# Visual Inspection in Dilapidation Study of Heritage Structure Using Unmanned Aerial Vehicle (UAV): Case Study As-Solihin Mosque, Melaka

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**Abstract**
Maintenance and preservation of inheritance structures is very important to avoid failure in design and structure. An efficient maintenance scheme requires periodical inspections associated with a reliable condition determination of the structure. Especially the process of data acquisition is a time consuming, labour intensive and technically complex task. The study aims to apply vision-based inspection and monitoring approach for heritage structures based on high quality aerial photos taken by remote controlled Unmanned Aerial Vehicle (UAV) to identify the type of defect in the outer structures of the heritage mosque's roof. In terms of quality and time, this approach contributes significantly to data acquisition and monitoring strategies and will provide increased efficiency in preserving heritage monuments. UAV equipped with high-quality photo cameras or high-quality video cameras provides opportunities to facilitate and speed up data acquisition and monitoring tasks. The processes involved in the study are planning and preparation before flight, data acquisition using UAV, image processing and data analysis from video to image. As the results from the analysis, a total of 39 locations have been identified and documented by defects such as cracks, plants, moss and fungus, rust, fade paint and others. All defective information obtained through visual inspection of the UAV can assist the Department of Heritage and the management team of the mosque in conservation and maintenance work.
**Keywords:** UAV, dilapidation study, heritage building,

## 1.0 Introduction

Historical buildings is defined as a single or a group of buildings, be it separated or detached, due to its architecture, homogeneous, or its place in the landscape, having a universal value that is noticeable in historical, art or science perspective (Jabatan Warisan Negara, 2012). Other than that, a building can be considered as historical should it withstand 100 years. In other words, if a building having architecture, aesthetic, history, documentary, archeology, economic, social, politic, soul, and symbolic can be considered as historical buildings (Fielden, 2000).

In Malaysia, almost all 100 years old mosque are gazetted as historical buildings by the state government. Ancient mosques in Melaka can be categorized as sino-electic. These mosques have on-ground floors similar to those in Indonesia. Normally the roof shape of these mosques can be seen in two or three layers (Mastor Surat, 2008). As-Solihin Sebatu mosque was built at the end of year 1896, is one of heritage mosques gazetted by Perbadanan Muzium Melaka (PERZIM) on 6th May 2014. The characteristics of layered roof or pyramid-like shape roof alongside Chinese patterns and carvings are exceptionally visible especially at the peak and end part of the roof. The usage of these Chinese inspired bricks and tiles can also be seen at the Melaka West Strait, most evidently in the Minangkabau district are made of wood and *ijuk* roof, which comes from *enau* tree. Mosques with pyramid-like roof tend to have a pagoda-like tower (Ezrin, 1971).

According to A. Ghafar Ahmad (1994), historical buildings in any country should be conserved due to its high values in terms of emotional, culture and functionality. There is a concern that these historical buildings will vanish, engulfed by time itself, without proper continuous conservation (Hobson, 2004). Hence, the effort to preserve and restore historical buildings in Malaysia should be done in any way possible from time to time for the younger generation having any chance to witness and enjoy in its restored state as it was hundreds of years ago or at least in its current state that has been re-established as a museum, gallery or hotel, not just a page in history, reference books in the library or just a picture in a postcard, which is currently happening (Bridgwood et al, 2003).

There are four stages to be conducted in preservation or restoration of historical building which are preliminary studies, dilapidation studies, action plan and execution of conservation programme (Jabatan Warisan Negara, 2012). Dilapidation studies are more towards the process of identifying the damage level of the buildings by using photos to indicate the before restoration process. According Ahmad Ramli (2002), in dilapidation work, visual inspection usually done by using binoculars and camera and specific documentation method to produce correct result. The concept of preserving heritage that has been in practise is authenticity in heritage conservation. Thus the conservation work of historical buildings should be carried out carefully to minimize disturbance to the structure and fabric of the building. However, the use of manual methods in the dilapidation work is at risk of harm and injury when it involves the process of recording images in high and hard-to-reach structures (Masiri, 2016). Limitations of access also result in poor image quality recorded.

