Asset Management of Drainage Facilities Using Advanced Technologies

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ABSTRACT

The Drainage Services Department, in collaboration of the Water Supplies Department, of the Hong Kong SAR Government has to invest and maintain an extremely large public urban water infrastructural asset to provide world-class water supply, wastewater, and stormwater services to enable the sustainable development of the Hong Kong Special Administrative Region (SAR). A brief outline of the concepts of asset management is given in this paper. Effective management of urban water assets needs extensive planning, design and construction, and operation and maintenance. Accurate real-time data collection, transmission, and management in different inter-related functions of asset management become extremely important for the effective and efficient functioning of asset management. Some of these advanced technologies that have been and may be adopted in the Hong Kong SAR are presented in this paper.

1. INTRODUCTION

The total area of the Hong Kong SAR, China is 2,755 m^2, including 1,104 km^2 of land and 1,651 km^2 of sea. The Hong Kong SAR is accommodating a population of approximately 7.1875 million as of mid-2013 [1] and one of the most important financial and trading centers in the world. The average population density of the Hong Kong SAR is 6,650 persons/km^2 as of mid-2013 [1]. However, most of the population is being housed in 215 km^2 of urban development because of steep natural terrain and stringent planning controls. Over 400 km^2 have been designated as protected areas including country parks, special areas, and conservation zonings. As a result, the most densely populated District Council district is Kwun Tong with a population density of 57,120 persons/km^2 [1]. The concentration of population and economic activities in such a small area exert an intense demand for urban water services to sustain the rapid economic development of the Hong Kong SAR, as urban water services are fundamental to public health, population well-being, sustainable development of communities and environmental protection. Therefore, these services are an important strategic sector of significant social and economic relevance. Urban water infrastructure assets represent a major fraction of the combined value of all public infrastructures in most economies. It is therefore essential to ensure their rational and efficient management. Effective urban water infrastructure asset management is the key in achieving adequate and sustainable levels of service in the long term [2]. A long-term approach to managing urban water assets is imperative in balancing performance, risk and cost [3, 4]. A brief outline on asset management of urban water systems is given. Advanced technologies to improve the effectiveness and efficiency of asset management functions are presented in this paper.

2. INFRASTRUCTURAL ASSET MANAGEMENT

The concept and sequence of life-cycle management for civil infrastructure as shown in Figure 1 is to derive the best performance from an asset at the lowest cost from acquisition to disposal. The basic concept is to plan, design and construct, operate and maintain, and renew the asset. The need for infrastructure is generated by growth, desire for improvement, regulatory pressure, system failure, or obsolescence. Such needs are evaluated by a needs assessment exercise. The needs assessment leads to a master plan and implementation plans. These plans are reviewed and then implemented, requiring budgetary and approval actions of the legislature. Design & construction of the facility may follow. Afterwards, the constructed facility is transferred to operations & maintenance (O&M) where regular inspection, maintenance and repairs will take place. When the facility wears out, it is rehabilitated, decommissioned, and may even be replaced. During this cycle, planners and managers must understand the systems, apply relevant aspects of the law and regulations, plan for risk management and emergency preparedness, manage data and information, and engage in overall management activities [5].

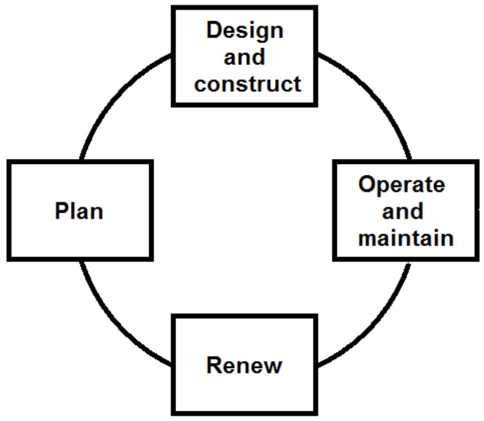

Figure 1: Life-cycle management (after [5])

2.1. URBAN WATER SYSTEMS

Urban water services are needed to sustain healthy, prosperous, and sustainable cities. Most urban water systems are composed of: (1) water supply system for drinking and related purposes; (2) wastewater system for handling of used water; and (3) stormwater system for urban flood control as well as drainage and runoff quality control. These systems provide safe drinking water, wastewater removal and treatment, and protection from damaging storm and flood waters. When they are properly managed, they add valuable amenities to communities and the natural environment. Moreover, they can be coordinated to create an integrated and sustainable system that operates in harmony with the natural environment. While these systems provide different types of services, they use similar equipment and components. An example of an integrated urban water system is shown in Figure 2 to illustrate a complex set of inter-related processes. The urban water system is part of the broader water environment that involves far-flung natural and built watershed systems as shown in Figure 3. In Hong Kong, water supplies service is provided by the Water Supplies Department and wastewater and stormwater services are provided by the Drainage Services Department, both of the Hong Kong SAR Government.

