Inspection of Discrepancies in Construction Temporary Safety Structures through Augmented Reality

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Abstract – Construction safety has been a major area for research for an extensive time as the number of accidents, injuries and deaths has not significantly declined, despite strong implementation of safety laws and major efforts of the construction safety professionals. According to the Ministry of Employment and Labor, Korea (MOEL) [1] from 2012 to 2015 the Construction sector occupied the highest percentage of fatalities among all sectors in Korea. Automation of the inspection process of Temporary Safety Structures on Construction sites (TSSC) can reduce fatalities and injuries on work site. This research proposes a unique approach for the safety inspection of TSSC by using an outdoor marker-less AR system along with Structure from Motion (SfM) to reconstruct the 3DCG (3-Dimensional Computer Generated) models by using photographs from different viewpoints. The system(framework) considers area mobility of the inspector and his long relative distance, along with local feature-based image registration technology to target the location for Augmentation of 3DCG models of TSSC. This system would enhance the inspection, verification, and installation of the TSSC and help in ensuring worksite safety of all individuals involved in the construction development process. In future research, a case study would be conducted to confirm the implementation of this framework and integrate other areas for further development.

Keywords –

Instructions; Construction Safety; Inspection; Augmented Reality; Feature-Based Image Matching; Structure from Motion

1 Introduction

Construction worksite safety is a comparatively high researched area, because of the soaring number of fatalities and injuries during development phase of the projects [1] [2]. Construction caused 20.9% of the workplace related fatalities in the United States from 2003 to 2008 (Bureau of Labor Statistics, 2008) (Census of Fatal Occupational Injuries (CFOI) - Current and Revised Data, 2018) and In South Korea it had the highest percentage of fatalities according to the Ministry of Employment and Labor[4]. The processes involved in construction project development should revolve around the central idea of worksite(occupational)safety, as it directly impacts physical human life safety of the workforce and all other humans beings involved in the construction processes, such as management, trades, and logistics teams. Safety can be ensured in certain scenarios by the proper usage of different types of Temporary Safety Structures such as safety fence, struts, guardrails, scaffoldings, handrails, temporary gates, and others. These Temporary Safety Structures on Construction (TSSC) sites require strict monitoring, detailed concentration of the inspector and need to be setup according to the safety design. This makes the safety inspection process a challenge, as construction sites can cover vast areas and site conditions can be unpredictable.

Currently, in most scenarios, the safety inspection is being conducted manually, wherein the safety inspector visits the worksite and enforces legal safety requirements and best practices. The inspector relies on his observation of the entire safety design, installation & verification processes, and his observation of the Temporary Safety Structures on Construction (TSSC), to ensures safety and provides help in avoiding any discrepancies(errors), which can possibly be a major cause for physical bodily harm (injuries) or even deaths on construction worksites. This method typically involves the usage of 2D drawings and requires detailed attention to temporary safety structures on large construction sites. This inspection method requires constant monitoring, strict and lengthier time span, which makes it predisposed to errors, because of the manual nature of the process. The inspector has limitations as a human being, such as concentration span duration and Vision fatigue, such limitations can lead to reduction in the number of discrepancies (errors) detected which in a large scale construction site can be a major cause of safety lapse. Due to these human limitations despite considerable effort from Construction Safety Professionals for worksite safety, the number of fatalities and injuries has not reduced and continues to be the highest in construction when compared to other industries.

The advancements of technologies for use in construction, such as Augmented Reality, can help improve construction worksite safety. Augmented Reality (AR) is already being actively used in architecture and urban design fields as it can integrate augmentation with the real-world scenes. Through the help of visualization feature of AR[5], construction safety inspection can be improved both at the design stage (3D design visualization) and later at the safety inspection stage for discrepancy monitoring.

Augmented Reality (AR) provides the users (construction professional) with an interactive experience, where the real-world environment and real-world objects are enhanced by computer-generated perceptual information. This proposed framework AR system would integrate real world scenes with 3D (3-Dimensional Computer Graphics) models, to facilitate the possibility of onsite safety inspection. The AR system is to be set for an outdoor environment, specifically for outdoor safety inspection. This is due to the relatively large distance that exists between the user and the 3D model in outdoor AR systems. Such a system would enable the safety inspector to monitor TSSC with the help geometric registration (location-based monitoring). The reference point is the position of the sensor such as GPS or 3D sensor [6], in contrast to when using a marker based method, where the position of the artificial marker servers as the reference point, which is an example of vision-based methods.