Therefore in this study, Unmanned Aerial Vehicle (UAV) technique can be used as an alternative tools in visual inspection in dilapidation survey (Masiri, 2016). According to Ahmad, A (2010), this device consists of a camera that can capture clear photos other than capturing videos. The usage of a micro UAV could identify the damage on the outer section of the buildings. Therefore this study will explain the process of visual inspection for dilapidation work of As-Solihin Mosque as historical building in Melaka. The outcome of this study is to get a clear view of the real damage on the roof structure of the mosque.

## 2.0 Literature Review

### 2.1 Unmanned Aerial Vehicles (UAV)

UAVs are aircrafts without human pilots and can fly autonomously controlled by a computer, remotely controlled by a navigator on the ground or semi autonomously as a combination of both capabilities (Hallermann, 2013). There are several types of micro UAV aircraft available in the market. UAVs can be categorized according to the endurance, speed, height and weight capacity of the load.

High Altitude Long Endurance UAV (HALE) is commonly used for scientific research purposes that can fly above 30,000 feet up to the atmospheric layer. Mid-Range UAV able to operate for more than 3 hours and at altitudes above 10,000 feet. For example, a UAV Predator capable of carrying missiles and also known as tactical and attacking mid-range UAVs. Meanwhile, Micro UAV is type that capable to fly in less than 1 hour and has limited load factor. This UAV design is based on glider planes and is capable of carrying small and light cameras. Although the micro UAV is capable of flying over 10,000 feet, for aerial capture purposes, the optimum level of useful image quality is between 800 feet to 1200 feet and images resolution between 6cm to 15cm per pixel.

Micro UAV DJI Phantom 3 Advance is used in this study to produce photos and videos of the outer section of the As Solihin, Sebatu mosque's roof. This particular UAV can fly in less than an hour and have limited load capacity factor. The UAV design is based on glider aircraft and could only carry a small but light camera. Even though this micro UAV can fly up to 10,000 feet horizontally, in terms of capturing aerial images, the optimum image quality can be captured between 800 to 1,200 feet while having a resolution of 6 cm to 15 cm per pixel. DJI Phantom 3 Advance is equipped with a camera that can capture both photos and videos using its 12 Megapixels Sony 1/2.3 inch CMOS sensor with 20 mm lens (35 mm equivalent) f/2.8. The visuals can be projected through a smartphone that has installed DJI Go App. According to Mohd Zambri (2012), it is built with a smart camera which supports 720p 30 fps HD and can be controlled by iOS or android devices. A MicroSD card with a capacity of 64GB is used that can store both videos and photos. The software can be downloaded through App Store or Google Play that should connect with the camera. The application connects the smartphone and the UAV through Wi-Fi connection. By using DJI Go application, the camera's functions can be controlled through the smartphone (Figure 1).


**Figure 1**: Communication Between Remote Controller, DJI Phantom 3 Advance dan Smartphone

Based on literature review, UAV is widely used in engineering to assist in obtaining information where such information is difficult for humans to obtain and engage security issues. UAVs in civil engineering are used for building inspections, monitoring of landslides, seeking autonomy and tracking of rivers, traffic, tropospheric pollution and water quality monitoring. The visual inspection of buildings using unmanned aircraft systems has shown that the use of an UAV represents an appropriate technique to create a first data base required for digital building monitoring (C. Eschmann, 2012).

Previous studies on the use of UAV in visual inspection by Masiri (2016) on Faculty of Civil Engineering and Environmental, University of Tun Hussein Onn Malaysia (UTHM) focused on the potential use of micro UAV flight in providing early information before maintenance work of high building be carried out. The result found that the use of UAV was able to be an alternative method to visually inspecting high external structures more easily and quickly. The process of building maintenance is performed without using a lot of manpower and the building inspection can also be done more frequently so that the damage can be detected earlier.

Another studies of UAV for the assessment of existing structures by Hallermann (2013) found that global positioning and inertial measurement units, built into these flight systems, allow an advanced navigation and semi-autonomous inspection flight. It is essential to get high quality photos for a reliable state determination of historical heritage structures and a detailed damage detection. In his study, the use of the UAV that produce a high quality and a high degree of detail airborne photos make it possible to detect very thin cracks between several bricks down to a few tenths of a millimetre of the historical building.

