THE USE OF CCTV IN THE EMERGENCY RESPONSE: A 3D GIS PERSPECTIVE

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ABSTRACT:

With the increasing threats and damages from the natural and man-made hazards, emergency response has become a critical challenge to the smart management of modern cities. Due to limited human resources, how to correctly and quickly assess the priority of disaster relief operations remains a major issue to the disaster management. While the emergency response team may continuously receive lots of disaster information from various sources, they are required to validate whether the reported situations is real or not. CCTV systems are one of the primary references for visually presenting the status in reality. However, current maps of CCTV are usually presented in 2D, such that the monitored spatial coverage is also restricted to 2D. From a 3D perspective, this paper proposes to integrate the GIS-based urban data and the field of view (FOV) of CCTV for improving the collection, management and decision making during emergency response. As the pressure for making prompt and correct decision is often overwhelming, the key issue is to find the best CCTV as soon as possible. Although the current result is only preliminary, the proposed approach demonstrates the advantages of enabling a "real" 3D spatial illustration about the spatial coverage information of CCTV systems by linking it to the features in the real world. With such standardized metadata for FOV available, further analysis can be readily developed, such as quickly determine if a feature is visible, if a reported disaster situation can be validated, and assess the area not covered by the current CCTV systems. By including the disaster events from the historical database, the proposed approach allows the responsible agencies to assess if the deployment and management of current CCTV systems can provide a satisfactory spatial coverage for the cities in the mitigation phase.

1. INTRODUCTION

1.1 General Instructions

Due to the increasing threats and damages from the natural and man-made hazards, emergency response has become a critical challenge to the smart management of modern cities. One key issue for the successful operation of emergency response is the ability to accurately monitor the ongoing disaster situations and assess the priority of disaster relief actions. Various approaches have been used for collecting the information about disaster situations. For example, the use of sensors allows the responsible agencies to receive continuously updated observations about the phenomena of interests. Especially after the booming growth of the IoT technology in recent years, the deployment of sensors at desired locations and the availability of 7/24 non-stop observations via internet have become increasingly easier. Reports by humans, professionals or general public, are another major source for collecting disaster information. From the voice phone in the earlier years to the text descriptions, photos and even videos in recent internet-based platform and social media, disaster information is observed, created and conveyed to the emergency responsible agencies (e.g., CEOC) for action reference (Maryam, Ali, Javaid, &Kamran, 2016). As the modern computer and telecommunication technology revolutionize the distribution of disaster information, to validate whether the overwhelming volume of reported disaster situation is true or not during high-pressure emergency response becomes a huge loading to the responsible agencies, especially when malicious news are involved. Unless validated, to directly share such disaster information to other stakeholders is obviously not appropriate. As the old saying goes, to see is to believe, visual inspection is obviously a preferred way for validating the reported situations because it provides additional information for experts to directly evaluate the levels of threats and damages, as well as make prompt and correct decisions according to the visual observations. Once an area is declared as a disaster site, the responsible agencies must closely and continuously monitor the changes at the reported place and its neighbourhood until the threat is gone. Since such demands of continuous and sometimes long-term observations are unlikely to be met by human observers, this paper proposes to integrate the GIS-based urban data and CCTV for improving the collection, management and decision making in emergency response from a 3D perspective. While the traditional 2D viewpoint is mainly based upon the map overlay concept, the proposed approach highlights the advantage of 3D characteristics of the FOV (Field Of View) information from CCTV systems and enriches the recording information by introducing 3D features into the process of disaster evaluation and decision making. The standardized metadata approach makes the interoperable use of CCTV systems operated by different authorized agencies possible, such that the commanders of emergency response team can flexibly designate and use any CCTV system available. The remaining of the paper is organized as follows, section 2 reviews the related works, section 3 explains the 3D modelling concept, related system architecture and the workflow of data process. Section 4 shows some of the analysed results, and finally section 5 provides the conclusion and discuss the future works.

2. RELATED WORKS

2.1 3D City Model

3D modelling and applications have been receiving increasing attention in recent years. A comprehensive review of applications using 3D GIS technology can be found in Biljecki et al. (2015). Agugiaro (2016) proposes an approach to fuse heterogeneous i sources of data into one consistent semantic 3D city model. Bremer et al. (2016) present a multi-scale 3D GIS approach for the assessment and dissemination of solar income of a digital city model. Kildedar et al. (2019) developed a tool that visualizes the earth and buildings in 3D environment to simulate floods so that effective strategies can be developed to enhance resilience and mitigate the effects of floods.

