring can result in sudden MC failure or stealing which badly affects the society and could causes several unwanted hazardous effects. To evaluate the overall monitoring systems to assign the need to design a fully automated monitoring system for MC, analysis will be presented in the next section based on this study.

This section shows the MC issues classifications with the available monitoring techniques. The classification is based on the environmental effect on the MC structure and extends to address the monitoring techniques used to monitor each MC issue.

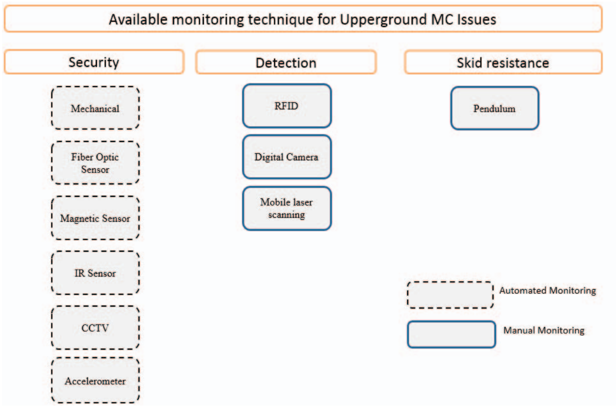

Fig. 2 Available monitoring techniques for upperground MC issues

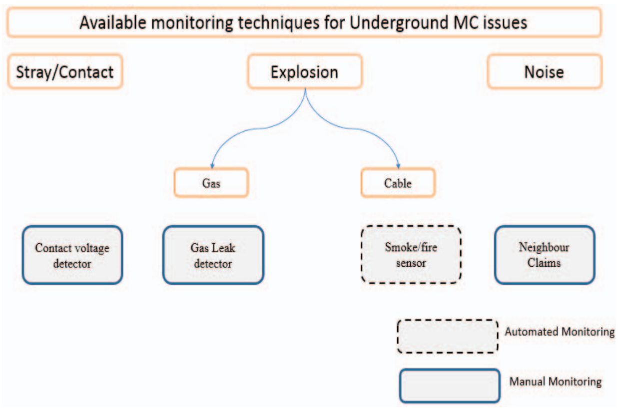

Fig. 3 Available monitoring techniques for underground MC issues

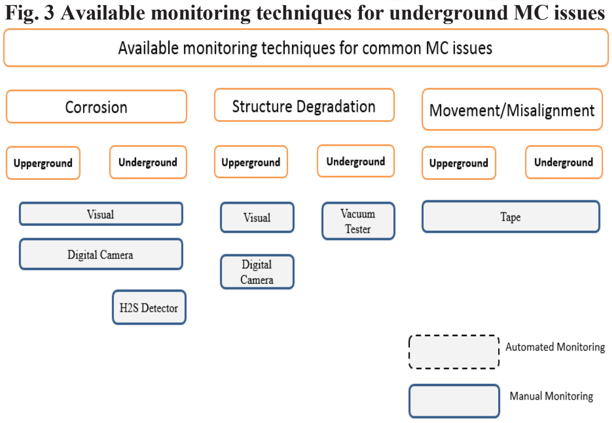

Fig 4 Available monitoring techniques for common MC issues

It has to be mentioned, that the techniques listed in this section are from several references more than those listed in the reference section, however, authors decided to give example for each reference of monitoring techniques (due to the limited number of pages allowed).

IV. DISCUSSION AND ANALYSIS

This section discusses and analyses the MC issues classification shown in section III and the available monitoring systems for MC monitoring to design a fully automated monitoring system for MC.

Based on the previous section, the available automated MC monitoring systems cover only 30% from the MC issues found. Table2 and Figure 5 identify the automated systems used for MC issues and the percentage of these automated systems to the manual respectively.

Besides that, from the survey, and by addressing and analysing the effect of each underground environmental utilities type effect on the health of the MC structure, it is found that Water/Sewer underground utilities is the most utility affect the MC structure by causing the most MC issues. Figure 6 represents the percentages of the MC issues causes by the different type of the underground utilities based on this survey.

Table 2 MC Issues and the available automated monitoring systems found.