## 3.0 Methodology

Generally, the methodology research begins with a plan before flight and pre-flight preparation. The next process is data collection through video recording process followed by image processing to detect damage and defects in external structures and image analysis involving editing using software.

## 3.1 Planning

A proper flight plan is essential to ensure the journey is smooth as expected. The path should be pre-determined to make the process of collecting data easier. The inspection and collection of data of As Solihin, Sebatu mosque is done by using UAV because it is equipped with a high flexibility camera compared with a classic aerial photo (Unger, J., Reich, M. dan Heipke, C. 2014). According to Samad (2013), UAV is dubbed as autonomous navigation system because it's capability to fly by using *Global Positioning System* (GPS) and check on the telemetry at *Ground Control Station* (GCS) as monitoring and controlling UAV during data collection.

According to Masiri (2016), the distance between the UAV and the building must be 2 meters or less while flying to produce clear quality recordings. In this study, grid concept is used as reference to identify the location of damage and defects. According to C. Eschmann (2012), the flight path of the UAV has to be vertical to get a clearer visual. The roof section is divided into 4 regions; front, back, left and right. The flight path is as Figure 2 to cover all area of the roof. The type of damage to be recorded is referring to the checklist of defects in the Heritage Building Conservation Guidelines, State Heritage Department 2012.

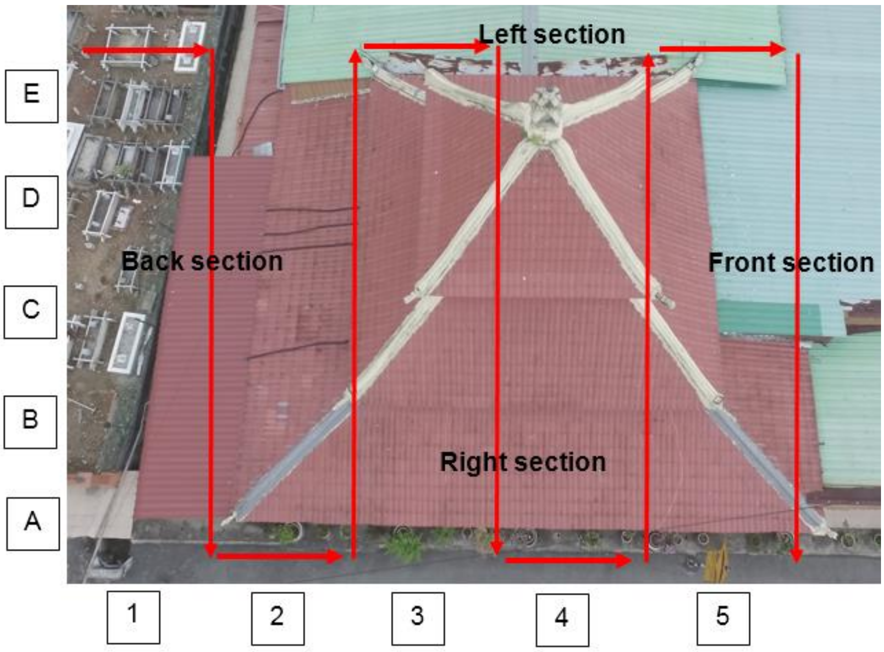


**Figure 2**: Flight direction according to roof section

### 3.2 Data Observation and Collection

Data collection involves video footages and images of the mosque's exterior roof structure by using UAV. The whole roof area is recorded as in Table 1. During the process of data collection, the UAV pilot collaborates with an observer to maintain the 2 meter distance from the roof. The task of an observer is to guide the pilot on the whereabouts of the UAV. The observer is responsible in avoiding any collision between the UAV and the mosque's structure by giving proper instructions to the pilot. At least two persons are involved during any data collection process. Figure 3 refers to the observer and the pilot for this study.

**Table 1**: Data collection from observation

| Roof section | Video | Image | Processed image |
|---|---|---|---|
| Front | 3 | 57 | 23 |
| Back | 1 | 38 | 13 |
| Left | 2 | 34 | 14 |
| Right | 2 | 56 | 25 |
| Total | 8 | 185 | 75 |


**Figure 3**: Data collection process

### 3.3 Video and Image Processing

Images are extracted through video footages that have been captured on the overall structure of the mosque's roof. Every image that has been produced will be processed and analysed based on the sections divided into grids (Figure 4). More detailed analysis is performed at any defective or defective location to obtain a clearer picture of any damage occurring. The zoomed image will be analysed using Adobe Photoshop. This study has taken the amount of damage or defect that has experienced over 5 times as a sample.