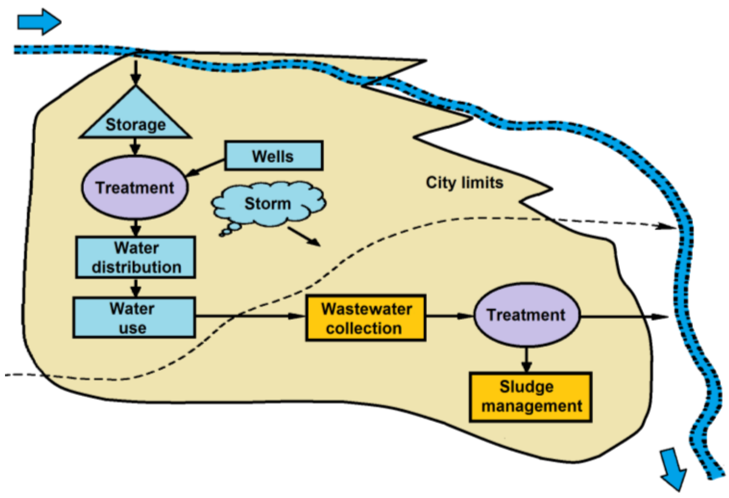

Figure 2: An integrated urban water system (after [5])

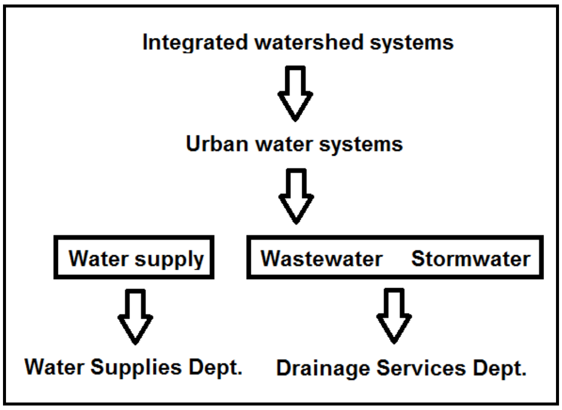

Figure 3: Systems within an integrated system (modified from [5])

2.2. Current Situation of Hong Kong

Hong Kong residents produce some 2.9 Mm^3/day of sewage. Approximately 93% of Hong Kong residents are being served by the public sewerage system, including a sewerage network of approximately 1,600 km in total length and around 280 sewage treatment facilities collecting and treating 2.7 Mm^3/day of sewage from residential, commercial, and industrial premises in the SAR prior to disposal to the sea for dilution and dispersion through submarine outfalls. However, while new towns in the New Territories have been provided with modern secondary sewage treatment works, the sewage infrastructure for the older urban areas has not been upgraded to cater for the level of development of Hong Kong in the past. The sewage infrastructure is now being upgraded under a SAR-wide sewerage rehabilitation and improvement program to cope with the development and the ever-improving living standard of the residents.

2.3. Asset Management

The term asset management has many definitions, one of the most succinct definitions is given in the *International Infrastructure Management Manual* of the New Zealand Asset Management Support (NAMS) as follows [6]: "*The combination of management, financial, economic, engineering, and other practices applied over the full life cycle of physical assets to provide the required level of service for present and future customers in the most cost-effective way.*" The Seattle Public Utilities defines asset management as [7] "… *way of doing business that maximizes the public's return on their investment in utility infrastructure by implementing utility-wide strategies that emphasize reliability in the assets and processes so that the desired levels of services are provided to our customers in the most cost effective manner*." The United States Environmental Protection Agency (U.S. EPA) defines asset management as [8] "*Asset management is maintaining a desired level of service for what you want your assets to provide at the lowest life cycle cost. Lowest life cycle cost refers to the best appropriate cost for rehabilitating, repairing or replacing an asset. Asset management is implemented through an asset management program and typically includes a written asset management plan*." Although definitions and concepts for asset management were mostly in place more than a decade ago, new methods, tools, and concepts continue to emerge. Nonetheless, the functions of an asset management system should work within organizational management programs and include [5]:

