AUTOMATED CONSTRUCTION PROGRESS MONITORING USING THERMAL IMAGES AND WIRELESS SENSOR NETWORKS

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Abstract: Construction progress monitoring has been perceived as one of the key factors that prompt the achievement of a construction project. However, assessing the progress is time consuming, costly and obliges specialized personnel to reduce disagreements and approximate the actual performance to the original plan as close as possible. Image processing is a promising method that has been developed for automated monitoring of construction projects. It has attracted increasing attention for progress monitoring, quality assurance and work space analyses. Nonetheless, remarkable drawbacks still remain in image processing, particularly for outdoor environment such as construction progress monitoring. The principle downside of image processing goes back to the image resolution. Ambient lightning condition significantly affects the image quality which does affect the accuracy of data, extracted from related images. Much research strives to reduce the level of errors for data extraction but so far none has been able to deliver complete satisfactory and reliable result. In this research a novel approach based on thermal image analysis is presented. The new method consists of three phases: First, collecting the thermal and original images by utilizing Infrared-Camera. Second, estimating the position of captured images by the use of wireless sensor network implemented in the work space. Finally, the 3D plan will be updated automatically in the Building Information Modeling (BIM) software. The preliminary experimental results from an actual concrete building construction site show the feasibility of inferring the actual state of progress by the use of thermal images to overcome the limitation of vision monitoring.

1 INTRODUCTION

Construction progress assessment has been repeatedly reported as an essential factor for the success of the large-scale construction projects (Zhan, et al., 2009; Bosche, 2010; Bosche, et al., 2009; Hongjo, et al., 2014).The traditional construction progress assessment methods require manual data collection and wide data extraction from drawings and schedules. Moreover, specialized personnel are required to collect and analyze such information. Automation construction progress monitoring can significantly impact the project management and increase the efficiency and precision of this process. It can record the current state of the construction and compare them with the target state and detect any deviations in the geometry and /or any variation in the schedule.

Thanks to the recent remarkable development of computing technology, image processing can play an essential role as an automated monitoring tool. On the other hand, the image processing seriously depends on the quality of the images. Ambient lighting conditions, image noise, shadows, occlusions, low detection of the object edges and other features can significantly affect the precision of the results hence it is difficult to fit the model to the actual object.(Rottensteiner, 2001).

In the meantime, Building Information Models (BIM) increasingly attracts many researchers to automate construction progress monitoring projects. The BIM is a comprehensive software which has the capability of comparing the 3D geometry of all components by considering their descriptions and relations (Eastman, et al., 2011). The model stores costs, element quantities, process data and all possible information for the whole project participants. It can provide the 4D model which is the combination of 3D geometry and schedule quality control (3D + time) (Gilligan & Kunz, 2007). Application of these models during construction process can be expanded by combination of BIMs with as-built models.

Nonetheless, linking as-planned models with collected photos for the purpose of monitoring construction progress is the main challenge in this area. First, it is difficult to match the location of taken photos with the sketch (check points). Second, the un-calibrated images with widely uncontrolled and unpredictable lighting conditions significantly may reduce the accuracy of results. Finally, the visibility and occlusions are known as the principal reasons to cause low quality images.

In general occlusions can be categorized as two types: (1) *static occlusions* which are caused by temporary structures (e.g., formwork or scaffolding); and (2) *dynamic occlusions* which refers to the movements of workers or construction machinery during photo collections.

This paper presents a method to overcome the issues related to low quality images and minimize the error from the extracted data of images by the utilization of the Infrared camera (IR-Camera). The major idea relies on the properties of the materials, particularly concrete, in construction buildings. This paper starts with an overview on the related work in section 2. Section 3 represents a comparison between traditional photos and thermal image method. The proposed approach is explained in details in section 4. The experimental results are presented in section 5.The paper concludes with a summary and future plans.

2 Related Works

The actual state of construction progress can be monitored either by laser scanning-based or image-based systems. Both systems generate point clouds from the surface of the buildings including occlusions. The general process of the proposed monitoring method are as follows: The BIM model and the project schedule are designed in the first stage. Next, the photos should be captured from the fixed construction location. Subsequently the actual state of the project are compared with the as-planned model. Finally, the system detects any deviations in the geometry and /or any variation in the schedule and updates the schedule of the remaining construction process.

