Various metal detection techniques engineering essay

Abstract- This paper presents a comparative study of various metal detection techniques that can be used for a walkthrough metal detector. A brief introduction of electromagnetism is followed by introductions to continues wave, Pulse induction, Beat frequency Oscillation, Magnetic field Gradeometry and Microwave imaging techniques. State of the art metal detectors and technology behind them has been reviewed. A comparative analysis of the above said metal detection techniques is performed.

The Project

Develop a walkthrough system to detect metallic objects with the ability to discriminate between potentially dangerous items.

Objectives

Maximum detection and discrimination capability

Detect and discriminate between a day to day metallic object (key rings, Belt buckles or spare coins) and a potential weapon (Knife, Folk or Gun)

Higher through rate

Less false alarms rate

Introduction

Metal detection technology is used in many industries around the world such as medical (detecting metallic foreign bodies in the human body), Military (Demining), Security (Screening people for potentially dangerous weapons), Food (detecting of metallic objects in food products) and professional treasure hunters. There are many technologies used in metal detection.

Beat frequency oscillation

Continues wave metal detection

Pulse induction metal detection

Magnetic field Gradeometry

Microwave Imaging

Most of the above mentioned techniques use some sort of electromagnetic approach in order to operate.

Electromagnetism

Electromagnetism is the physics of electric fields. A Changing magnetic field would generate an electric field the reverse is also true a moving electric field would generate a magnetic field which is used in metal detection. [1]

Magnetic field created around the wire due to the current flow.

The metal detectors operation depends on simple principles such as Faraday's law, Amperes law, Gauss's Law and Biot savart's Law. The basic idea in a metal detector is a magnetic field generated from the excitation coil induces an eddy current on the metallic object which generates a weak magnetic field which will be picked up by the same coil or a pick up coil(s) depending on the detection technique used. [1], [2]

Ampere's Law

" The line integral of magnetic flux density over any closed path is proportional to the rate of change of electric field and electric current in the enclosed region. The km factor is the relative permeability, equal to 1 in free space." [3]

Faraday's Law

" The line integral of electric field over any closed path is proportional to the rate of change of magnetic flux in the enclosed region."[3]

Gauss's Law

" The integral of magnetic flux density over any closed surface is zero" [3]

Law of Biot Savart

" The current element dl on a current filament contributes a magnetic field, dB, in a direction normal to the plane formed by dl and the vector r "[3]

Metal detection techniques

Continues Wave (Very Low Frequency)
[17]

Very low frequency (Induction balanced) technology is the most used method in metal detection. It is used in all kinds of metal detectors e. g. demining, walkthrough, food industry… The very low frequency method consists of an excitation coil and pick up coil some have a third feedback coil. An electric current (sinusoidal wave) is supplied to the excitation coil via

an oscillator circuit. The pickup coil is placed in a way that the excitation coils magnetic field will not interfere with it.[1] [4]

How does it detect metallic objects?

When the excitation coil is supplied with current it creates a magnetic field around it when a metallic object pass by this coil the magnetic field will create an Eddie current on the metallic object which will create its own weak magnetic field. The pickup coil will pick up this magnetic field and generate a current. By analysing the phase shift and amplitude the metallic object is detected. [5] [6]

Advantages:

Low cost, Discrimination ability, multiple objects could be detected

Disadvantages

Limited inspection area

Modern metal detectors use an advanced version of this technology combining multiple pickup coils and digital signal processing.

Pulse Induction

[17]

Pulse induction method uses a single coil to transmit and pickup signals. It operates by switching high current through the transmitter coil which generates a short magnetic field at the end of the current pulse the magnetic field reverses and vanishes suddenly which results in an electrical

spike. This spike last a few micro seconds which allows another current to run through the coil this is the reflected pulse and is very short this repeats over and over. [7] [8]

How does it detect metallic objects?

When the transmitter coil is supplied with a high current pulse the current causes a magnetic field to surround the transmit coil. The Eddie current caused by the field flows on the metallic object. The coil pick up signals from the metallic object after the transmit pulse ends. The length of the reflected pulse is monitored by a sampling circuit. If the reflected pulse last longer than normal it means a magnetic field is present hence a metallic object is present. [7] [8]

Advantages

Good penetration ability

Disadvantages

Less discrimination ability because the pulse decay very fast.

This metal detection technology is widely used by treasure hunters due to its ability to penetrate beyond other techniques it is also used extensively on walkthrough detectors despite having less discrimination ability.

Beat Frequency Oscillation
[17]

Beat frequency oscillator is the oldest and the basic type of metal detection technique. This technique employs two coils one coil is the search coil (search oscillator) and the other coil is the reference coil (reference oscillator). When a pulse is supplied to both the coils it will start generating radio waves which will be on the same frequency. The output of the coils will be connected to a mixer and filtered through a low pass filter in a way that as long as the frequencies stay the same there will be no output.[9]

How does it detect metallic objects?

When the search coil is over a metallic object the metallic object will create a magnetic field on its own because the Eddie current created within the object as a result of the radio waves from the search coil. This magnetic field then causes disturbance on the search coil which will result a frequency shift in the search coil. As soon as a frequency difference is detected between the search coil and reference coil a tone will be produced. [9]

Advantages:

Low cost, very basic technology used

Disadvantages

Low penetration ability, zero discrimination ability between objects.

Although this is an old technique it is still used extensively by the hobbyist treasure hunters because of ease of use and low cost.