Figure 1. Shows a Safety Inspector monitoring Temporary Safety Structures on Construction site

2 Related Work

2.1 Marker-less AR for Inspection

Generally, the proposed system is to be used for outdoor inspection. If a system is sensor based then, one of the key challenges is to get accurate AR. This requires precise tracking of the geometric registration between the live video stream and 3D reconstructed model image. The reference point for geometric registration is proposed to be positioned near (close) to the user (inspector), hence, the sensing errors that can significantly influence the error of the 3D model registration may be reduced. Whereas, in artificial marker-based methods, it is possible to place any large size markers near the target objects. Moreover, the marker needs to be captured properly, with the right angle, by the AR Camera. This imposes limitations on the mobility range of the user and requires placement of a large sized marker. A Marker-Less AR system would enable the Inspector to monitor the construction site from a distance and enhance his mobility. This mobility factor is the primary reason for the advancement of Marker-less AR (which do not require artificial Markers) Technology for example [7], [8] and [9]. The development of a geometric registration method which corresponds point cloud data to natural features of the real world was developed by Yabuki [10]. This method requires natural feature to be continuously captured by the AR Camera, it also requires special equipment to acquire point cloud data, as the system would use to 3D laser scanner to collect the large amount of data for the point cloud.

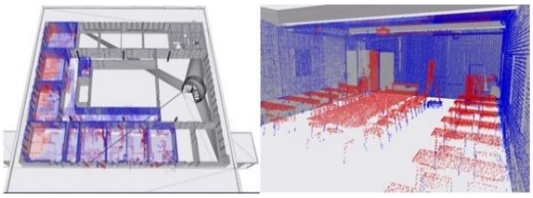

Figure 2. Shows a sample regarding point cloud data & objects segregation for 3D modelling

The 3D Model displayed on the screen uses the equation developed by Zhengyou Zhang [11], where the equation s symbolizes expansion or reduction factor with u and v as the position that draws the object according to the coordinates.

$$s\begin{pmatrix}u\\v\\1\end{pmatrix}=\begin{pmatrix}f&0&c_x\\0&f&c_y\\0&0&1\end{pmatrix}\begin{pmatrix}R_{3\times3}&T_{3\times1}\end{pmatrix}\begin{pmatrix}X\\Y\\Z\\1\end{pmatrix}$$

f denotes the value of the focal length, c_x and c_y determine the coordinates of the center of the image, these values are known as the parameters of the camera where R is rotation matrix and T is the translation matrix of the camera. All these values are known as the external parameters of the camera. The values of X, Y, Z denote the position of the object in the real-world coordinates.

The internal parameter generally remains constant(unchanged), unless camera lens is changed, and can be calculated through camera calibration. Specific to the photograph's viewpoint are the position and posture data of the camera, for the external parameters. This is the primary reason for the calculation of the external parameters for the AR system. For Marker-based system the calculation takes place via the position of the marker, whereas for marker-less system another calculation method is required. Subsequently, for this study, a novel marker-less based system, along with feature-based image registration technology was used. Additionally, to enhance mobility the system utilizes the sensor-based registration and does not require a marker. The point cloud data used in the system is reconstructed by Structure from Motion (SfM).

2.2 Structure from Motion for 3D modeling

In direct contrast(to Lidar), Structure from Motion(SfM) [12], requires multiple pictures taken from different point of views to create a point cloud data of the TSSC [13]. This a low-cost alternative tool to 3D lasers scanning for creating models [14], it is an emerging method. The system does not utilize any special equipment such as laser scanners.

A major feature of the proposed system is that it does not require any specialized equipment (such as sensors for geomatic-registration between the Augmentations and the real world) as it uses sensor-based registration. Additionally, Artificial Markers are not required (they decrease user mobility and flexibility). Lastly, point cloud data used in this system is reconstructed through SfM and no special equipment such as laser scanners are required. These reconstructed models will be used for 3D model creation.

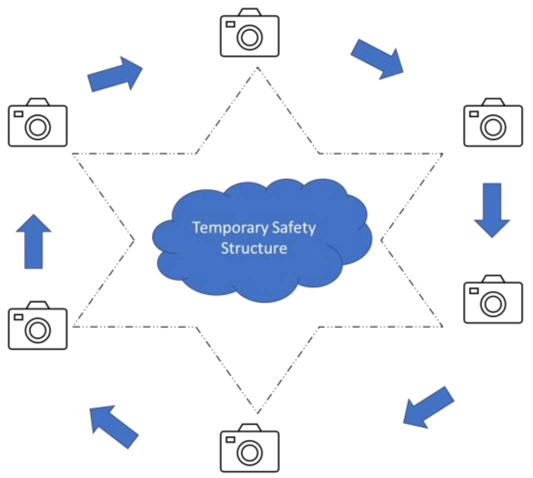

Figure 3. Shows the Image capturing process required for Structure from Motion (SfM)

Figure 4. Shows a sample of different reconstructed models of objects from SfM

This study presents a framework based on a novel marker-less AR system which utilizes local feature-based image registration and Structure from Motion (SfM) technology for discrepancy inspection. The system provides free mobility, reduced limitations, requires less effort and is inexpensive for use in outdoor AR application.