Image and video data collection have been known as an affordable method for many construction companies. Numerous studies have been conducted to utilize and improve the image data for construction project monitoring and management purposes. Neto et al. (2002) proposed a color-edge-detector algorithm to identify the construction components. In this method a predefined library based on the RGB ranges for different materials is created. The algorithm traces the edge of an object and compare the RGB values of the pixels by initial library in a clockwise direction. Zou and kim (2007) developed a method based on HSV (hue, saturation, and value) and color to compute the idle time of hydraulic excavators automatically. In Golparvar-Fard et al. (2009), time-lapsed images have been created with all BIM components to specify whether or not specific areas have similar expected appearances. Ibrahim et al. Zhang et al. (2009) and Lukins and Trucco (2007) present similar automated method with different recognition stage. In their method the comparison is between pre-calibrated images and previous photos. Specific area of interest are analyzed by focusing on pixel changes to detect any differences from past photos. The time-lapsed images method has the most automation reported so far. However, it has numerous limitations: (1) fixed camera has limited the analysis to the only closest structural frame to the camera; (2) lighting conditions and shadow issues significantly affect the image processing; (3) dynamic occlusions make it difficult to analyze the components; (4) static occlusion may result in false detection (Golparvar-Fard, et al., 2009).

The laser scanning-based systems have similar steps with image based systems. A laser range scanner is utilized to collect point clouds and merge them into a 3D model in CAD/BIM. Recent applications of this method can be mentioned as construction quality control (Akinic, et al., 2006), condition assessment (Gordon, et al., 2003), health monitoring (Park, et al., 2007) and component tracking (Bosche, 2010). Despite the accuracy of this system, costs, resolutions, the mixed-pixel issues, regular sensor calibrations and slow warm-up time are noted as the main drawbacks of this method (Bosche, 2010; Kiziltas, et al., 2008).

All previous studies have expanded the feasibility of image processing for construction. However, few efforts have been made to improve the image quality in various constructions with different illumination conditions. Thus, this paper presents another method to overcome unstable ambient lighting conditions and dealing with occlusions limitations.

3 THERMAL IMAGES VS TRADITIONAL PHOTOGRAPHS

For decades, construction industries utilized camera to provide project documentation. Traditional methods of utilizing printed type film cameras are being replaced by digital formats. Digital images offer a unique ability and convenient method for monitoring construction project progress. They can provide an acceptable return on investment (ROI).Hence, digital camera is an essential tool for managing construction projects (Brilakis, 2007) . Automated construction cameras play an important role for real-time data analysis and project documentations. High Resolution Digital Cameras are utilized to take static images at set intervals for monitoring process (Hannon, 2007) .

Automatic object identification is one of the principle application of cameras. Camera matching method is utilized to compare the actual state with as-planned models and then track the progress in relation to scheduling (Navon, 2006). Further, integration with Building Information Modeling (BIM), can identify any deviations in the geometry. Thus, it is important to recognize objects from taken images. Development of image processing algorithms has greatly aided for this purpose. However, there are some serious challenges related to photometric method. First, ambient lightning conditions is the main problem. Low lighting may result in poor analysis. Second, occlusions can significantly reduce the image quality which causes high percentage error in image processing. To overcome such issues, a new method based on Infrared-Camera will be discussed as following.

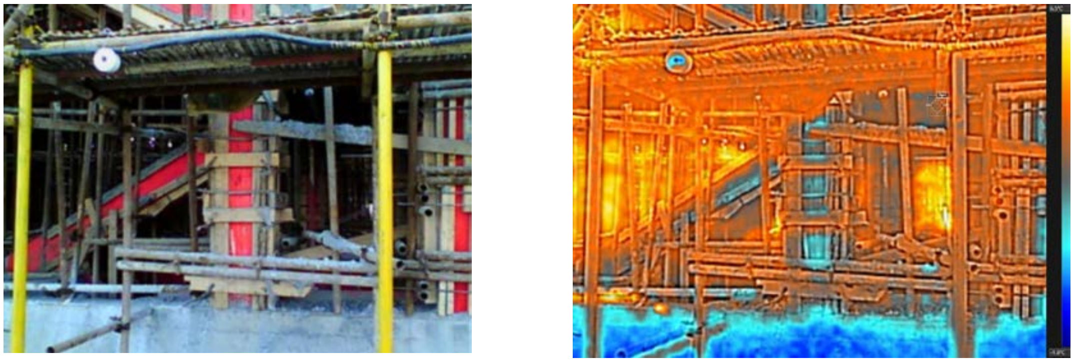
Infrared-Camera (IR-Camera) is a non-contact camera that absorbs the heat energy from surface and give an illustration in the form of thermal images. This device allows users not only measure temperature, but also detect and evaluate any heat-related parameters such as humidity.
Furthermore, most of the construction material properties, can be considered as heat-related materials. Concrete is a good example for representing these properties. For instance, new built concrete elements have different temperatures in comparison with other materials. Figure 1 and 2 illustrate the differences of temperatures on the surface of concrete columns and stairs, respectively. The areas with different temperatures are completely clear. Figure 1, confirms that even concert behind a formwork can be detectable.