With the innovated technology advances of sensors and image processing, to create a large-scale 3D GIS data, outdoors and indoors, is no longer a big challenge. For example, Vosselmanand and Dijkman (2001) propose an approach for constructing 3D models of the urban environment with airborne laser altimetry. Takase et al. (2003) develop a system capable of generating 3D city models by using laser profiler data, 2D digital map and aerial images. In recent years, the development of UAV, digital images and image processing algorithms further improve the acquisition and processing of 3D building data. For example, Yamazaki et al. (2015) propose an approach for using Structure-from-Motion (SfM) method with images acquired by UAV to construct 3D city models. Balsa et al. (2018) present an approach that combines laser scanning and photogrammetry data for establishing 3D city models in historical cities (Balsa-Barreiro &Fritsch, 2018). With the degree of automation continuously improves, the time and cost required for constructing a large area of 3D buildings also steadily decreases, which also makes the quick assessment of hazard damages possible.

Because the 3D GIS technology can provide realistic illustration of the phenomena in reality, many cities launch 3D city project over the last few years. For example, the Singapore Geospatial Collaborative Environment (SG-SPACE) initiative is a whole-of-government initiative that creates an environment where the public and private sectors and the community can collaborate together to create a wide range of innovative applications and services using geospatial technology. SG-SPACE includes 60 themes of spatial information and 34 services available to the public. 3D city is one of the major applications in SG-SPACE (Sahib, 2015). In Netherland, the government departments use the 3D city models to facilitate asset management, utility services operation and maintenance, as well as emergency management and disaster response. The extended 3D CityDB, together with the pgRouting library, allows users to perform several types of (network) operations et al., 2018). The New York City Department of Information Technology & Telecommunications (DoITT) builds the NYC 3D Building Model based on aerial survey and the planimetric database, and there are more than one million building footprint in the dataset. This dataset has been used widely from various kind fields (Bonczak & Kontokosta, 2019). In Berlin, there are about 550,000 buildings photographed from the air and measured. And these data has been used for creating 3D buildings for the purpose of application. At the moment, many cities use WebGIS for showing the 3D phenomena, some of them even provide service for downloading 3D data in open data formats (e.g., KML or CityGML data) or commercial data formats (Berlin Partner, 2015) on the basis of individual features.

While there are many 3D GIS systems capable of illustrating 3D phenomena, many of them are restricted to visual inspection only. 3D city projects typically select a number of data themes and model the phenomena of interests with feature types by following open standards (e.g., CityGML). For example, the virtualcitySYSTEMS provides web-based download portal for the 3D city model of Berlin encoded in CityGML (Kim &Pietsch, 2015). The municipality of Rotterdam develops an interactive web-based 3D GIS system that can import BIM format (Sebastian, Böhms, &Helm, 2013). Recent development of OGC standards like i3S (Bröring, Vial, &Reitz, 2014) and 3D tiles (Schilling, Bolling, &Nagel, 2016) further simplifies the 3D applications streaming services in the Web-based environment via commonly accepted standards. As buildings are closely related humans' daily lives, all the 3D city projects include building as one of the data themes.

Figure 1 Berlin virtual 3D city model
(source: Jürgen Döllner, 2006)

Once the 3D buildings are available, various applications can be re-examined from the 3D perspective. For example, Krüger et. al (2012) discusses a case of using CityGML Energy ADE for the identification, classification, and integration of energy-related key indicators of buildings and neighbourhoods within standard 3D building models. From the viewpoint of spatial data infrastructure (SDI), 3D building data can be created by authorized agencies and shared with other agencies for different purposes of applications. This research will focus on the use of 3D building data in disaster related applications.

2.2 FOV Analysis of CCTV System

In the 2D map, a CCTV is often represented by a point symbol based on its location. Operators may click the point symbol to get the streaming video of the CCTV. This approach, however, can only show the geographic distribution of the CCTV and not the spatial coverage the CCTV. This implies operators know where the CCTV are, but do not know to where they are deployed to monitor. Even if a sector is added to the 2D map to indicate the direction and the FOV of the CCTV, it still lacks the height and orientation information of the CCTV to determine its actual viewshed.