- Capital improvement planning
- Maintenance management
- Capital and operating budgeting
- Needs assessment
- Inventory of assets
- Fixed-asset accounting

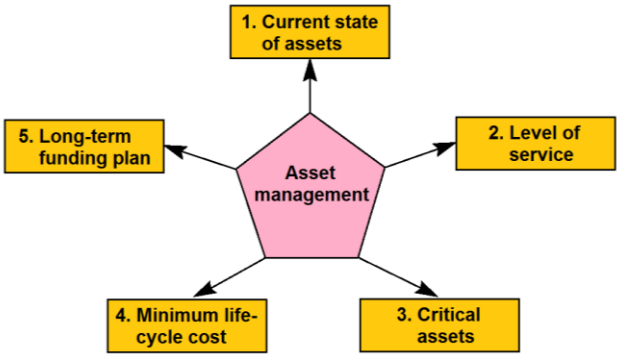

Figure 4: Asset management steps from the U.S. EPA best practices guide (after [8])

These functions are not independent processes. In fact, they involve shared activities among the different functional parts of organizations, especially planning, engineering, finance, operations, and maintenance. Effective and efficient implementation of these functions can results in better customer service, effective capital improvement programs and budgets, better cost control for infrastructure management and operations, readily available information for decision documents for capital improvements, better guides for operations and maintenance practices; effective compliance of regulations, and higher service levels. Many best practices in asset management have been reported, including those of the New Zealand Asset Management Support [6], the United States Environmental Protection Agency [8], the American Society of Civil Engineers [9], the American Water Works Association [10], the American Public Works Association [11], the Construction Industry Research and Information Association of the United Kingdom [12], among many others. An example from [8] is depicted in Figure 4.

Effective asset management of urban water systems produces significant benefits for water, wastewater, and stormwater customers by focusing on the integrity of infrastructure which is an integrated indicator that measures quality of materials and original construction, and current conditions. As shown in Figure 5, the inputs to integrity are qualities along the planning-design-construction-O&M chain or the entire life cycle as shown in Figure 1. High integrity infrastructure produces higher reliability, greater capacity, and better overall effectiveness, leading to improved service, lower risk and greater safety, improved public health and environmental stewardship, and better protection against flood damage. Moreover, high-quality constructed facilities last longer and perform better [5]. Therefore, the relationship between original quality of materials and construction and current conditions is obvious. Assuming high quality of materials and construction, the variation of conditions of a water, wastewater, or stormwater system with time is

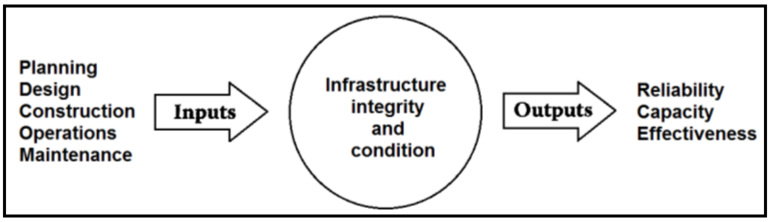

Figure 5: Inputs to infrastructure integrity (after [5])

depicted in Figure 6. The conditions of a facility will normally hold up in early years, and it may require only a small investment to restore the facility to its original conditions. As it ages, more maintenance and upkeep are required to maintain its good conditions. Later on, it may take much more, or may be even the full present cost of demolition and replacement. However, in the case of pipelines, replacement may only be required after many years of service and might be achieved by more economical trenchless technologies.