Different data can be extracted from thermal images. Another parameter which can be focused on is humidity. It should be noted that there is no need for additional images to utilize and extract different information. It is possible to utilize the same thermal image with different filters. Figure 3, represents a concrete column in terms of humidity. The zones with yellow color show the humid areas.
Therefore, due to the different colors of concert elements with scaffoldings, it is possible to easily remove occlusions from thermal images.

Referring to the introduction section, lighting conditions are known as a big challenge in photometric progress monitoring. To show how thermal images can solve such these problems, figure 4 and 5 have been taken in a poor lighting condition. It is approximately impossible to detect columns from these images. However, in the thermal images, they are easily detectable.

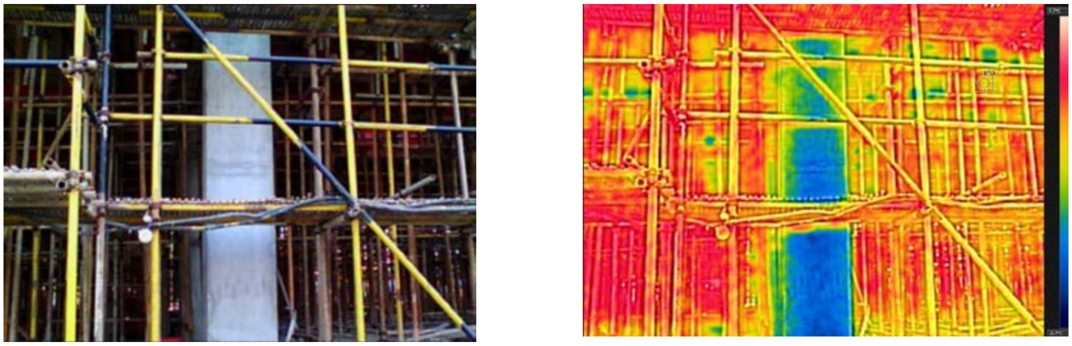
In some cases, it is very difficult to detect the existence of objects from the construction images due to the high aggregation of scaffoldings or other occlusions. Thermal images can be really helpful in such cases. Figure 6 represents a messy environment. Figure 6c shows the result of image processing that applied on the thermal image on this busy environment. It shows how thermal images can be useful for detecting the existence elements.

Moreover, there are some other filters which can be applied on thermal images such as Iron, Lava and so on. Numerous empirical experiments showed that humidity and temperature filters are adequate to gain reasonable results in image processing.



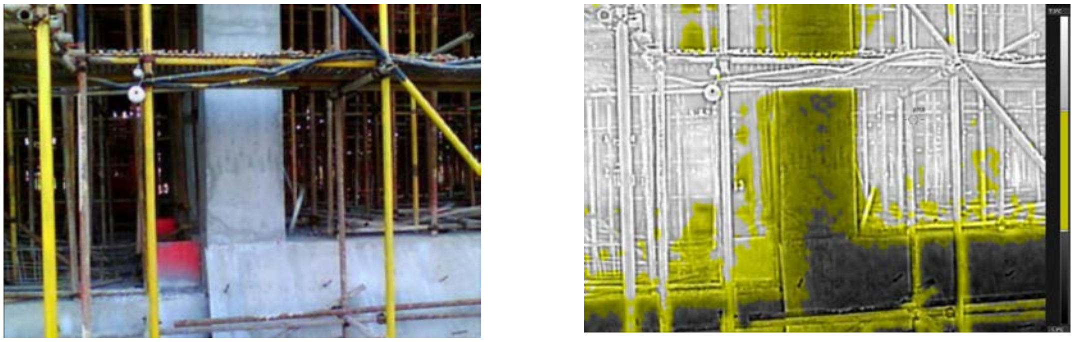
(a) Original image (b) Thermal Image

Figure 1: Different temperature area on the surface of concrete columns and stairs