3 Overview of the Proposed System

In this Framework, the proposed system is dived into two sections: Initial-Processing and Core-Processing.

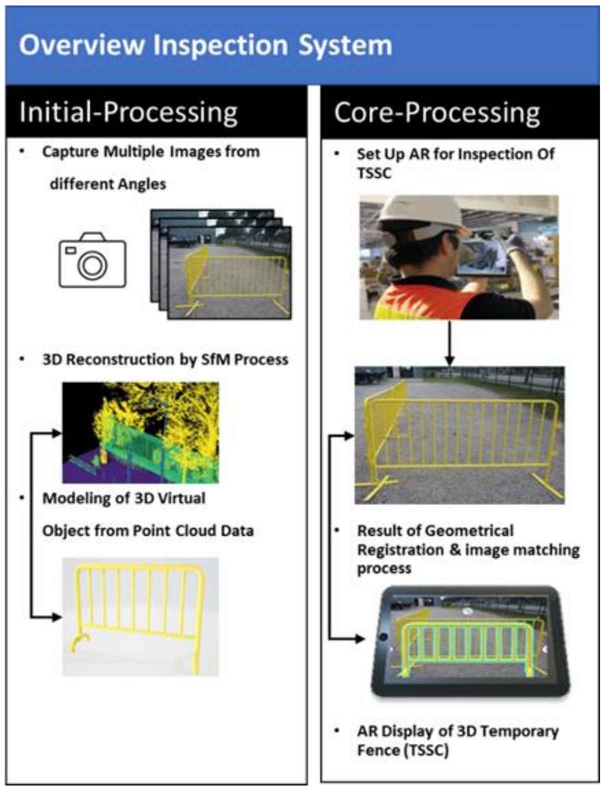

Figure 5. Shows the System Overview

Under the Initial-Process, in the first step, a 3D model of the environment will be reconstructed using the Sfm method, using the pictures taken from multiple viewpoints. The entire data regarding position and orientation of all the viewpoints would be stored in a database. In the second step the coordinates of 3D model generated for augmentation (Safety Fence in this scenario) are to be defined relative to the 3DCG models of the reconstructed environment that was created (reconstructed) using SfM and stored in the database. Finally, the keys point and features from all the pictures used in SfM will be extracted and stored in a separate text file. In addition, the file paths of the all the pictures will be saved in a separate text file.

For the proposed research based framework, the user (inspector) is asked to utilize an advance local feature detector and descriptor known as Speed-Up Robust Features (SURF)[15], as it is based on the improvements from the Scale-Invariant Feature Transform (SIFT) which is used for point detection proposes.

In the Core-Process, Firstly, all the files created in the Initial-Processes step should be imported. Secondly, real time extraction of the features of the live video would be extracted using SURF in real time, the features will then be compared with the features of the stored image in database. Finally, the precise rendering of the 3D virtual objects using position and orientation data of the camera and finding the most similar image in the database will takes place in AR display. For tracking to take place, motion vectors will be calculated by using optical flow. Finally, the calculation of the external parameters would consider internal parameters, Position of points on the screen and the world coordinates of their corresponding points.

To achieve real-time processing, 3 speed enhancement should be applied to processes, firstly, SURF processing, to compare keys features of live video images and all stored images in the database. Secondly, Locality Sensitive Hashing (LSH)[16] algorithm should be applied instead of the full search by linear search algorithms. Finally, a multithreading technique is proposed to be applied for feature extraction during the SURF process. In the Image Registration processing step, the live video images should be trimmed to only process the central area.

3.1 Processes, Software & Libraries

The system design for the proposed project will be implemented using C++ through a combination of multiple open source software applications and libraries. In this context the Initial-Processes will use OpenMVG (Open Multiple View Geometry version 1.6), which is an open source software to conduct Structure from Motion (SfM). Secondly, for 3D modelling Trimble SketchUp (Version 66.1.), which is another opensource software to define the coordinates of the virtual 3D objects.