The program elements of the water asset management system should include:

- Optimizing the life-cycle value of assets
- Promoting continuous improvement in assets
- Establishing a capital improvement program
- Developing a financial plan
- Assessing asset conditions
- Monitoring performance and service levels
- Managing the risk asset failures
- Instituting a data management system such as inventory, locations, attributes, etc.
- Developing O&M strategies

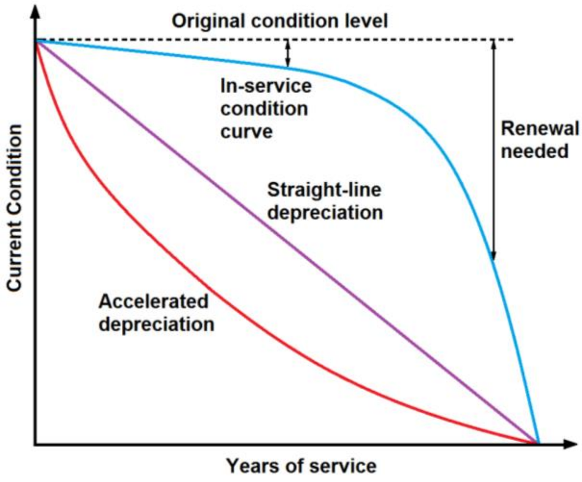

Figure 6: Infrastructure condition curve (after [5]

In this paper, the discussion is focused on urban water assets, in particular, assets on wastewater system and stormwater system in Hong Kong. As Hong Kong has been rapidly developed over past decades, our urban water assets were often out of sight and out of mind after construction, and the construction details are thus only known to the consultants and contractors involved in the construction or maintenance of these assets. As a result, they are often neglected. As the systems expand with time, the infrastructures become mixtures of the old and the new. Infrastructural asset management becomes more challenging because of more stringent regulations, retirement of personnel, and inheritance of vast underground utility systems of unknown conditions and attributes by new managers. More importantly, it becomes more difficult and costly to install new technologies in old systems, as the old systems may not be compatible with the installation requirements of new technologies.

The public systems are capital intensive and require effective management tools to care for their infrastructures on a life-cycle basis. While the public is willing to pay higher rates for electricity or mobile phone services, they resist paying full price to support urban water infrastructure, probably because they do not understand the complexity and cost of urban water services. Large investments have to be made to provide urban water services, and their ratio of fixed-asset costs to ongoing operational costs is high. Therefore, cost becomes another obstacle to install new technologies into old systems. Nonetheless, any new asset management practices should: (i) be integrated with existing practices; (ii) maximize the value of the existing data, information, processes, and procedures; (iii) are more likely to be successfully implemented throughout the organization; and (iv) form a solid foundation from which to further evolve [11].

3. ADVANCED TECHNOLOGIES FOR ASSET MANAGEMENT

Most asset management systems require tremendous amount of data to operate, from needs assessment, engineering and construction, real-time condition assessment, operations and maintenance to financial management. It works across different units in an organization and coordinates functions in an integrated, data-centered approach to manage the organization's physical assets as shown in Figure 7. For example, the same set of data on pipeline locations, conditions, performance, and capacities may be used

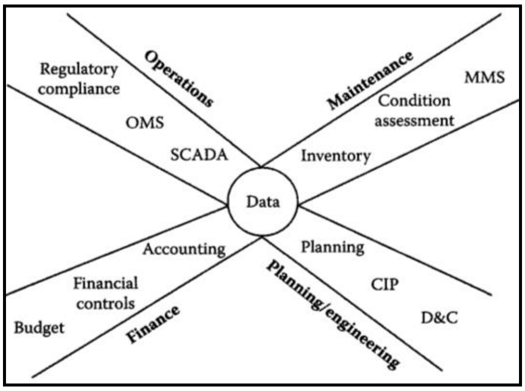

Figure 7: Data-centered approach to asset management (after [5])

by operations, maintenance, planning, engineering, and even finance staff. The data-centered approach can increase effectiveness in programs such as capital improvement, response to sudden and unexpected pipe burst, and reliability-centered maintenance. As a result, most advanced technologies are information technology (IT) based. The challenges with IT are to collect, transmit, store, and retrieve data more accurately and efficiently, and to use the data to improve decisions, leading to better outcomes, and not to generate more unnecessary data that are not used effectively. The ideal is to enable workers to share accurate and up-to-date information among functional departments in real time.

3.1. Quality control of construction materials

As discussed earlier, high-quality constructed facilities last longer and perform better. Therefore, quality control of construction materials during the construction of new facilities is of paramount importance. For better construction efficiency, better quality control, and more environmentally friendly construction, many structural components of new facilities are prefabricated outside Hong Kong, in particular reinforced concrete components. For example, the precast prestressed concrete pile has a lower carbon footprint than the steel H-pile of similar design load-carrying capacity [13]. They are also significantly cheaper. Therefore, this type of pile should be more widely utilized when the geologic conditions are favorable for environmental and economic reasons. However, there are many manufacturers in mainland China producing these piles of significantly variable qualities although their appearance is practically identical. It is extremely difficult to identify piles made by poor quality manufacturers after they have been thoroughly mixed with piles made by good quality manufacturers by unethical piling contractors. Moreover, it is difficult to locate the poor quality piles after installation, even if replacement of these piles becomes absolutely necessary.