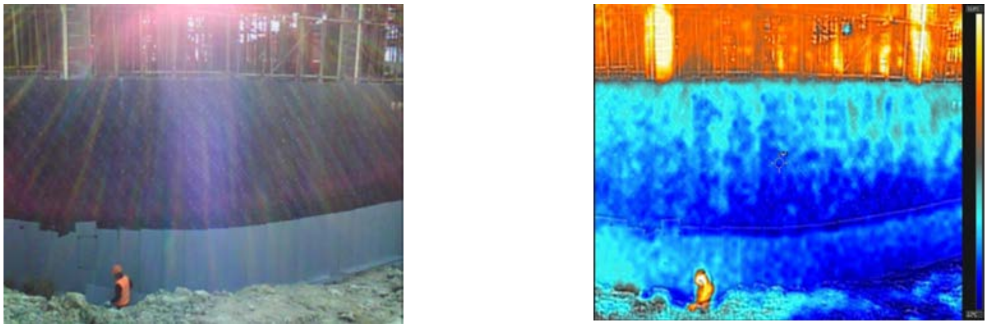
(a) Original image (b) Thermal Image

Figure 2: Different temperature area on the surface of concrete columns



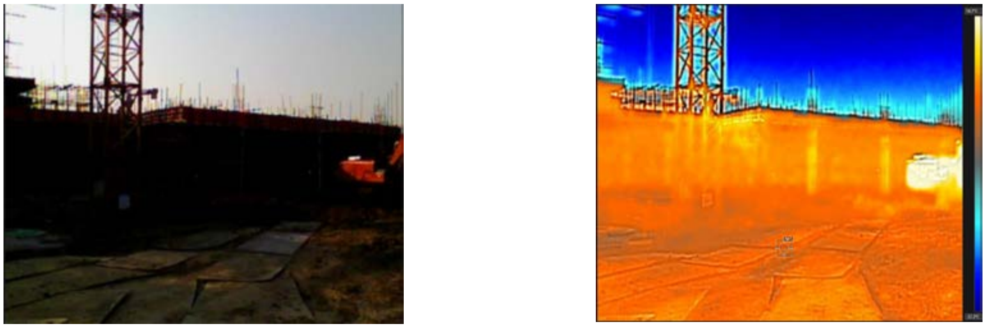
(a) Original image (b) Thermal Image with humidity filter

Figure 3: Different humid area on the surface of concrete columns



(a) Original image with poor lighting condition b) Thermal Image from low quality image

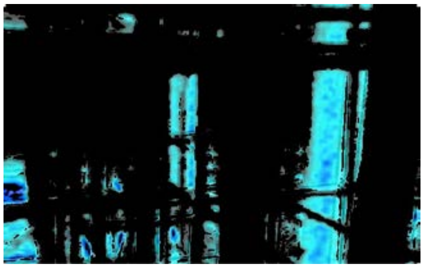
Figure 4: Identify areas from poor lighting condition image



(a) Original image with poor lighting condition b) Thermal Image from low quality image

Figure 5: Identify areas from poor lighting condition image

a) Original image from a noisy environment b) Thermal Image from low quality image



c) image processing result

Figure 6: Identify objects from a noisy environment

To sum up, thermal image can be a really helpful method to detect objects in a busy environment and has the potential to solve the issues of low quality images. In the next section, the concept of process will be discussed.

4 CONCEPT

Referring to the past explanations and examples, in a messy environment, it is difficult to identify objects and extract constructed building parts. The principle concept of this paper is to utilize the differences of colors in the thermal images to aid image processing algorithm obtaining more accurate results. Original, thermal and humidity images have been used to compare the actual state with as-planned models.

These types of images can overcome low quality image issues. Consequently, image processing can more easily detect objects from the combination of original, thermal and humidity images.

4.1 Recording

There are four steps to generate point cloud: Image acquisition, location and orientation of image, image conformity and co-registration.

4.1.1 Image acquisition

Referring to section 3, an Infrared-Camera (IR-Camera) has been selected as a data acquisition tool. Thermal images can be used in any busy environments. During this step, the whole construction site should be covered.

4.1.2 Location and orientation of image

To find out the location of taken images, a wireless sensor network based on ZigBee is implemented around the construction site. CC2430 and CC2431 sensors are utilized as reference and mobile nodes, respectively. This technology can estimate the coordinates of mobile target with high accuracy. The photographer requires to wear the mobile node during acquisition process. According to the time of each image and the estimated location of photographer, the position of each image can be identified .Therefore, it is more convenient to record control points.

