Faculty of Engineering

Development of Time Domain Inverse Scattering Algorithm for the Detection and Imaging of Buried Objects

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Development of Time Domain Inverse Scattering Algorithm for the Detection and Imaging of Buried Objects

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Signature

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DEDICATION

Dedicated to my beloved parents, relatives and friends

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ABSTRACT

The tremors from the earthquake created heavy damages and cracks to some buildings, infrastructures and caused landslips. Therefore, the post-hazard assessments have to be held to certify the quality and condition of the damaged buildings, infrastructures and lands before continue to use it in the future. Object and crack detection is widely used in structural health monitoring (SHM) application especially in civil structure. There are some of previous methods use for the object and crack detection such as ground penetrating radar (GPR), non-destructive microwave radar and analytical method. Those methods are able to detect the presence of the unknown buried object. However, the information that obtained from the methods is not enough because they are not able to reconstruct the image such as shape and size of the unknown objects. In this research, a new approach is proposed which combines the advantages of both Forward Backward Time Stepping (FBTS) technique and Overset Grid Generation (OGG) method in Finite Difference Time Domain (FDTD) method to develop the efficient numerical method for the image reconstruction in the detection of unknown object and cracks under the soil. Firstly, the accuracy of proposed method is investigated by analysing the measured electric signal or direct problem with empty grids and in stationary case between the proposed method with FBTS technique utilizing FDTD method only. Then, the investigation is furthered to inspect the accuracy of the proposed method by analysing the different kind ratio of grid size between the main mesh and sub mesh. The proposed method is then applied to SHM application focusing on crack and object detection. From the results obtained in Section 4.6.1(a) and 4.6.2(a), it is shown that the proposed method has 5.22% error for object detection; meanwhile the crack detection has 21.55% respectively. Therefore, it is observed that the proposed method can detect and reconstruct the image of

the objects and crack clearly because the percentage of relative error is near to the actual value.

Keywords: Microwave imaging, inverse scattering, overset grid generation, Finite Difference Time Domain, Forward Backward Time Stepping, image reconstruction, buried object, crack detection

Pelaksanaan Algoritma Teknik Hamburan Songsang dalam Domain Masa untuk Pengesanan dan Pengimejan Objek yang Tertimbus

ABSTRAK

Gegaran yang berlaku semasa gempa bumi telah menyebabkan banyak kerosakan dan keretakan pada bangunan dan infrastruktur serta tanah runtuh. Oleh itu, penilaian taraf bahaya bangunan yang terjejas perlu dilakukan untuk memastikan kualiti dan keadaan bangunan, infrastruktur dan tanah yang rosak sebelum meneruskan penggunaan kawasan tersebut pada masa yang akan datang. Pengesanan objek dan retak digunakan secara meluas dalam aplikasi pemantauan kesihatan struktur (SHM) terutamanya dalam struktur sivil. Sebelum ini, terdapat beberapa cara digunakan untuk pengesan objek dan retak seperti "Ground Penetrating Radar (GPR)", "non-destructive microwave radar" dan "analytical method". Namun, kesemua cara ini hanya dapat mengesan kewujudan objek dan retak sahaja dan tidak dapat memberi informasi yang penuh seperti untuk mengesan saiz, bentuk dan bahan objek tersebut. Oleh itu, tesis ini menggabungkan kelebihan dua teknik iaitu "Forward Backward Time Stepping (FBTS)" dan kaedah "Overset Grid Generation (OGG)" di "Finite Difference Time Domain (FDTD)" untuk membangunkan kaedah berangka yang efisien untuk pembinaan semula imej dalam mengesan objek dan keretakan di bawah tanah. Pertama, ketepatan gabunggan kaedah ini dikaji dengan membandingkan gabungan kaedah yang baru dengan FBTS-FDTD. Seterusnya, ketepatan kaedah ini dikaji dengan simulasi menggunakan nisbah ukuran grid yang berbeza. Akhir sekali, gabungan kaedah yang baru ini akan dilaksanakan dalam pengesanan objek dan retak. Melalui keputusan dari kajian yang dilakukan, peratusan kesalahan untuk pengesanan objek dan retak ialah 5.22% dan 21.55%. Berdasarkan peratusan tersebut, gabungan kaedah yang baru ini terbukti dapat mengesan objek dan retak kerana nilai yang ditunjukkan sangat hamper dengan nilai sebenar.

