DESIGN AND IMPLEMENTATION OF A METAL DETECTING SURVEILLANCE DEVICE WITH AN EMBEDDED PROGRAMMABLE MICROCONTROLLER UNIT USING RADIO FREQUENCY COMMUNICATION LINK

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Abstract

In Nigeria, there is a growing need for security, surveillance and an upgrade in raw material mining. With rampant bomb scare, hand held metal detecting units have been purchased and are in use, but they are limited by proximity of the user. This paper presents a system that allows the remote viewing of the surrounding vicinity to about 2000mm, while the movement of the conveying vehicle is also controlled remotely from a distance up to600m. The affixed front mounted metal detector coil can be moved left to right from the remote device scanning for metals at a maximum depth of 60mm producing an audio indication of frequency change in the presence of mostly ferrous metals from a maximum distance of about 5000mm. The system incorporate a mobile unit and a robotic sweep arm which enable metal detection to be done from a distance in unsafe zones and hard to reach spots. This work is useful for tunnel checks, discovering metal pipe locations during drilling, landmine detection and surveillance applications.

Keywords: Surveillance, metal, detection, vehicle, remote

Introduction

A metal detector is a portable electronic instrument which detects the presence of metals nearby. Metal detectors are useful for finding metal inclusions hidden within objects, or metal objects buried underground. They often consist of a handheld unit with a sensor probe which can be swept over the ground or other objects. If the sensor comes near a piece of metal this is indicated by a changing tone in earphones, or a needle moving on an indicator. Usually the device gives some indication of distance; the closer the metal is, the higher the tone in the earphone or the higher the needle goes (Metal detector Document).

The first industrial metal detectors were developed in the 1960s and were used extensively for mineral prospecting and other industrial applications. Uses include de-mining (the detection of land mines), general surveillance; the detection of weapons such as knives and guns (especially in airport security), geophysical prospecting, archaeology and treasure hunting. Metal detectors are also used to detect foreign bodies in food, and in the construction industry to detect steel reinforcing bars in concrete, pipes and wires buried in walls and floors. The incorporation of a remote-controlled mobile system to the metal detector makes it more useful. It could be used to explore human unreachable spots (under vehicles, inside tunnels) and unsecured prone areas (mine and booby trapped fields).

Surveillance is the monitoring of the behavior, activities, or other changing information, usually of people for the purpose of influencing, managing, directing, or protecting them (Surveillance architecture). This can include observation from a distance by means of electronic equipment (such as CCTV cameras), or interception of electronically transmitted information (such as Internet traffic or phone calls); and it can include simple, relatively no- or low-technology methods such as human intelligence agents and postal interception. Surveillance is extremely useful to governments and mostly law enforcement to maintain social control, recognize and monitor threats, and prevent/investigate criminal activity. With the advent of programs such as the Total Information Awareness program and ADVISE, technologies such as high speed surveillance computers and biometrics software, and laws such as the Communications Assistance for Law Enforcement Act, governments now possess an unprecedented ability to monitor the activities of their subjects. Surveillance includes the use of all forms of information and data gathering means to achieve its purpose, with the advent of modern information age it has become more effective and valuable as it gives power and a sense of security to whomever controls it.

Safety is very important, with the rampant increase in explosion scares and security issues. Hence, a method of acquiring data from a safe remote location during exploration or surveillance is important. This can be in the form of miniature surveillance equipment, which can be easily remote controlled whilst performing all or any of the following activities;

1. Production of visual imagery of the surrounding environment

2. Metal detection ; for land mines, channel inspection,

3. Surveillance of nooks and crannies; inside pipelines, sewage passages.

To accomplish this kind of activities, the basic metal detector can be mounted on a portable Microcontroller organized carriage vehicle.

Most metal detectors are based on the concept of change of inductance of an inductor caused by mutual inductance with a neighboring metal or ferromagnetic material. This has risen to various genres of metal detectors evolving with many sophisticated methods for boosting sensitivity. Metal detector circuits are basically of four kinds (metal detector);

1. Induction balance or very low frequency (VLF)
2. Pulse induction (PI)
3. Beat-frequency oscillation (BFO)
4. Off Resonance Discrimination (ORD)

The most used being the BFO circuit which comprises a search coil, usually 6 centimeters or more in diameter connected in the circuit to oscillate between 100Hz -150 kHz. A second internal oscillator operating on the same frequency is included and a tiny part of each signal is taken to a mixer and a beat note is produced. When the search coil is brought near metal, the inductance of the coil is changed slightly, altering the frequency and thus the tone of the note. A note is produced continually and metal is identified by a frequency change in the audio note. This paper requires an intelligent “manager” to coordinate all activities. This includes communicating with the control buttons, encoding, decoding and other peripherals. The selection of the microcontroller is usually based on the required functionality of the system, like; number of required input/output ports, pulse width modulation module ports, signal processing speed. The ideal processor should be able to handle required throughput of the entire system, as large amounts of data are to be clocked in each cycle. The microcontroller usually has a program flash memory with a rated durability of up to (10000 erase/write cycles) (Amer M.I.). Data manipulation is done with its RAM, while the EEPROM is utilized for non-volatile data storage.

