IMPLEMENTATION OF A NEW TECHNIQUE FOR MAGNETIC IMPROVISED EXPLOSIVE DEVICE DETECTION

HAMZAH NASER MAHMOOD

UNIVERSITI SAINS MALAYSIA

2018

IMPLEMENTATION OF A NEW TECHNIQUE FOR MAGNETIC IMPROVISED EXPLOSIVE DEVICE DETECTION

by

HAMZAH NASER MAHMOOD

Thesis submitted in fulfilment of the requirements
for the degree of
Masters of Science

July 2018

ACKNOWLEDGEMENT

After a long journey of effort and diligence culminated in the completion of this research, the outcome is indeed one of the most enriching experiences in my life, where I have gained a valuable insight into the unique combination of different disciplines and helped in broadening my knowledge.

Therefore, first and foremost, I would like to take this opportunity to express my sincere gratitude to my supervisor, Prof. Dr. Widad Ismail for her continuous guidance, support and never-ending patience throughout the entire research period.

Secondly, I wold like to thank my university, Universiti Sains Malaysia, for their generous support by making this more than just about studies. I was fortunate enough to be granted a fellowship under their supervision, where it has exposed me to an invaluable hands-on experience to further sharpen my skills.

I would also like to thank my fellow course mates, especially at AIDL research group and the lab operators, for providing ideas and explanations when I was in doubt and contributed whether directly or indirectly to the success of this research.

Finally, I would like to extend my appreciation to my parents for their continuous motivation and being morally and financially supportive throughout my studies.

TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION

CHAPTER TWO: LITERATURE REVIEW

CHAPTER THREE: METHODOLOGY

CHAPTER FOUR: RESULTS AND DISCUSSIONS

CHAPTER FIVE: CONCLUSION AND FUTURE WORKS

APPENDICES

LIST OF PUBLICATIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

|B|	Magnetic Field Density Magnitude
3D	3 Dimension/Dimensional
ADC	Analog-To-Digital Converter
Am^2	Magnetic Moment
AMR	Anisotropic Magnetoresistance
AOAV	Action On Armed Violence
BH_{max}	Maximum Energy Product
B_r	Residual Induction
Cm	Centimetre
CMOS	Complementary metal–oxide–semiconductor
FEMM	Finite Element Method Magnetics
G	Gauss
GMR	Giant Magnetoresistance
H_c	Coercive Force
Hz	Hertz
I^2C	Inter-Integrated Circuit
IED	Improvised Explosive Device
KG	Kilo-Grams
Km/h	Kilometre/hour
LED	Light Emitting Diode
LSb	Least Significant Bit
M	Meter
m^2	Meter squared

MDS	Magnetic Detection System
mG	Milli-Gauss
MGOe	Mega-Gauss•Oersted
mm^2	Millimetre squared
mT	Milli-Tesla
NdFeB	Neodymium Iron Boron
nT	Nano-Tesla
Oe	Oersted
PC	Personal Computer
SQUID	Superconducting Quantum Interference Device
T	Tesla
UART	Universal Asynchronous Receiver/Transmitter
USB	Universal Serial Bus
v	Volts