With the emergence of 3D modelling, viewshed analysis becomes a common function in the 3D module of GIS software. A viewshed analysis requires users to deploy a camera in the 3D GIS system based on its exterior orientations and determine the area visible from the camera. Many current GIS software, e.g., ArcGIS pro, skyline support the viewshed analysis based on the available 3D data (e.g., buildings and DTM). In the indoor situation, Albahri &Hammad (2017) propose a novel approach for calculating the camera coverage in buildings. The result demonstrates the necessity of including the height information of the camera when calculating the coverage, such that invisible spots behind obstacles can be detected. Chen et. al (2013) use 3D FOV analysis in the MRT stations to evaluate the coverage of CCTV system in MRT stations. However, the result is still presented in a 2D map (Figure 2).

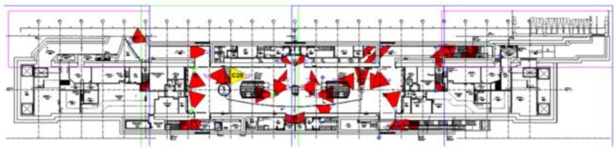


Figure 2 The CCTV coverage in a 2D floor plan view
(source: Huan-Ting Chen, 2013)

3. CONCEPT

Being deployed at almost any desired location, CCTV nowadays has become an extremely useful and effective tool for monitoring the changes of dynamic phenomena in the real world. How to include CCTV systems as an operational component in the emergency response mechanism requires additional analysis from the perspective of disaster management. The proposed approach includes 5 major steps, discussed in the following sections.

3.1 Data Construction

To facilitate the viewshed analysis, data for 3D building, road network, DTM and CCTV system is required. The building data is preferred to be linked to the census data, such that further assessment based on the impacted buildings due to disasters can be completed. The LoD of the building data represents how accurate and detailed a building is modelled. Since the choice of LoDs has different degree of influence on the outcome of the viewshed analysis, more tests should be conducted to determine which LoD should be adopted. As this research only intends to test the feasibility aspect, we choose LoD 1 in this research to reduce the calculation costs. The responsible agencies of the CCTV systems are required to provide the information of the exterior orientation for each CCTV in the geographic space, namely, the coordinates parameters of the location and the rotation parameters around the three axes. The exterior orientation information serves as the basis for deploying ("locate" and "orient") the camera in the next step. Figure 3 shows the different viewpoints of the same 3D building dataset.

Figure 3 3D-city data

3.2 FOV Analysis for Single CCTV

With the data acquired in the first step, FOV analysis is performed for every CCTV. Different from the cone-shaped FOV analysis in 2D scenario, the result of the FOV in this case is represented as a quadrangular cone. In Figure 4, the analysis outcome shows only a portion of the building are visible from the CCTV and the buildings may block the line of sight, such that some regions mithin the FOV are actually invisible from the CCTV. If the viewshed analysis outcome is shown in 2D map, the cone-based illustration fails to indicate only the green area is visible and not the area above. Meanwhile, the 2D illustration will also wrongly show the red area is visible, while it is in fact not. This demonstrates the necessity and advantages of introducing the 3D perspective to better model the spatial coverage of the CCTV systems. Of course, the better geometric representation of the 3D features in the analysis is, the better the FOV analysis outcomes are.

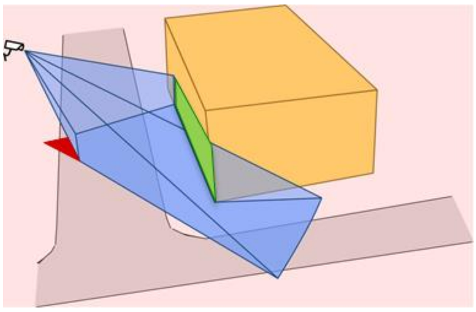


Figure 4 FOV analysis of individual CCTV

3.3 Spatial Coverage of FOV

Based on the viewshed analysis outcomes, we propose to record the relationship between the FOV of CCTV and the 3D features. The spatial coverage of the FOV is recorded by a multi-surface feature, the polygons that are visible from the CCTV. Due to the effect of visual blocking, the FOV comprised of the "visible polygons" are not necessarily neighbouring with each other. The ID of the visible features is recorded together with the ID of the CCTV. With such information recorded in the database, query can be issued between these two types of information in either way for acquiring another type of information (i.e., from CCTV to visible features or from features to the CCTV that provide visual inspection). Together with the exterior camera, the information of the FOV and the ID of the visible features are recorded as the metadata of the CCTV.