The aim of this paper is to report the design and implementation of a metal detecting surveillance device with an embedded programmable microcontroller unit, using a serial radio frequency (RF) communication link. It views the status of all activities within the environment through a visual display unit, while it scans for metals.

Methodology

The device’s basic function is to detect metallic objects and receive movement control signals from a remote location via an RF link. This will be implemented in two stages, which are the Hardware and Software stages.

Hardware implementation

This stage comprises the design and construction of mobile metal detection unit and the remote control unit. The mobile metal detection unit comprises

1. A microchip controlled miniature vehicle designed and constructed, to act as a carriage mechanism for the movement of the metal detector; the system also receives commands from the control unit via an RF receiver module and decodes them before sending these signals to the needed peripheral devices.

2. A high sensitive beat frequency Oscillation type metal detector designed using the square wave oscillator principle and affixed to the mobile equipment,

3. A wireless camera installed on the carrier to transmit images around the equipment to the remote location.

The RF remote control unit comprises

1. Buttons programmed to produce control signals, which are interpreted and encoded

by the microcontroller then sent out via an RF transmitter.

2. A microcontroller unit (MCU) which acts as the brain to control the actions of the surveillance system.

3. The Display Unit

Software implementation

After construction, the required microcontroller is determined based on the system requirements of the device input/output (I/O) ports, number of internal modules and processing speed. A High level language program is written to control the entire system with the aid of a computer programming software, and then compiled to machine language producing a .Hex file which can be simulated in ISIS professional application software on the software version of the microcontroller. On passing the simulation, the .hex file is uploaded into the microcontroller flash ROM using a Programming board and Winpic800 computer program as an interface.

Literature review

According to Awodele (2009), a good security system consists of four layers with the two basic layers being the environmental design which refers to the physical structures and personnel set in place to monitor and handle physical threats to an area; Such as walls, metal detectors, security officials and video monitoring which is the video surveillance system that basically contains a camera or any other Charge Coupled Device (CCD) transmitting visual imagery of the surroundings. They utilized the pulse induction type metal detector, which had flaws of poor discrimination between metals and also incorporated a wired CCTV camera and specified that the surveillance layers should be able to function independently and also work as a unit.

Hankin, Hertz & Simon (2011) studied the use of metal detectors for security purposes, by installing them in security lapse areas like secondary schools. They concluded that the presence of this equipment within the school premises helped to cut down the carrying and use of weapons like guns, blades, e t c, thereby increasing safety of students and school staff.

In recent times with the availability and ease of accessibility of electronic components like transistors, integrated circuits and microcontrollers, Metal detecting systems have been upgraded to perform various other functions, like send an SMS alert on detection, or automatically tag the location with some paint substance, or even notify individuals at a remote location.

Yaakov (2005) demonstrated in his paper a metal-detecting technique that is appropriate for either magnetic or non-magnetic metals, which is the beat frequency Oscillation (BFO). This was achieved by detecting non-magnetic metals, based on the search coil inducing a current in the non-magnetic metal object, such that the eddy current opposes the field producing it. In a material such as ferrite, the field is concentrated and enhanced, therefore producing an opposite effect. The magnetic effect of the eddy current in the non-ferrous (low permeability) metal will depend on the total number of electrons moving around which is proportional to the conductivity of the material. The beat oscillations technique is simple, sensitive and inexpensive equipment.

Candy (2008) mentioned the biggest technical change in detectors as the development of the balance coil system, which is a variation of the induction Balance type. This system involved two coils that were electrically balanced. When metal was introduced to their vicinity, they would become unbalanced. What allowed detectors to discriminate between metals was the fact that every metal has a different phase response when exposed to alternating current. Even with discriminators, it was still a challenge to avoid undesirable metals; because some metals have similar phase responses e.g. tinfoil and gold, particularly in alloy form. Thus, improperly tuning out certain metals increased the risk of passing over a valuable find. Another disadvantage of discriminators was that they reduced the sensitivity of the machines.

The use of microcontrollers in the construction of metal detectors has allowed all of the vital pulse timing to be optimized, and set in software during development. All of the timing is set by division from the 4MHz microcontroller clock and so is extremely accurate and free from jitter and drift which would otherwise appear as noise and reduce the circuit sensitivity (Mark S 1999).