MC Issues	Available automated monitoring systems
Security	✓
Detection	×
Skid resistance	×
Stray/Contact	✓
Explosion (Gas)	×
Explosion (cable)	✓
Noise	×
Corrosion	×
Structure degradation	×
Misalignment/Moving	×

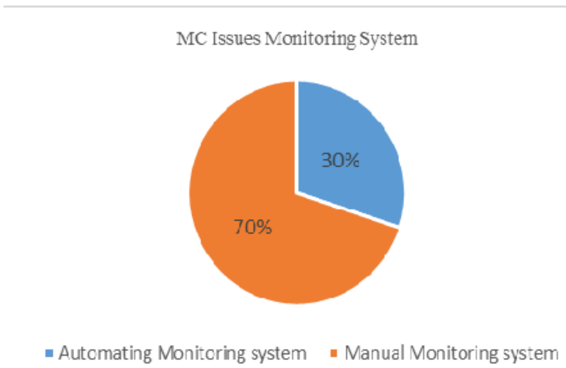

Fig. 5 Percentages of the automated and the manual monitoring systems available for monitoring the MC issues

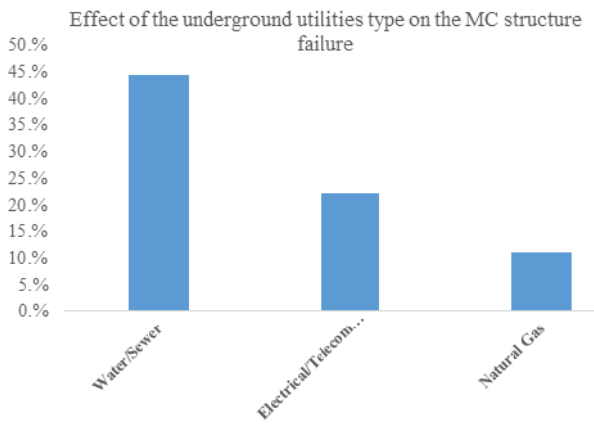

Fig. 6 Effect of underground utilities type on MC structure

Using automated systems to identify the MC issues is needed to reduce the cost and secure the society. However, the design a fully automated MC monitoring systems faces several challenges and need to be reliable to the smart cities and IOT concepts which are used by modern governments to protect the society.

The power consumption challenge is very essential, because the automated system lifetime is mainly based on the battery lifetime. Replacing the battery several time during MC lifetime is not reliable or sufficient from the cost view. This point is very critical especially that the maximum number of MC issues that are monitored automatically in one system is only two issues and the lifetime is about only one year.

Reducing the power consumption has many debate aspects as shown in Figure 7[28]. However, as fully automated cast iron MC monitoring system is not found till now, the sensor type selection is the most effective point need to be addressed. According to several references like [29], DAQ module need to be activated more than any module of the wireless monitoring system (like the fully automated MC monitoring system) regardless the concept of the monitoring strategy (Trigger- Driven or Scheduled-Driven) as shown in Table 3 [29] and by using some types of active sensors, the power consumption will increase more[30]. However, because of the different type of the underground utilities, it can be concluded that the fully automated MC monitoring system is not universal and depends on the type of underground utilities. This fact can reduce the power consumption of the DAQ design. Currently, the authors study the design of low power consumption DAQ for fully automated monitoring systems and the results of the current research is considered as future work.

Generally, several techniques had been done from several researches to reduce the power consumption. In Table 4, selected examples of these techniques used to reduce the power consumption, are shown.

However, power consumption is still one of the biggest challenges for design automated monitoring systems.

Another challenge is the cost. By entering SC and IOT era, monitoring systems need to be of low cost and suitable to be controlled and managed via the internet. From the survey, available MC monitoring systems from one side and SC and IOT from the other side did not mentioned in any reference before to the knowledge of the authors. This opens a new research field to investigate. Besides that, some of the monitoring systems used in several applications including some current automating MC monitoring, used the off shelf monitoring systems hardware platform like Imote2, Waspmote (which is called also motes) and by using open source software cloud, controlling these motes via internet become more easy and reliable[31]. However, the cost of these modules is still high. On the other hand, a new hardware technology is spreading very fast which is open source hardware like Beaglebone, Raspberry Pi[32]. These systems are very promising and proved to be used in several SC and IOT applications, because of the low cost and the ease to be programmed. However, open source hardware suffers from the high power consumption with respect to the off shelf motes mentioned before[32]. Figure 8 shows examples of the current consumption and price of selected motes and open source hardware [32]. Open source hardware, opens a new gate for research to use it in several monitoring applications like fully automated MC monitoring system by redesign it to be less power consuming and to be used for SC and IOT applications.