3.4 Catalogue Service

In this step, the standardized metadata mentioned in the previous section for all the available CCTV is collected and a catalogue service is created. The major outcome is the area that can be or cannot be monitored by the current CCTV systems. The advantage of introducing standardized metadata is the enablement of managing different and heterogeneous CCTV systems handled by various domain stakeholders, such that it is possible to build a complete picture for the monitored regions or even the whole city. Dependent on the deployed locations, a place may be monitored by more than one CCTV (the green polygon in Figure 5), but it may be also not visible even if all the CCTV systems are considered. Such invisible regions or features may become the blind spots of the modern cities and deserve more special attention.

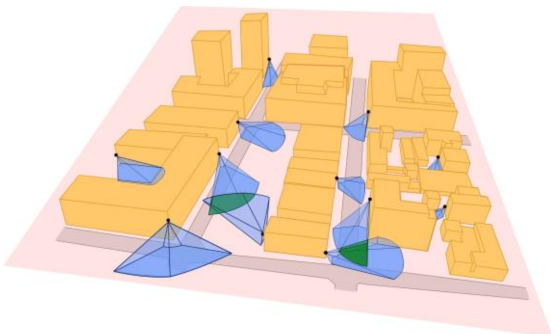


Figure 5 The FOV analysis of multiple CCTV system

3.5 Application of FOV Information

The FOV information in metadata and database can be used in any applications that require continuous monitoring. From a disaster management perspective, once a disaster situation report is received, the mechanism can easily determine which CCTV should be trigged for further validation by performing 3D geometric intersection test between the location of reported disaster and the FOV information of the CCTV system. If the reported disaster can be associated with particular feature (e.g., disaster situations are often reported according to the name of the features), the candidate CCTV can be quickly located by the data generated in section 3.3. Should the disaster indeed occur by visually inspecting the streaming videos from the selected CCTV, then the ID of the CCTV is added to the tracking list and will be kept in the list as long as the disaster situation is still valid.

Once the relationships between the buildings and the FOV of CCTV is established, queries based on selected feature or CCTV can be readily implemented. Figure 6 shows that operators can issue queries with the camera ID or object names and the system can response to the users based on the relationships stored in the database. After validating the disaster situation, operators can further enquire the information of nearby buildings to assess the disaster relief operations, e.g., assessing the number of senior citizens that may need to evacuate in a flooding situation.

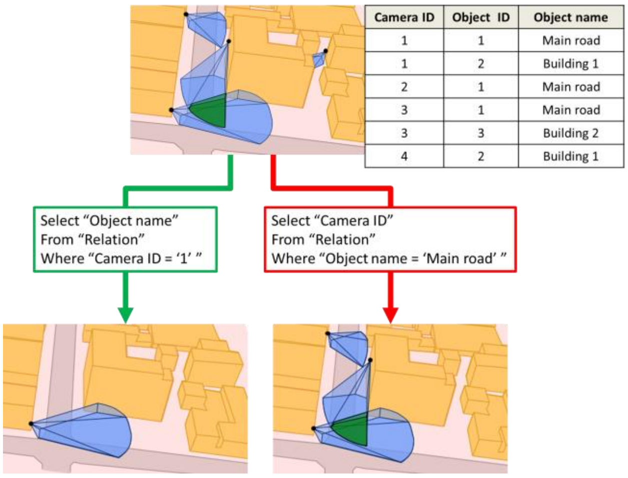


Figure 6 Relationships between CCTV and the 3D features

Meanwhile, the proposed mechanism can be also used in the mitigation phase of the disaster management, where we can analyze the locational relationships between the location of the disaster events from the historical disaster database and the FOV metadata of the CCTV systems. For those past disaster situations not visible from the current CCTV systems, and especially those regions with long history of disasters (e.g., area prone to floods), these regions should be found and further evaluated if it is necessary to deploy new CCTV.