Kata kunci: *Pengimejan gelombang mikro, songsang berselerak, janaan grid bertindih, "Finite Difference Time Domain", "Forward Backward Time Stepping", pembinaan semula imej, objek tertimbus, pengesanan keretakan*

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LIST OF ABBREVIATIONS

2D	Two-Dimensional
3D	Three-Dimensional
ABC	Absorbing Boundary Condition
CFL	Courant-Fredrichs-Lewy
CFS	Complex Frequency Shifted
CG	Conjugate Gradient
CPML	Convolutional Perfectly Matched Layer
CT	Computed Tomography
EM	Electromagnetic
FBTS	Forward Backward Time Stepping
FDTD	Finite-Difference Time-Domain
GPR	Ground Penetrating Radar
LADAR	Laser Detection and Ranging
MPI	Message Passing Interface
MRI	Magnetic Resonance Imaging
NDT	Non-Destructive Testing
OGG	Overset Grid Generation

PDE	Partial Differential Equation
ROI	Region of Interest
SHM	Structural Health Monitoring
TE	Transverse Electric
TM	Transverse Magnetic
TWRI	Through-the-wall Imaging
UWB	Ultra-Wideband

CHAPTER 1

INTRODUCTION

1.1 Motivation of Research

Object detection and recognition is a significant task in image processing and computer vision. It is used to identity of an object that obtained in an image regardless of the object's location, shapes and sorts of the material. This kind of technology allowed humans to know any kind of object in the real world simply without any efforts. However, the computerize recognition of object in image is not an easy task. During the past few decades, objects and crack detection have gained attention among the researchers and has application in many areas. It has been widely used in military and criminology, archaeology, medical imaging, geophysical exploration and structural health monitoring [1–6].

In military and criminology area, the object detection application is very important for the Military and Law Enforcement [3, 7]. One of the techniques that always been used in military applications is through-the-wall radar imaging (TWRI) [8]. Many researchers show interest in TWRI with many kinds of significant civilians and military application. TWRI technology is implemented for surveillance and humans' detection and interior objects in urban environments. Moreover, it is also used for search and rescue operations in military situations. In TWRI technology, ultra-wide band (UWB) radar and compact Doppler radar show the potential for real time imaging, and giving non-invasive detection and observing the cardiopulmonary activity for several subjects.

In medical imaging, the object detection application is commonly used in cancer or tumour detection [6, 9–11]. The early detection and diagnosis of cancer is important as it can increase the chances of successful treatment. Besides, treatments for early cancer are

often less complex and cheaper than treatments for more-advanced disease, sparing patients and families' greater hardship. There are various types of imaging for cancer's detection and monitor the cancer's condition and its spread. The first common method is computed tomography (CT) scan, which produces cross-sectional imaging by computer [12]. CT scan is using x-rays and a computer to produce detailed images of the inside of human body. It generates image from different angles. Then, the computer will put the images together to make a 3 dimensional (3D) image [12]. Secondly, magnetic resonance imaging (MRI) is a non-invasive and not a painful technique. A strong magnetic field and radio waves used in MRI so that it can provide thorough images of the organs and tissues in the body [13, 14].

Besides, the object detection is also widely applied in structural health monitoring application especially in the civil structure to detect the buried object and also cracks [15–17]. The structural health monitoring (SHM) is a method that needs to be applied in the detection of the damages. The infrastructures, including bridges, lands and buildings, begin to weaken once they are built and used for a long time. It is very important for preserving safety and reliability of the civil infrastructures for daily use especially to public. In addition, the health monitoring should also be done for the infrastructures that have been affected by the nature disaster such as tornadoes, earthquakes and hurricanes. These scenario can cause some of the collapsed buildings are buried underground during the disaster happened. The buried concrete can result the structural failures and collapses in the future [5, 16, 18].

The damage of the building and civil structures can be identified at an early stage to avoid any failures that will result in a devastating fatality [18, 19]. There are few methods that have been used to detect the buried object and cracks. One of the methods is by using

ground penetrating radar (GPR) tomography [20]. The GPR tomography is a method with high resolution ratio, real-time display and flexible to apply for detecting the buried object. The second method is by using non-destructive microwave radar to inspect buried object in concrete structures [18]. In this research, the microwave inverse scattering technique; Forward Backward Time Stepping (FBTS) technique is proposed with the integration of Overset Grid Generation (OGG) method and Finite Difference Time Domain (FDTD) method into the new proposed algorithm. The proposed method will be used for the object and crack detection in structural health monitoring (SHM) in civil application especially for post-hazard assessment after the natural disaster.