PELAKSANAAN TEKNIK BARU UNTUK PENGESANAN BERMAGNET PERANTI BAHAN LETUPAN BERMAGNET YANG DINAIK TARAF

ABSTRAK

Peranti Bermagnet Bahan Letupan yang Dinaik Taraf (IED) yang juga dikenali sebagai sejenis bom melekit adalah alat yang mudah dibina namun memberi kesan yang boleh membawa maut. Oleh itu, penyelidikan ini menekankan pengehadan bagi kaedah-kaedah yang telah dicadangkan untuk mengatasi ancaman ini dan bahayanya yang semakin meningkat dengan menunjukkan kekurangan persediaan eksperimentasi secara sistematik, ketiadaan nilai komersial selain kemungkinan yang tidak dapat dielakkan untuk merisikokan keselamatan kakitangan semasa mengendalikan beberapa sistem yang disebabkan oleh kekurangan automasi atau tidak menjadi mudah alih. Penyelidikan ini telah menyiasat satu pengesan bergred pengguna yang mampu mengesan satu medan bermagnet dalam ± 8 Gauss. Pengesan ini digunakan untuk mengesan magnet untuk meniru IED bermagnet. Magnet-magnet tersebut adalah dua bahan yang berlainan (berbeza dalam kekuatan ketumpatan medan magnet) dengan jumlah kiraan yang berbeza, dan ia telah digunakan untuk menghasilkan kemungkinan senario yang berbeza. Magnet-magnet tersebut adalah Neodimium dan Seramik dengan purata ketumpatan fluks masing-masing sebanyak 12,500 dan 2,500 Gauss. Tambahan pula, satu teknik baru telah dibangunkan dan dilaksanakan sebagai satu teknik pengujian sistematik yang praktikal berdasarkan kawasan eksperimen yang bergrid, yang mana ia adalah bersaiz sel individu yang sesuai dengan ancaman yang disifatkan. Teknik baru ini dinilai menggunakan pengesan dengan tujuan untuk meneroka sejauh mana kebolehannya untuk pengesanan IED bermagnet. Sebagai keputusannya, ia telah menghasilkan keputusan dalam bentuk yang mudah dikesan dan membuka jalan kepada analisis selanjutnya. Keputusan teknik baru ini telah mendedahkan bahawa kemungkinan pengesanan ancaman menggunakan pengesan yang digunakan bersama-sama dengan magnet di bawah kes-kes tertentu, di mana kes terburuk adalah ~ 181.4% kemungkinan pengesanan manakala kes terbaik adalah sehingga ~ 1666.7%, pada jarak 8.5 cm jauh dari pengesan. Walau bagaimanapun, bermula dari jarak 17 cm jauh dari pengesan dan seterusnya, bilangan nombor magnet yang berbeza dari dua bahan berbeza mula menyumbang secara berbeza kepada variasi bacaan. Nilai-nilai pembezaannya adalah serendah ~ 0.72% hingga ~ 2.1% pada jarak masing-masing 42.5 cm hingga 51 cm untuk bahan seramik, manakala bahan Neodimium adalah serendah ~ 2.3% dan 2.5% pada jarak masing–masing 59.5 cm dan 42.5 cm. Akhirnya, penyelidikan ini akhirnya mencadangkan kebolehpasarannya berbanding dengan yang lain yang menjadikannya sebagai alasan kukuh untuk kajian masa hadapan yang berkaitan dengan pembangunan sistem pengesanan bermagnet IED yang melibatkan kos rendah dan mudah alih.

IMPLEMENTATION OF A NEW TECHNIQUE FOR MAGNETIC IMPROVISED EXPLOSIVE DEVICE DETECTION

ABSTRACT

The Magnetic Improvised Explosive Devices (IEDs), also commonly known as a type of a sticky bombs, are simply constructed devices yet very lethal. Consequently, this research highlights the limitations of methods that have been proposed to counteract this threat and its ever-increasing danger by indicating their lack of systematic experimentation setups, commercial unavailability in addition to the inevitable possibility of risking personnel safety while operating some systems due to lack of automation or being not portable. The research has investigated a consumer-grade sensor that is capable of sensing a magnetic field ranging within ±8 Gauss. The sensor is employed for sensing magnets to mimic the magnetic IEDs. The magnets are of two different materials (contrasting in magnetic field density strength) with different counts, and they were used to develop different possibilities of scenarios. The magnets are Neodymium and Ceramic with an average flux density of 12,500 and 2,500 Gauss respectively. Furthermore, a new technique has been developed and implemented as a practical systematic testing technique based on gridded experimental area, which has an individual cell size corresponding to a characterized threat. This new technique is evaluated using the employed sensor with the purpose of exploring its extent of employability for Magnetic IEDs detection. As a result, it has allowed the representation of the results in a traceable manner and paved the way for further analysis. The results of the new technique have revealed that the chances of threat detection using the employed sensor in conjunction with magnets under defined cases, where the worst case there is a ~ 181.4% chance of detection whereas the best case it could be as high as ~ 1666.7%, at a distance of 8.5 cm away from the sensor. However, starting from 17 cm distance from the sensor onwards, different number of magnets of the two different materials begins to contribute differently into readings variations. Its extent of distinguishability values is as low as ~ 0.72 % to ~ 2.1 % at a distance of 42.5 cm to 51 cm respectively for Ceramic material, while the Neodymium material is as low as ~2.3% and 2.5% at a distance of 59.5 cm and 42.5 cm respectively. Finally, the research eventually recommended its employability in comparison with others laying the ground for future studies concerned with developing low-cost, portable Magnetic IEDs detection systems.