The problem is solved by embedding a Radio Frequency Identification (RFID) tag into each reinforced concrete component so that each component has a unique identification. A special scanner equipped with a global positioning system (GPS) is manufactured to scan the tag at regular intervals or at transfer points during transportation. Using the advanced technology, the global position of the reinforced component is accurately documented starting from the manufacturing plant to the final destination of installation as a function of time. The possibility of mixing good quality reinforced concrete components with bad quality reinforced concrete components is completely eliminated. Moreover, replacement of an installed structural component is possible if it becomes absolutely necessary, as the installation position is well documented. The real-time data on the position of the reinforced concrete component so collected can also help manufacturers, engineers, and contractors to control the logistics of manufacturing, transportation, and installation of reinforced concrete components.

3.2. Proper disposal of construction and demolition materials

The Environmental Protection Department of the Hong Kong SAR Government has established stringent regulations on the disposal of construction and demolition (C&D) materials [14, 15]. Depending on the inertness of materials to be disposed of, the materials have to be delivered to different facilities for further processing. The problem is how to ensure compliance of these regulations.

RFID tags can be installed on trucks transporting construction and demolition materials. Mobile scanning devices can be used at the originating point and fixed scanning devices can be installed at the destination to track these trucks to ensure proper disposal of construction and demolition materials. The real-time data so collected can also help engineers and contractors to monitor the construction progress. In fact, a similar truck tracking system has been implemented by the Housing Department of the Hong Kong SAR Government to monitor the movement of construction and demolition materials for their construction projects.

3.3. Wireless sensors

Different toxic and non-toxic gases are generated during the wastewater treatment process. The generation of these gases may or may not be normal in the treatment process. The presence and/or concentrations of these gases are indicators of the quality of the incoming wastewater, effectiveness and efficiency of the treatment process, treatment cost, conditions and performance of the treatment facility, capacity of the treatment works, potential health hazards to operators of the treatment facility, maintenance cost, etc. Some toxic gases may be hazardous to the public and the environment. Therefore, immediate and effective remedial actions upon detection of these toxic gases are extremely important for the protection of public health and the environment. The key issues are accurate detection of these gases at strategic locations and real-time transmission of the concentration data to responsible personnel to take appropriate remedial actions.

It is extremely difficult to install wired sensors in old treatment facilities at some locations due to physical constraints. The availability of power source also limits the locations available for installation of these sensors. Moreover, every wired sensor has to be calibrated after it has been installed in place, as the calibration depends on the length of the connecting wire, i.e. the electrical resistance of the connecting wire. If the sensor has to be moved to another location, it has to be re-calibrated. Calibration of the sensor for gas concentration measurement is not an easy task, as environments of known gas concentrations have to be provided to enclose the sensor during the calibration process. Handheld sensors are not able to perform the monitoring function continuously without manual operations.

Wireless sensors have been developed to solve all these installation and operation problems. For example, an integrated carbon monoxide (CO) and carbon dioxide (CO_2) has been developed to measure these two gases in real time in casinos in Macau. The sensor is powered by battery so that it can be installed at any strategic location. A mobile phone Subscriber Identity Module (SIM) card is installed in the sensor to transmit the collected data through the mobile phone (GPRS) network or WiFi network and the internet to a control computer continuously in real time. A schematic illustrating the data collection and transmission process is depicted in Figure 8. As data are transmitted wirelessly, the sensor can be installed at any location effortlessly. It can also be replaced on a regular basis for re-calibration and recharging of the battery.

The gas concentration monitoring technology can be readily adopted for other gases of concern for wastewater treatment facilities, culverts, different types of chambers, confined spaces, etc., as sensors for different types of gases are readily available on the market. As the collected data can be transmitted continuously in real time, it is possible to use the data to alert responsible personnel through SMS when a preset alert level is reached, and to trigger alerts for immediate remedial actions and/or temporary evacuation of nearby residents when necessary for safety reasons.