1.2 Problem Statement

Figure 1.1 illustrates the overview of this whole research about. Structural health monitoring (SHM) is the process of applying a damage detection and characterization strategy for engineering structures such as bridges and buildings. SHM is frequently used to detect damages at early stage. SHM can be regarded as a kind of natural hazard management. Therefore, SHM will be applied in this research to detect the extent of damages and hazards after-effect the Earthquake disaster. Earthquake is an unexpected trembling movement that happened at the earth's surface. It is also referred as a quake, trembler or tremor. There are some common effects of earthquakes such as infrastructural damage (building, roads, bridges), landslides, liquefaction, and tsunami [23, 24].

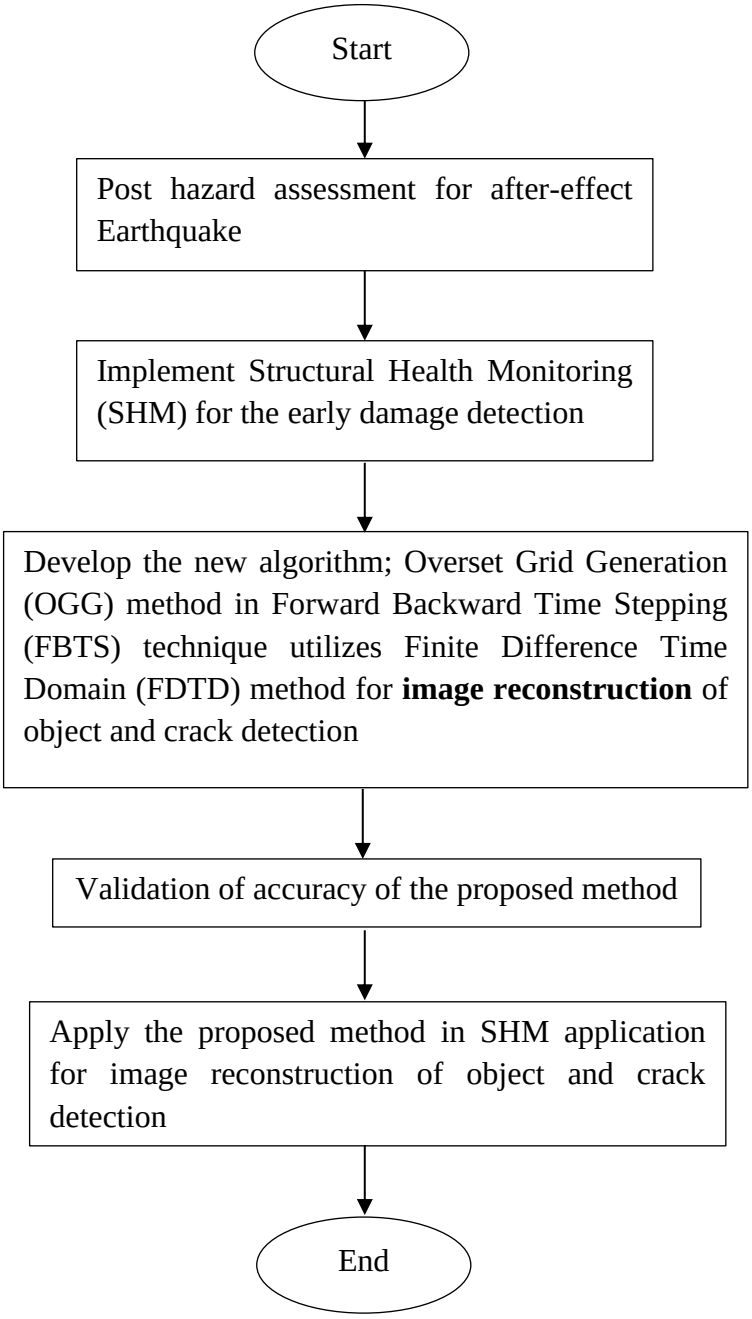

Figure 1.1: Overview of the Research Flow