CHAPTER ONE

INTRODUCTION

1.1 Overview

In their harmless form, sticky devices, such as sticky containers or pads and many other more have been known to exist for more than a decade now associated with an increase of use. However, a nation will be dealing with different type of story during wartimes as it incites other types of “sticky” devices that may come to mind to one of ordinary skill in the art.

Wartimes in general are hostiles to the nation’s environment putting everyone’s life at a high risk and endangerment. Such conditions generate an atmosphere of permissibility for hostile acts. Those acts come in many forms, but one threat in particular considered as one of the major causes of deaths and injuries among civilians in general, and has been systematically used against the brightest, most distinguished, and most highly regarded academics and scientists.

The threat is known as the Magnetic IEDs (**I**mprovised **E**xplosives **D**evices) and they are often constructed from materials at hand. They are magnetically affixed bombs placed to vehicle undercarriages or concealed locations. Magnetic IEDs exterior are formed of a detonation circuitry in addition to strong magnets. The purpose of using magnets with such characteristics is to make sure that the Explosive Device adheres firmly to the targeted vehicle.

1.2 Problem Statement

There are several problems in the methods implemented or proposed to counteract the threat that can be generally represented in the following points:

- Personal safety

  (Icove and Lyster, 2013) and (Icove, et al., 2014) employed a rather conventional detection techniques that requires the presence of an individual in order to inspect for the threat (not automated), which means the person is exposed to an imminent danger.

- Commercial unavailability

  Proceeding from the aforementioned point (Personal Safety) and its references, it is obvious that there is an additional costs incurred due to detection devices operation. Furthermore, the detection techniques offered implies inaccessibility for civilians, and therefore, they are deemed non-commercial solutions.

- Some detection systems limited to designated areas

  Although some detection systems are stationary (not portable) or restricted to a certain area (e.g. fixed security checkpoints), the threat is not. Magnetic IEDs are easily concealed, they are considerably small and can be used anywhere at any time as long as the target is accessible. In fact, systems such as vehicle’s undercarriages checking system (UVIScan, 2016) and Fido XT Explosives Trace Detector (Ma and Bock, 2013) are designed to accommodate the needs of most explosives detection applications but it is only applicable at its designated areas.

- Inadequate or complete lack of systematic testing procedures

  Research papers such as (Abid and Mustafa, 2012) using laser triangulation coupled with image processing detection technique or (Johnston, et al., 2010) that utilizes vehicle weight measurement comparisons based on tire pressure or magnetic field measurements lacked systematic steps to assist building a better illustrative understanding of sensors detection capabilities.

To conclude, and based on the problem statements above, there is a need to for a practical systematic testing technique. This technique is evaluated using a consumer-grade magnetic sensor with the purpose of exploring its extent of employability for Magnetic IEDs detection. The research should eventually lay the ground for future studies concerned with developing low-cost, portable Magnetic IEDs detection systems. The stated points are further elaborated on under Chapter 2.