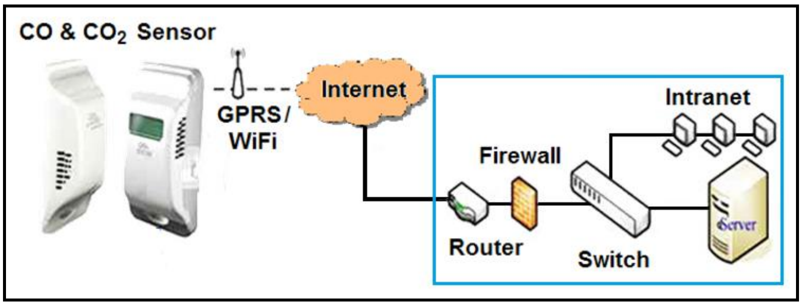

Figure 8: Wireless collection and transmission of gas concentration data

3.4. Mobile biometric authentication device

Collection of water samples, and inspection and maintenance of various facilities are carried out by technical staff of urban water systems on a routine basis. However, it is not an easy task to keep accurate records for such sampling, inspection, and maintenance works. Moreover, it is not an easy task to keep records on the chain-of-custody of samples, and to track any possibility of sample tampering and/or contamination. It also takes an effort to ensure the required maintenance works identified during routine inspections are carried out in a timely manner.

A mobile biometric authentication device equipped with a RFID contactless card reader, a GPS, and a radio-frequency fingerprint sensor has been developed to accomplish the tedious tasks of tracking who is doing what in where simultaneously in real time [16]. The device was originally designed to satisfy the reporting requirements of the Construction Workers Registration Ordinance of the Hong Kong SAR. However, it can be easily adopted for different applications.

The use of a radio-frequency fingerprint sensor can overcome many fingerprint scanning problems associated with the optical scanner so that the device can be used in harsh environments [16]. Moreover, the scanner can perform the life recognition function to prevent tampering or abuse of the device. The device is powered by a mobile phone battery to maximize its mobility and flexibility. The working principle of the device is depicted in Figure 9.

The device is operated in two phases. Phase 1 is the recording phase and phase 2 is the operation phase. During the recording phase, the fingerprint of the technician is scanned by the radio-frequency fingerprint sensor, a selected portion of the fingerprint is transformed by a proprietary algorithm into a unique alpha-numeric code, and the code is then stored onto the technician's staff identity card. The selection process is also part of the proprietary algorithm. As the technician's staff identity card is always in the possession of the technician, there is no privacy issue regarding his fingerprint code. Moreover, there is no reverse algorithm to revert the unique alpha-numeric code to a fingerprint for protection of privacy. Even if the reverse algorithm exists, it can at best recover a selected part of the fingerprint.

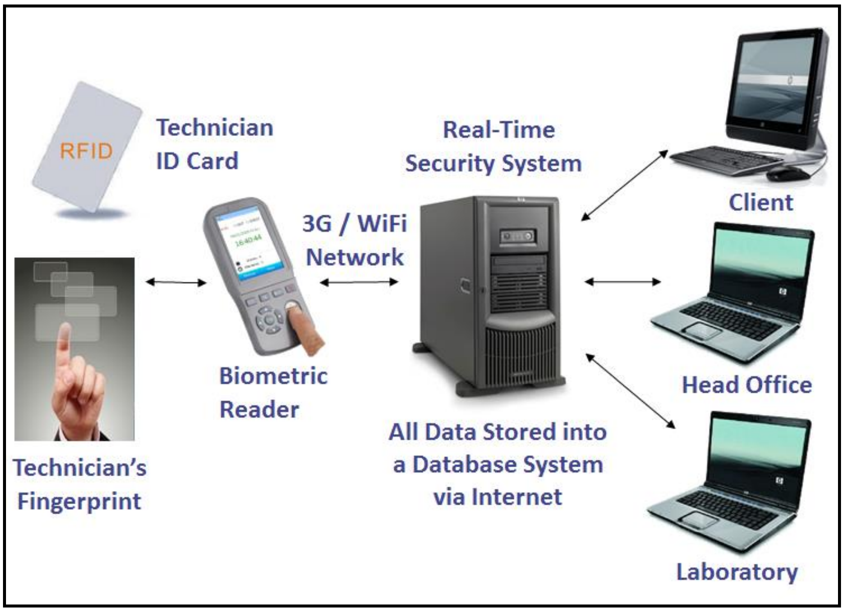

Figure 9: Working principles of the mobile biometric authentication device

During the operation phase, the stored code is first read by the RFID contactless card reader from the technician's staff ID card. The device then scans the fingerprint of the technician, transforms it into an alpha-numeric code, and compares it to the code read from the technician's staff ID card. The device can thus be used to authenticate the identity of the card holder, locate his global position at the time of authentication, and record the time of authentication. Various functions can also be programmed on the device to suit the application needs of the user. The data collected can be transmitted to a database system via internet in real time.