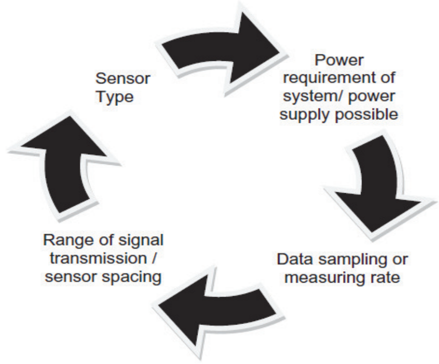

Figure 7 Several aspect of debates for power consumption reduction [28]

Table 3 Power states for wireless monitoring system [29]

	Trigger-Driven			Schedule- Driven		
Mode	**DAQ**	**CU**	**Comm.**	**DAQ**	**CU**	**Comm.**
S_0	-	-	-	off	off	Off
S_1	Off	Off	Off	-	-	-
S_2	On	On	Off	On	On	Off
S_3	On	On	Tx	On	On	Tx
S_4	On	Idle	Off-	On	Idle	Off
S_5	On	On	Rx	On	On	Rx

Table 4 Selected Techniques used to reduce power consumption

Power consumption techniques	Method of the technique	Comment
Battery	high capacity battery such as D batteries (15000 mAh) instead of widely used AA batteries (2000_2400 mAh)[33]	the sensor nodes' lifetime can be extended about 7 times longer.
Energy harvesting	Using PZT sensor to harvest energy from traffic vibrations [34]	Not efficient till now to the knowledge of the authors
Low sampling rate ADC	Compressive sensing[35]	Relax the ADC sampling rate requirement and can be used for both DAQ and Communication Modules
Monitoring in low sampling time rate	Monitoring each 6 hours[36]	Reduce the need of activating the monitoring systems for long time based on that structure failure take long time.
Energy management algorithms	Adaptive Sampling Algorithm (ASA)[30]	This method depends on the specific sensor, whose power consumption is significantly larger than that of the Comm. Module

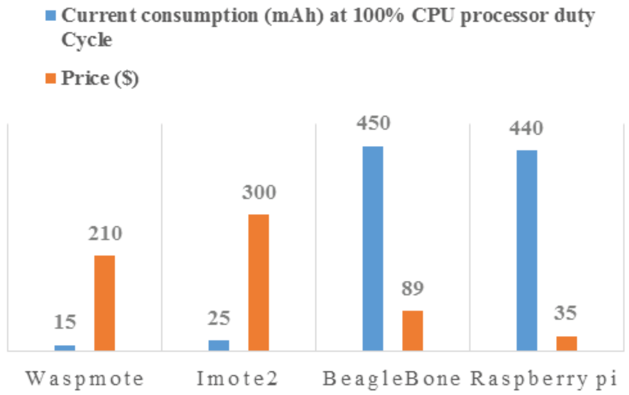

Figure 8 Example of current consumption and price for off shelf mote and open source hardware [32]

It can be observed from the previous discussion that the design of a fully automated monitoring systems for MC needs more effort, especially with the lack found in the current automated monitoring system to monitor all of the MC issues. It is clear that the fully automated monitoring system for MC will have to include the upperground MC issues monitoring techniques, common MC issues and has the ability to attach other sensing techniques for underground MC issues based on the type of the utility beneath the MC.

Most of the automated monitoring system for underground utilities, use the MC as a holder to monitor these utilities [37]–[41]. This means that the design of a fully automated monitoring system for MC should also be able to attach more sensors that can be used to monitor the underground utilities. This will need more care in the design as it will be more complex and therefore more power consumption is expected.

To conclude, this section analyses the proposed classification of the MC issues and shows the gap area in the research for the design of a fully automated monitoring system for MC. It extends to identify the expected challenges that face this design. The effect of the type of underground utilities on the MC structure was also mentioned in this section.

V. Conclusion

By entering the smart cities and IOT era, monitoring infrastructure needs to be more developed. The first stage to monitor the underground infrastructure is to monitor the manhole cover, especially with the increased MC failure, which dramatically affects the safety, security and the economy of the society.

This paper presents by far the most comprehensive survey of MC issues to date, classifying these issues, and showing the available monitoring system used. The authors traced origins of the MC issues and presented a statistical analysis showing the gaps found in the current automated monitoring system for the MC.

The paper shows the shortage of the current automated monitoring systems for MC to monitor all the MC issues especially the upperground MC issues. Therefore, it is concluded that a fully automated monitoring system for MC issues is still in the early stages and needs more effort to establish especially to overcome the power consumption challenge.

Studying the design requirements of a fully automated monitoring system for MC taking into consideration other design challenges like cost, harsh environment, and memory and network requirements are still in progress as a future work for this research.

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