For Core-Processes OpenCV (Open Source Computer Vision – Version 4.3.0), another opensource library is proposed to be used for live video stream capture and image matching. For Parallel processing

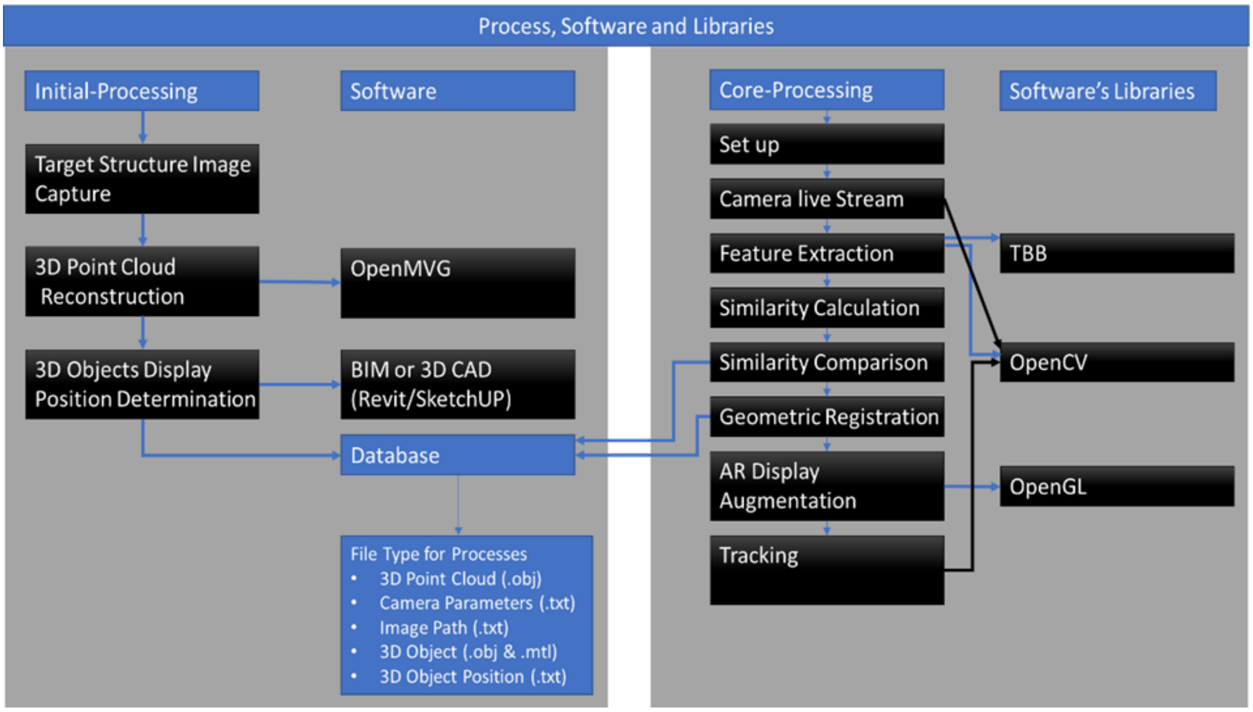

Figure 6. Shows the process, Software and Libraries required for the system

library Threading Building Blocks (2019 Update 8) was used. For Drawing 3D models on the AR display FreeGULT(Version freeglut 3.2.1), it is a toolkit for OpenGL (Open Graphic Library).

4 Designed System Verification Process & Limitations

The 3-step verification process for the proposed system, both the Initial-Processing and Core-Processing need to follow the set 3 steps, for the system to work properly.

Step 1: Location Information and tracking

- Tracking Route of TSSC
- Photography route of SfM
- Registration Position

Step 2: Image Matching

- Live Stream Capture & database Feature Based-Image Matching with SURF

Step 3: Augmented Reality 3D Model Super imposition

- AR Tracking while the User is Walking
- AR Display of Vector Motions
- 3D Model Augmentation

The generated data for each process needs to be saved into the database and will be utilized in the next step until the final step is completed and results are shown.

The proposed system is limited in its geometrical registration to the photography route of the temporary safety facility, this limitation can be overcome by the incorporation of addition photography routes to the TSSC. The 3DCG models face the challenge in tracking due to hand shaking, which can be overcome, by the average of the motion vectors in plural frames can be used when calculating the external parameters, this improvement will require development of new algorithms.

5 Conclusion & Future Research

This research proposes an implementable framework for Inspection of discrepancies in Construction Temporary Safety Structures through Marker-less Augmented Reality, that uses Structure from Motion (SfM) to reconstruct the 3DCG (3-Dimensional Computer Generated) models by using photographs from different viewpoints, along with feature-based image registration technology for construction safety inspection. The system if implemented can enhance the discrepancy monitoring of the Temporary Safety Structures inspection process by providing onsite visual aid of 3DCG models and allow location tracking. The system is limited to photography route and can cover additional routes. In future research, a case study would be conducted to confirm the implementation of the framework, its feasibility as an alternative and further improvements that an enhance the processes, such as blockchain based secure database management system, for the data collection of the system.

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