Figure 7 explains the workflow of the proposed approach. Note the intended outcome is not only an illustration of viewsheds of CCTV systems most current GIS software can already provide, but rather a stronger linkage between the CCTV systems and the visible features in the neighbourhood to facilitate more effective management about the capabilities and limitation of the CCTV systems. As the disaster-related applications require continuous observation ever since the disaster occurs and being validated, we believe a CCTV-based mechanism works in a standardized fashion can conquer the heterogeneity issue and fully integrated with the disaster decision making system).

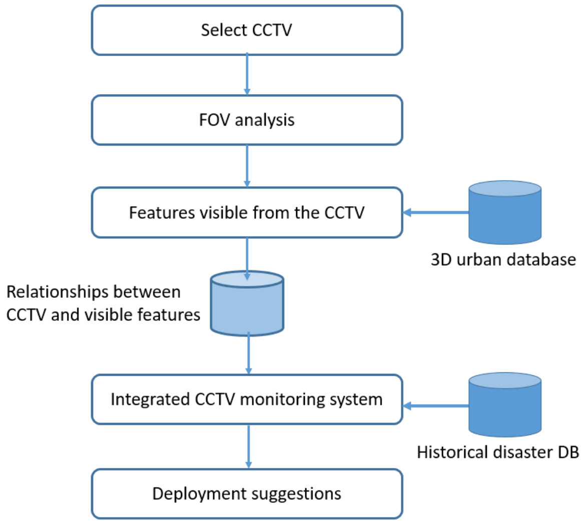


Figure 7 Workflow of the proposed approach

4. TEST RESULT

Zhu et al. (2018) summarizes two major approach for building 3D urban models, the procedural modelling approach and the urban reconstruction approach As the proposed approach intends to explicitly record the relationships between a CCTV and its visible features, the 3d urban data must be built following procedural modelling approach. For each building, the attributes include the id, address, floor, height, etc. For CCTV, in addition to the exterior orientation information, other parameters, such as the sensor format, the focal length of a lens, and the distance from the objects (Chen et al., 2013), must also be considered .

With the metadata of CCTV and 3D building data available, DTM and satellite imagery data are introduced to provide a more realistic application environment. Many GIS software can be used to create 3D building data, e.g., Esri CityEngine, SuperGeo SuperGIS, Trimble Sketchup Pro, etc. Trimble Sketchup Pro is used for creating 3D data because it provides a user-friendly interface, a set of powerful 3D modelling tools, the capability of importing 2D map to assist the data creation, and most importantly, the supports of the 3D spatial analysis. The LoD of the 3D buildings in the current study are restricted to LoD 0. Figure 8 shows the detailed process of our proposed solution:

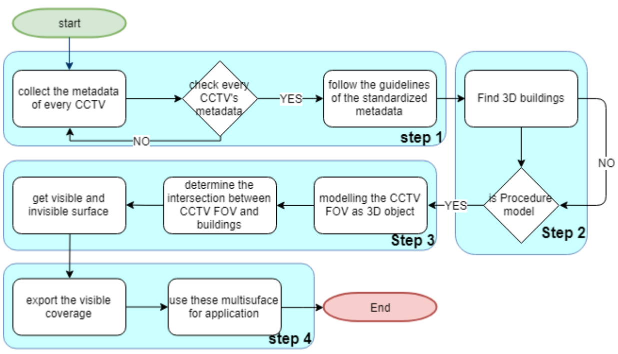


Figure 8 The data handling process

There are four major steps in the data process workflow. In the first step, the metadata information for every CCTV must be collected and validated. If there is any required information missing, the CCTV cannot be correctly deployed according to its status in reality. Different CCTV systems must follow the guidelines of the standardized metadata to provide the required CCTV information. The second step checks if the 3D building data is created following the procedural model approach. If the 3D buildings are created following urban reconstruction approach (e.g., 3D buildings created via remote sensing imagery or Lidar point clouds) or do not come with required attribute information, then it is necessary to further process the data. The third step determines the viewshed of each CCTV. Since both the CCTV FOV and the buildings are modelled in 3D, we use the built-in function “intersect” in Sketchup Pro to determine their intersections. If only one CCTV is considered, the features in the test systems are hence interpreted as either visible or invisible. Finally, we export the visible parts and store the relationships between visible features and the CCTV. The geometry representation of the stored FOV information is by default multi-surface in this research. According to the intersection results, a surface in the original 3D buildings may be subdivided into a number of sub-surfaces labelled with either visible or invisible. Each sub-surface has a link associated with its original surface.