**Figure 4**: Section of roof divided into grid

Adobe Photoshop is used to produce better images and easier to identify the type of defect the structure is currently having (Figure 5).

(i) Before editing (ii) After editing

**Figure 5**: Editing of photo image before and after using Adobe Photoshop

Each image has different techniques depending on the image and type of damage that occurs. Structural damage caused by plants is identified using *Diffuse Glow* and *Find Edges* technique. To identify the types of corrosive surface damage, *Craquelure* and *Grain* technique analysis are used. Damage such as rusty and decay structures uses the technique of *Brush Strokes Accented Edges*. There are several other analysis techniques used to detect different types of damage to the outer structure of the mosque's roof.

## 4.0 Results and Discussions

The result of the image analysis obtained from UAV flight video recording has found some defects in the mosque's roofs occurring in several locations based on the position determined by the grid method. This study has used video image recording due to the better image quality of the video compared to the normal photo shoot obtained using conventional methods. Furthermore, the video recording can save time and battery consumption on a micro UAV aircraft. The UAV is equipped with a camera that offers the possibility to map different areas quickly and with high flexibility compared to classic aerial photos (J. Unger, 2014). Therefore, UAVs are becoming popular for use low budget and use in large scale mapping (Darwin (2014).

Overall, 39 damage images have been detected from 8 videos recorded by the UAV. At least 2 operators are involved in recording video for the entire As-Solihin mosque's roof. This allows for visual inspection to be done frequently to detect damage early. This finding is consistent with the results of the study conducted by Masiri (2016) which states that the maintenance of buildings using UAV does not involve large manpower and UAV can be used as an alternative method in improving the building inspection process compared to conventional methods.

The results gathered through image processing of each section of the roof are shown in Table 2.

**Table 2**: Type of defects according to roof section

| Section | Type of defect | Location of defect | Total defect | Overall total of defect |
|---|---|---|---|---|
| Right | Fungus and mossy | 3E,3D,3B | 3 | 8 |
| | Cracks | 3D,3B,3C,4B | 4 | |
| | Rusty and decay | 2A | 1 | |
| Front | Fungus | 2D,2C | 2 | 7 |
| | Cracks | 2D,2C | 2 | |
| | Rusty and decay | 2B | 1 | |
| | Peeling paint | 2D | 1 | |
| | Shifted structure | 3A | 1 | |
| Left | Fungus | 3E,3D | 2 | 10 |
| | Cracks | 3D,2D | 2 | |
| | Plants | 3D | 1 | |
| | Peeling paint | 4C | 1 | |
| | Rusty and decay | 4B,5C | 2 | |
| | Surface eroded | 4C | 1 | |
| | Fade paint | 5D | 1 | |
| Back | Fungus | 3E,3D,3C,4C | 4 | 14 |

| | | | | |
|---|---|---|---|---|
| | Cracks | 3D,3C,4C,4B | 4 | |
| | Peeling paint | 3E,3D | 2 | |
| | Rusty and decay | 2D | 1 | |
| | Broken tile | 2C | 1 | |
| | Surface eroded | 4C | 1 | |
| | Rusty and dirty | 1B | 1 | |

From the results shown in Figure 6, it is clear that the back side of the roof has the most defects which is 36% while the front side of the roof has the least amount of defects which is 18% of the whole amount of defects of the roof.