4.1.3 Image conformity

In the next stage, images with approximately an equal orientation and coordinates have to be identified. Determining the overlapping images makes it easier to rectify photos based on image pairs. Afterward, dense-matching is applied on the resampled images and original ones. According to the disparity definition which is the distance of two pixels along an image row, for each pixel, a relating pixel in the other picture is hunt. The semi-global-matching (SGM) method is a suitable way to compute the disparity (Hirschmuller, 2008). Finally, by the use of exterior orientation of images and the depth of the point (disparity), the 3D points can be triangulated. (Refer to Rothermel et al. (2013) for more details.)

4.1.4 Co-registration

If the control points and coordinates are not existed in the construction reference frame, corresponding features extracted from images have to be measured to calculate the transformation parameters. Obviously, only proofed building parts can be utilized for this step.

4.2 Technological dependencies

In the present industry, construction schedules are planned manually in an effortful, time-consuming and error-prone proceeding. Refer to Huhnt (2005), it is possible to move on automatic process generation by detecting technological dependencies. The version 4 of the standardized data model Industry Foundation Classes (IFC) represents the *IfcProgress* entity which mentions the process information and dependencies between building elements (BuildingSmart, 2014). Following, the concept of the technological dependencies is discussed. Assume a three level building which consists of four columns and one slab in each floor. The columns on the second floor cannot be constructed before the first slab is finished. The first slab also depends on the columns beneath it. These dependencies are specified as technological dependencies. The graph is a suitable method to represent these dependencies (Deo, 2011). According to the graph laws, removing each node results in disconnecting that branch. It should be noted that each node represent a checkpoint component in this research which is essential for identification of objects from the point clouds (refer to section 4.3).

4.3 Comparing as-built and as-planned state:

This stage includes two principles. Direct and indirect verification of construction components. The first part is applied based on the point clouds found directly from images. Second part is implemented based on analyzing the model and graph priorities to identify and remove occluded objects.

4.3.1 Matching point cloud and object surface:

In direct verification, the existence of building components can be confirmed by calculating a parameter named M. This factor is based on the orthogonal distance d from the surface of building component to a specific point by noting the accuracy $\boldsymbol{\delta_d}$. Following equation shows this relationship.

$$(1)\quad \mathrm{M} = \frac{1}{\mu_d} . \sum_i \left(\frac{1}{d_i . \delta_d}\right) \qquad \text{with } d_i = \begin{cases} d_i = d_i & if\ d_i > d_{min} \\ d_i = d_{min} & if\ d_i \leq d_{min} \end{cases}$$

All objects of surface with the Δd surrounding distance are considered for calculation. Afterward, the surface is segregated into quadratic raster cells with the size of x_r. The parameter μ_d represents the distance mean value which is calculated among all points and the surface within on the raster cell. The value d_{min} denotes the condition which limits the maximum weight of a point. Finally, calculated M can be compared with a threshold S to confirm the raster cell as an existence point.

5 CASE STUDY

To show the feasibility of thermal images, an experiment is conducted on a 5 story university building which currently is under construction. This building located in Suzhou, China. According to a regular schedule the building was captured by means of IR-Camera. Figure 7, 8 and 9 illustrate the original, thermal, and humidity images, respectively.
Figure 10 illustrates fifteen parts of the building in a raster cell plot. The points with larger deviation than 5 centimeters have been removed. The range of raster cells are adjusted to x_r =10 cm.
Other parameters are adjusted to $\Delta d = 5$ cm, d= 2 cm and δ_d=1 cm. The grey areas represent the confirm raster cells. It should be mentioned that figure 10 indicates the results based on the combination of original and thermal (Rainbow HC – Humidity) images.

From the figure 10 and table 1, it can be confirmed that all elements cannot be verified ambiguously with collected data. Part 13 has a rate of 95% which is extracted from thermal image while part 11 has not any confirmed raster cells as it is still under construction. Parts 14 and 15 are also under construction process but could be identified by 66% and 72%, respectively. It can be explained as the temperature of concerts inside formworks and the angle of sunshine. Parts 3, 4 and 5 could be detected easily from the humidity image as there are not covered by formworks.