Figure 9 shows a 3D test scenario for a single CCTV. The buildings are illustrated in the color of white. After the processes in Figure 8 is completed, the regions illustrated by the color of green and red respectively indicates the visible and the invisible part within the FOV. From Figure 9, it is clear that the viewshed of a single CCTV may be extremely restricted by the nearby buildings. Every CCTV is deployed for a particular reason, therefore it does not necessarily require to have a very good viewshed outcome. In this example, the narrow street and the lower deployed location certainly impose limitation on the viewshed outcomes. It is also clear that the geometric representation of the viewshed outcome is a multi-surface and its sub-surfaces are not necessarily neighbouring with each other. Following similar process, the viewshed for every CCTV can be analyzed and stored accordingly.

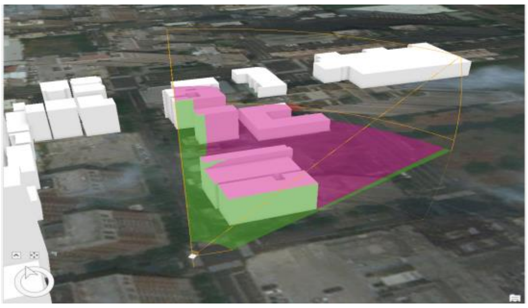


Figure 9 The 3D coverage of a single CCTV

Figure 10 shows the multi-surface approach when both the FOV and 3d features are simultaneously considered.

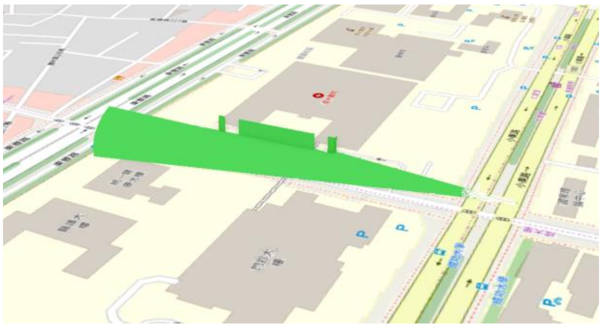


Figure 10 The coverage of single CCTV

The scenario in
Figure 11 illustrate the relationships between the viewshed outcome and the introduced city phenomena (building, network or other_area in this research). The multiplesurface depicted by the color of blue indicates the visible region from the given CCTV.

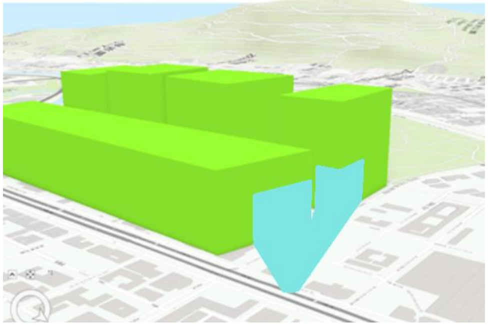


Figure 11 The coverage of single CCTV

When more than one CCTV are considered, the visible coverage scenarios expand to include regions that are visible from more than one CCTV. For a reported disaster, the number of usable CCTV is as few as 0 (i.e., invisble), and as many as the total number of CCTV (i.e., visible in all CCTV). Figure 12 illustrates one case with two CCTV. The geometric intersection of the viewshed of the two CCTV represents the region visible in both CCTV. The geometric intersection test may increase the complexity of managing the FOV information, but it also implies a better understanding about the spatial coverage of the current CCTV systems during emergency response.