1.3 Objectives

I. To investigate the capability of a consumer-grade magnetic field sensing component to be applied for a new technique in Magnetic IED detection.

II. To design, develop and implement the proposed magnetic IED detection technique.

III. To characterize, evaluate and recommend the proposed technique of Magnetic IED detection.

1.4 Contributions

Magnetic IEDs are often constructed from materials at hand, therefore, and proceeding from that fact, the means to defeat this threat shouldn’t exceed that scope, thus the outcome should have impact on cost (in terms of reduction) and hopefully will incite automated (none human operated) systems to reduce human casualties.

In fact, this research not only offers an advantage in terms of portability in case of considering a security system that detects Magnetic IEDs employing such sensors, but also the fact that it paves the way for standardized tests using sensors of a similar type.

The proposed technique aims to provide a systematic (gridded area based on a characterized threat) testing feasibility to enable detection area visualization and mathematical representation. Moreover, since the collected data is based on practical experimentations, then it can be considered for further investigations/feasibility of implementations.

1.5 Scope and Limitations

This research aims to establish a proper testing technique with the help of magnetic field sensing component and estimates detection range of a hypothetical Magnetic IEDs. Although the research covers practical work, it is still considered at fundamental stages due to several limitations. Those limitations can best be illustrated with the following points:

I. The Magnetic IED Physical Dimensions

   Due to challenges in obtaining the actual magnetic IED which normally involving military agency, therefore, the physical dimensions of Magnetic IEDs either referenced to a source or concluded off a general observation.

II. The Shape of Magnets

   Magnets comes in many shapes, sizes and strengths, therefore, the experiments conducted are based on magnets available at hand, however, both of its material and size is defined so the results are limited to those definitions.

III. The Sensor's Sensitivity

The sensor used is available commercially at an extremely low cost; correspondingly, its performance is quite poor to a certain degree while its sensing ability is limited to 2 milli-gauss field Resolution in ±8 Gauss Fields.

IV. Testing Ground

The initial area (space) dimension used for conducting the various experiments is defined as a substitute for dealing with different vehicle sizes. In this regard, the methodology chapter elaborates further on this matter.

1.6 Thesis summary

The content of this thesis is presented in 5 chapters. The first chapter introduces the background of the topic discussed while defining the problems, objectives, contributions, scope and foreseen limitations.

The second chapter is reviewing some theoretical or practical works that are either closely or directly related in addressing the topic of this thesis. Furthermore, the chapter highlights some of the important basics regarding the device(s)/materials used along with their characteristics.

The third chapter concerns the methods, concepts and/or requirements and assumptions used to reach the final stages of obtaining the desired results, and in turn, the fourth chapter discusses in a greater detail those results with proper tabulations and graphical representations.

Finally, the fifth chapter concluded the thesis by some conclusions and recommending some points that has potential to be considered for future works.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Wars, regardless of its claimed objectives or goals, have never benefited humanity in the long term even if the opposite is proven in the short term. That is attributed to the fact of its extreme destructive nature and being, more often than not, immoral. In fact, those characteristics oppose any progressive steps seeking to advance mankind.

Few major recent wars had broken out in different regions of the world and, as usual, the civilians had the biggest share of the total casualties. However, what distinguishes modern-day wars is the fact that they have a great deal of documentation, through which researchers have been able to uncover a hidden agenda to target the future of the countries, and the invasion of Iraq in 2003 serves as a good example.

Amidst war’s aftermath, Iraqi academics have been exposed to numerous threats, which ranged from verbal insults inside the university campuses, beating, kidnapping to assassination (Majeed, 2010). In August 2006, the Iraqi Ministry of Higher Education released a staggering figure of fleeing academics, which reached more than 3,250 from the beginning of that same year (Ghosh, 2006), while according to the Iraqi Association of University Lecturers about 300 academics had been killed before early 2007 (Crain, 2007). Furthermore, the same association prepared a study in 2006 described the levels of fear experienced by the Iraqi