Magnetic Field Gradeometry

11: Walk-through frame

12: Control unit

47-53: Aluminium tubing (gradiometers inside)

56-57: Base plate and post

58: Cabinet

(US patent 6133829)

A magnetic gradiometer is a device that can measure the rate of change of a magnetic field.

Two magnetic gradiometers are placed in both sides which monitors the magnetic field of the earth once a metallic object passes through a disturbance will occur in the earth's magnetic field this will be picked up by the magnetic gradiometer which indicates a presence of a metallic object. [10] [11]

Advantages

Wide area inspection, passive magnetic field measurements

Disadvantage

Inability to detect multiple objects.

Magnetic field Gradeometry is a rather interesting new concept which could be used for metal detection. Research in this area seems to be rather limited. None of the current metal detectors use this technology.

Microwave Imaging

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A microwave is an electromagnetic wave. A microwave security system can detect any object concealed within a human. It uses microwaves to image an object on a human. Basically microwaves will be emitted towards the human via an antenna and the reflected waves will be captured with the same antenna after emitting multiple beams and processing them through a 3d image processing software a 3d image will be created showing the concealed objects.

Advantages:-

Can detect any object it doesn't have to be metal

Accurate positioning of the object

Active holographic body imaging

Disadvantages:-

Time consuming

Costly

stand-still inspection

Possible danger to health.

Although this is one of the best methods to detect objects it is not practical due to the above mentioned disadvantages.

State of the art Walk through metal detectors and analysis.

Garrett PD 6500i 2. Ceia SMD600 Multi Zone

Garrett PD 6500i 33 zone pin point metal detector is a state of the art walk through metal detector. It has the ability to pin point where the potentially dangerous metal object is held omitting the day to day metal objects such as car keys, belt buckles, spare change etc... [12]

Ceia SMD600 Multi Zone metal detector is a highly accurate ultra sensitive Walkthrough metal detector it posses the same capability as the Garrett PD 6500i. [13]

The walkthrough metal detector technologies have evolved considerably over the last 40 years earlier metal detectors used Very low frequency method (sub category of continues wave technique) and pulse induction method (still widely used). The pulse induction method was widely used in the past two decades but lacks the ability to discriminate between objects, which make it unsuitable for modern day requirements (will be discussed later).

Most modern walkthrough metal detectors including the ones shown above uses

Continues wave multiple sensor technology which will allow the capability of multi zone detection.

Digital signal processing in order to get good discrimination ability using a microprocessor.

Advantage of multi zone detection over single zone detection.

The objective of a practical walkthrough metal detector is

Maximum detection and discrimination capability

Higher through rate

Less false alarms rate

False alarms are a problem in modern walkthrough metal detectors false alarms could occur because of external noise in the system or lack of discriminating ability in the system.

Most single zone walkthrough metal detectors operate using the pulse induction technique which clearly lacks the ability to discriminate between the objects therefore will result in high number of false alarms which will significantly reduce the through rate.

Multi zone metal detectors use continues wave multi sensor technology which will allow pin point detection which will result in high through rate but the false alarms will still be a problem due to the lack of discrimination. [14] [15] [16]

Advantage of Digital signal processing over Analogue signal processing.

Analogue signal processing

Analogue signal processing means processing signals using analogue signal means. Sinusoids, impulse and step signals are commonly processed using analogue signal processing.

Digital Signal processing

Digital Signal processing is representation of the signals by a sequence of numbers or symbols and the processing of these signals.

To overcome the false alarm rate and to increase the discrimination ability within objects modern walkthrough metal detectors use digital signal processing. The amplified output from the receiver coil is an analogue signal so an analogue to digital converter is used. The converted signal is then sampled and analysed using a computer program which allows good discrimination ability. [14] [15] [16]

By combining the continues wave multiple sensor technology with digital signal processing metal detector manufactures have tried to achieve the above mention objectives for a walkthrough metal detectors. Although modern metal detectors have the ability to discriminate between a harmful and non harmful object it lacks the ability to correctly identify an object.

System configuration of a modern multi zone metal detector

Oscillator

Excitation Coil

Metal Object

Pickup coil

Pickup coil

Pickup coil

Phase detection

Amplitude detection

Microprocessor

Audio Tone

Conclusion

Technique

Advantage

Disadvantage

Continues Wave (VLF, Induction Balance)

Low cost

Discrimination ability

Multiple objects could be detected

Limited inspection area

Pulse Induction

Good penetration ability

Less discrimination ability

Beat frequency Oscillation

Low cost

very basic technology

Low penetration ability

Zero discrimination ability

Magnetic field Gradeometry

Wide area inspection

Passive magnetic field measurements

Low cost

Inability to detect multiple objects.

Microwave Imaging

Can detect any object

Accurate positioning

Active holographic body imaging

Time consuming

Costly

stand-still inspection

Possible danger to health.

While analysing the above table it is clear the best method for concealed weapon detection is microwave imaging but due to less practical nature it is clear microwave imaging does not suit the project.

Magnetic field Gradeometry is an interesting innovative way of metal detection but due to its inability to detect multiple objects this technique isn't the best option for the project.

Beat frequency oscillation is the oldest and the simplest of all the techniques but this technique has zero discrimination ability between object and less accurate due to these reasons this technique cannot be used

Pulse induction technique is currently used in most metal detectors it poses good penetration ability but lacks discrimination between objects therefore cannot be used for this project.

The final technique is the induction balance technique this technique cannot be used for wide area detection but has the best discrimination ability amongst all the techniques hence suit the project the most. A modified version of this technique is used in modern walkthrough metal detectors.