When the device is used in conjunction with a bar code scanner in the sampling process, all the water samples can be properly labeled and tracked, including who collects the sample, where the sample is collected, and when the sample is collected. The recording process is repeated every time when there is a change of custody of the sample, so the chain-of-custody will not be broken.

When the device is used in routine inspection and maintenance, the results of inspection can be transmitted to a database system to remind maintenance staff to take follow-up actions automatically. When the maintenance staff has commenced the required maintenance works, the status of the maintenance works can be updated by the maintenance staff continuously until the works have been completed.

3.5. Non-destructive evaluation of subsurface conditions

Underground voids can be created by soil erosion generated by leaking water from water-carrying utilities. These underground voids, if undetected, can increase in size progressively, leading to maintenance problems, difficulties during installation of new pipes, or in more extreme events, sudden ground subsidence-collapse without any early warning. The accident occurred at Li Yuen Street East on 24 April 2007, plunging four street vendors, three men and a woman, and five stalls into a hole of 8 m long, 4 m wide and 4 m deep [17, 18], is an excellent example demonstrating such disastrous problems. The damage would be much more devastating if it occurs during peak hours underneath a road carrying heavy traffic. Unfortunately, these existing underground voids and their propagation and growth would probably be undetected until accidents occur. Therefore, these underground voids have to be detected and repaired before the situation becomes disastrous. However, it is impractical, if not impossible, to open up every part of the ground surface to look for these voids. The situation is more acute in populous and congested urban developments such as Hong Kong. It is evident that there is a need to develop non-destructive methods to detect underground voids effectively and reliably from the ground surface.

The Drainage Services Department of the Hong Kong SAR Government commissioned a study to evaluate the viability of detecting these underground voids from the ground surface using non-destructive geophysical methods. The viability of different methods available in Hong Kong was reviewed and a field evaluation program on two selected techniques was conducted. It can be observed in the field evaluation program that the techniques of ground penetration radar survey and shallow seismic reflection survey were able to detect voids underneath a concrete pavement with varying degrees of success.

When mapping an underground void from the ground surface by scanning using different types of waves, strong signals are received first, indicating the top of the void. However, a broad wave pattern will be generated afterwards by multiple reflections from within the void, obscuring the signal from the bottom of the void. Therefore, locating the bottom of the void can be a technical challenge [19]. Moreover, it should be noted that the pipeline itself is also a void, making it very difficult to differentiate the void of the pipeline and the voids in the vicinity of the pipeline created by soil erosion.

A new concept was cultivated during the investigation process. It may be worthy considering modification of some of these existing geophysical methods slightly so that the scan can be performed along the pipeline. Both the emitter and the receiver can be installed in a plug which travels inside the pipeline, so that any voids along the pipeline can be detected. Theoretically, this approach will provide a more direct measurement as it is likely that the voids generated by water leakage are located close to the pipeline. This approach has been tried in Japan and appears to have the advantage of a more direct measurement of the soil mass around the pipe, avoiding interference from objects such as ducts further away [20]. In fact, the technique of surface wave-time domain reflectometry is readily available for metallic pipe using this approach. Moreover, the technique can also be used to map the alignment of the pipeline accurately, providing useful information for other functions of urban water asset management.

4. CONCLUSIONS

Asset management is extremely important on the maintenance of the integrity of urban water infrastructures. High integrity infrastructure produces higher reliability, greater capacity, and better overall effectiveness, leading to improved service, lower risk and greater safety, improved public health and environmental stewardship, and better protection against flood damage. Data collection and management are important functions of asset management. Some advanced technologies in data collection, transmission, and management in different aspects of asset management for urban water systems are presented in this paper. Some of these technologies are readily available on the market and they can be implemented in Hong Kong immediately. However, some of these technologies of high potential may require further research and development prior to practical implementation.

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