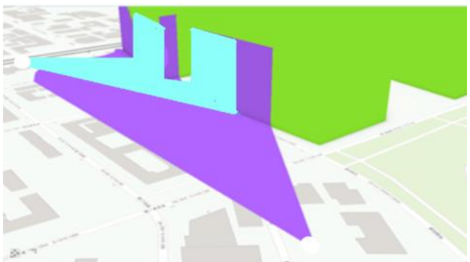


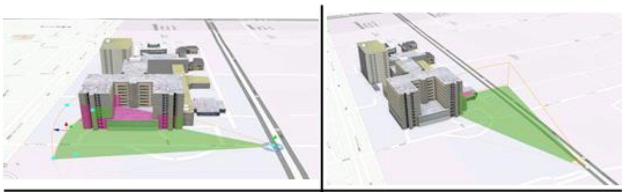
Figure 12 The coverage of multiple CCTVs

In the following test, the NCKU hospital is chosen as the test building and a portion of standardized metadata for the three CCTV is created, as shown in Figure 13.

a. 3D urban model　　b. the CCTV metadata

Figure 13 The test data

After deploying the CCTV, the visible and invisible regions are determined. Figure 14 shows the viewshed outcome of two CCTV. One is deployed for monitoring the status of the road in front of the NCKU hospital (Figure 14a). In addition to the road, the viewshed also covers a portion of the building of the NCKU hospital. Another CCTV is deployed to monitor another road on the other side of the NCKU hospital (Figure 14b). The viewshed only cover a small portion of the hospital building.



a. the FOV of CCTV 1　　b. the FOV of CCTV 2

Figure 14 The FOV of CCTV

The test scenario is a heavy rain occurred on August 24, 2018. Photos distributed in social media shows flood occurs in front of the NCKU hospital (Figure 15a). After reviewing the photo, there is indeed flood situation, so the operators can pinpoint the disaster as Figure 15b shows. The red point in the Figure 16 indicates the location of the reported disaster. With the recorded viewshed information, we can quickly determine the CCTV that to the be triggered according to the topological relationships between the viewshed and location of the report disaster. According to Figure 16, CCTV01 appear to be a candidate to validate the reported disaster. But if the disaster location is in the region with red color, then CCTV01 cannot provide visual reference.

If the photo is geo-tagged (e.g, acquired from the EXIF of the photos), we can easily obtain the location where the photo is taken, then use such location information to determine which CCTV should be used to validate the disaster situation. Although this process is straightforward, we nevertheless need to point out the place for taking photo is sometimes not the place of disaster. The geo-tagging process thus requires special attention. The case in Figure 15a is an interesting one. The title grabbed from social media is “flood in front of NCKU hospital”, but the place for taking photos is actually the intersection of the Shen-Li road and the Hsio-Dong road, a place very close to the location of CCTV01. Therefore, the information acquired from text description and EXIF is actually different.

a. Photos provided by crowds　　b. the location of disaster

Figure 15 The reported disaster situation.

Figure 16 The FOV of CCTV01

When there are more than one CCTV, the analysis must take multiple coverage into consideration. Figure 17 is the test scenario that includes three CCTV. Since the common geometric intersection between the viewshed of CCTV01 and CCTV02 is already stored in the database, both of them should be triggered because the location of reported disaster falls within the common geometric intersections.

Figure 17 The visible coverage of multiple CCTV

5. CONCULATION

Information acquired from CCTV is unique and valuable. Lack of the ability to manage, control and share such information impedes the development of smart cities. While the traditional 2D GIS systems force users to select and operate the CCTV information from a limited and specific viewpoint, they often fail to provide accurate information for making prompt and correct decision. This paper argues the integration of FOV of CCTV and urban data from a 3D perspective provides an additional dimensionality for emergency response. In terms of disaster management, the advantages of the proposed approach are extremely obvious, as it enables the validation of reported situations with real-time visual information. This is especially important for handling unorganized data submitted by inexperienced social media users or general public, because their information may be very useful and up-to-date, but to directly share such information without any validation is risky. The worst scenario is the fake or incorrect information may cause overwhelming and unnecessary panic among the general public. Sharing the standardized FOV information from different stakeholders further helps to facilitate the development of an integrated CCTV monitoring system. This metadata-based mechanism enables decision makers to find and use any available CCTV during the emergency response. As the analyzed outcomes are feature-based, further analysis based upon the semantics and attributes of the 3D features is possible. The success of the proposed approach is certainly restricted by the details and the accuracy of the 3D urban data, as any object not modelled may have additional block influence and the FOV information after analysis may be incorrect. We demonstrate the introduction of 3D GIS can effectively and efficiently improve the current practice and the accuracy of the decisions, more studies on the standardizations of the FOV of the CCTV and the 3D urban information is still necessary in order to take full advantages of the available CCTV.

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