Figure7: Original image

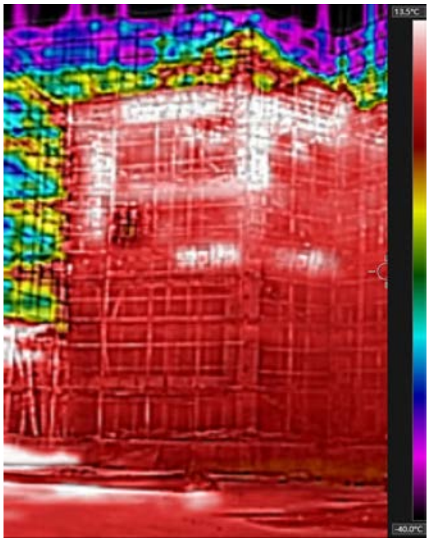


Figure 8: Thermal image

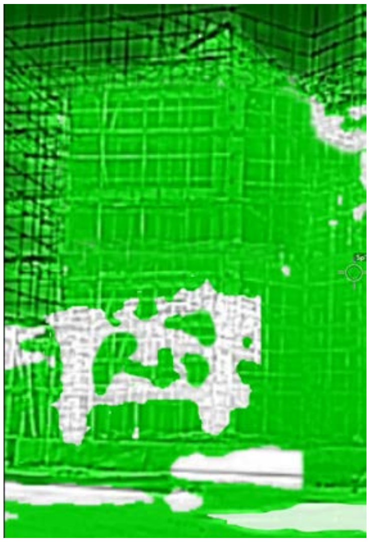


Figure 9: Humidity image

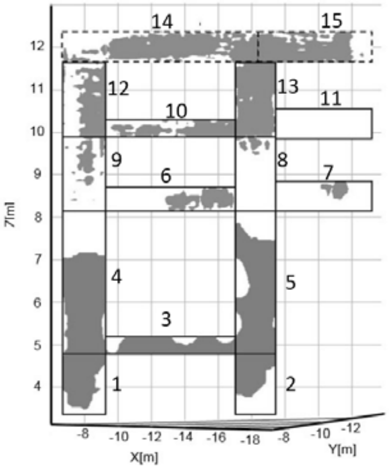


Figure 10: Raster cells on object surface

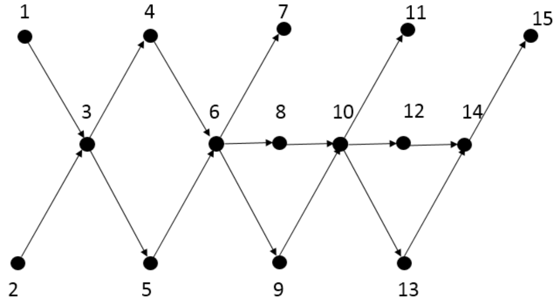


Figure 11: Precedence relationship graph

According to the discussion in section 4.2, technological dependencies can be helpful to detect objects which are not identified from images. Figure 11 shows the related graph for this part of the building.

Part 6 has few confirmed raster cells. However, by applying dependencies from column 4 and 5 which have 68% and 75% confirmation, it is possible to verify the unclear part. The same method can be applied for columns 8 and 9 which have few confirm raster cells. Parts 10 is confirmed by a high percentage. Hence, columns 8 and 9 can be considered as complete elements.

To sum up, image processing only on the original photo, cannot identify all the building elements due to the low quality of image, poor lighting conditions and messy environment. However, the combination of original, thermal and humidity images resulted in a high range of object detections.

Table 1: Percentage of confirmed raster cell per object

Part number	Existing elements	Part number	Non-existing element
13	95%	15	72%
3	79%	14	66%
5	75%	11	0%
10	71%		
4	68%		
1	67%		
2	56%		
12	55%		
6	24%		
9	20%		
7	13%		
8	8%		

6 DISCUSSION AND FUTURE WORK

This paper presents a novel approach based on thermal image analysis for monitoring construction progress projects. For Image acquisition step an Infrared camera is utilized to capture related photos. The goal is to improve the data, extracted from images for monitoring the progress of construction sites. Thermal images offer additional information than traditional digital cameras. Temperature and humidity differences are the main parameters that utilized to improve the quality of images for image processing step. To identify the orientation and location of taken photos, a wireless sensor network based on Zigbee is utilized in this research. The implemented experiment shows that there is a much greater potential accuracy to be achieved than traditional methods. However, all existence elements could not be verified ambiguously with collected data. To increase the accuracy of the analysis, a graph method is also applied in this research.

There are some other filters such as Iron or Lava which may increase the quality of images in some cases. Future research will target at extracting more information from thermal images and integrated with the color attributes provided by BIM.

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