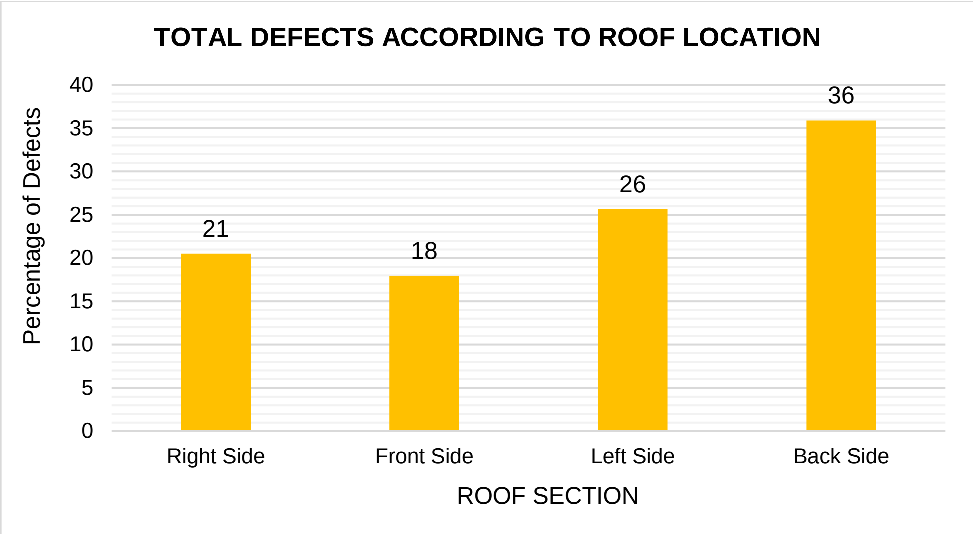


**Figure 6**: Graph of total defects according to roof location

A few type of defects on the roof have been identified such as moss and fungus, cracks, plant infested, peeling paint, rust and decay, faded paint and others. The graph in Figure 7 clearly shows that cracks on the exterior structure of the roof having the most effect at 31%, followed by moss and fungus at 28%. Plant infestation, cracked roof tiles, shifted structure, rust and dirty are minor defects detected on the roof.

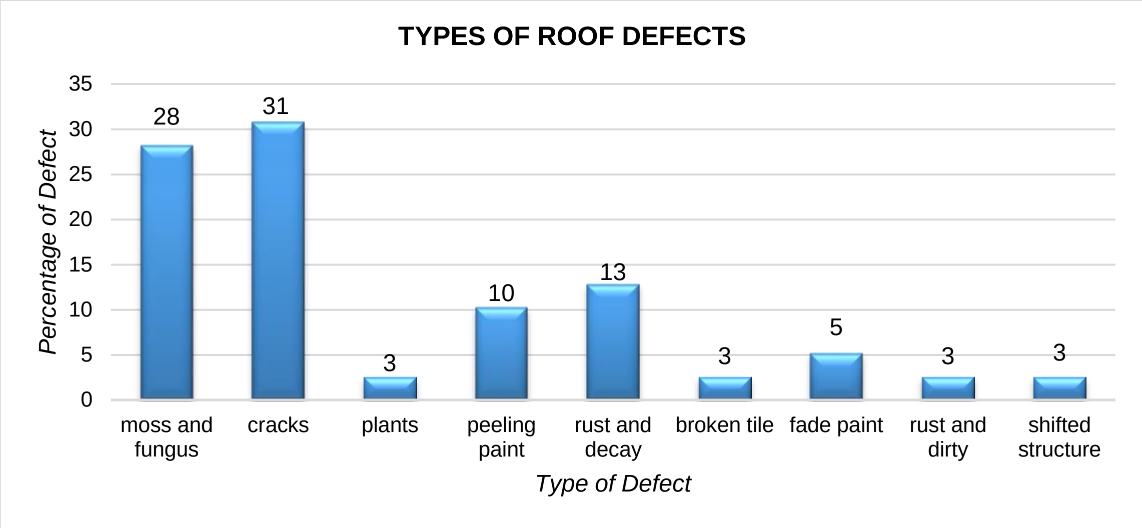


**Figure 7**: Graph of total roof defects according to defect types

## 5.0 Conclusion

In conclusion, visual inspection in dilapidation of the heritage building by using Unmanned Aerial Vehicle (UAV) provide an alternative method to identify the defect occur at exterior of the building. The images that are recorded and processed gives a clear analysis on the type of defects occur at the building's structure. The usage of UAV in building inspection makes it possible to access those hard to reach areas and record the defects without damaging the original structure of the building. A scheduled inspection can be easily executed because the defects of the building can be easily detected for the conservation process to be performed by the related parties.

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