Nwankwoa et al. (2013) designed an Electronic Surveillance System using a Metal detector which sends a message (SMS) or makes a call to a stored security number through a data cable on detection of a metallic substance. The data cable acts as an interface between the microcontroller and the cell phone, the system also incorporates a Liquid Crystal Display (LCD), which is interfaced in a 4-bit communication mode with the microcontroller. The programming language used was a high level language called basic, which was uploaded into the microcontroller using a programmable serial board. This Dissertation is recommendable for real life applications, as it offers Security of lives and property which had always been a major concern.

Nyein (2016) in his design and implementation of land mine detection robot, they pointed out that success of land mine detection and removal ought to be nearly100%, but the mostly used method is the manual de-mining which is very slow and very dangerous for the life of the operating personnel. Hence it was necessary to develop a robot assisted mine detection method that is safe, more accurate and faster than manual method by mounting a metal detector configured in beat frequency oscillation (BFO) circuit on the system.

Masunaga & Nonami (2007) consider metal detectors as the most reliable sensors for mine detection work. However, landmine detection performance of the metal detectors is highly dependent on the distance between the sensor heads and the buried landmines. Therefore, the landmine detection performance of the metal detectors could be substantially improved if the gap and attitude of the sensor heads can be controlled.

System design

Hardware design

Functional Requirement of the Mobility system: DC motor capable of accelerating a 2.83kg, two wheel drive metal detecting mechanism with wheel diameters of 4.2cm at a rate of 0.9ms^{-2} To determine the torque (force) that must be generated at each wheel in order to meet the functional requirement.

Mass = 2.83kg, Acceleration **=** 0.9 ms^{-2},

Calculate required force in SI units

Force = Mass × Acceleration **1**

Force= 2.83kg ×0.9ms^{-2}

Force = 2.547 N

The Total force required to meet the Functional Requirement is 2.547 N. However, the vehicle has 2 driving motors and wheels. Therefore each motor/wheel combination needs only supply half the required force,

Wheel Force = 1.274 N

The requirement for each wheel can be calculated using

Torque = Force × Distance **2**

Distance (Wheel Radius) =0.021m

Force = 1.27 N

Wheel Torque= 1.27×0.021= 0.0267Nm

Wheel Torque in milli-Newton meters is = 26.7 mNm

Hence the required torque at each wheel is 0.0267 Newton meters.

To determine the required wheel RPM to maintain a speed of 1 meter per second,

Wheel speed in RPS = $\frac{Speed\ (ms^{-1})}{Circumfrence\ (m)}$ [rps] **3**

Wheel Circumference = π x Diameter = 3.142 x 0.0267 = 0.0840 meters

Required Speed ` = 1ms-1

Wheel speed in RPS = $\frac{1}{0.0840}$ [rps]

Wheel speed = 11.900 rps

But wheel speed in rpm = 7.575 × 60

Wheel speed = 714.047 rpm

H-bridge design

The h-bridge design is highly dependent on the motor current.

Voltage rating = 6 – 12V

Current ratings, nominal current = 150 mA

Stall current = 250 mA

A low power BC337 NPN transistor is selected for use and operating features maximum collector current of 800mA.

$$Rs = V_{in\,(max)} \times \frac{h_{fe}}{I_c} \quad 4$$

For the control transistor, BC337

H_{fe} = 630, I_c = -3A, $V_{in\,(max)}$ = 5V (maximum possible voltage from the microcontroller)

Therefore

$R_{s1} = \frac{5 \times 630}{-3}$

$R_{s1} = \frac{3150}{3}$

R_{s1} = 1050 Ω ~ 1.2kΩ

For the TIP32PNP Bipolar Junction Transistor required to source 250mA

H_{fe} = 50, I_c = 250mA

$V_{in} = V_{BE} + V_{th}$

Where Vbe = base emitter saturation voltage = -1.8V ,Vth = threshold voltage = 0.7V

V_{in} = -1.8 + 0.7 = -1.1V

Therefore, $R_{s2} = \frac{-1.1 \times 50}{250 \times 10^{-3}}$

$R_{s2} = \frac{-55}{250 \times 10^{-3}}$

$R_{s2} = -0.22 \times 10^{3}$

R_{S2} = 220Ω

For the TIP31 NPN Bipolar Junction Transistor required to sink 250mA

H_{fe} = 50, I_c = 250mA, V_{in}= 6V (maximum possible voltage at the base)

Therefore, $R_{S3} = \frac{6 \times 50}{250 \times 10^{-3}}$

$R_{s2} = \frac{300}{250 \times 10^{-3}}$

$R_{s2} = 1.2 \times 10^{3}$

R_{S2} = 1.2kΩ

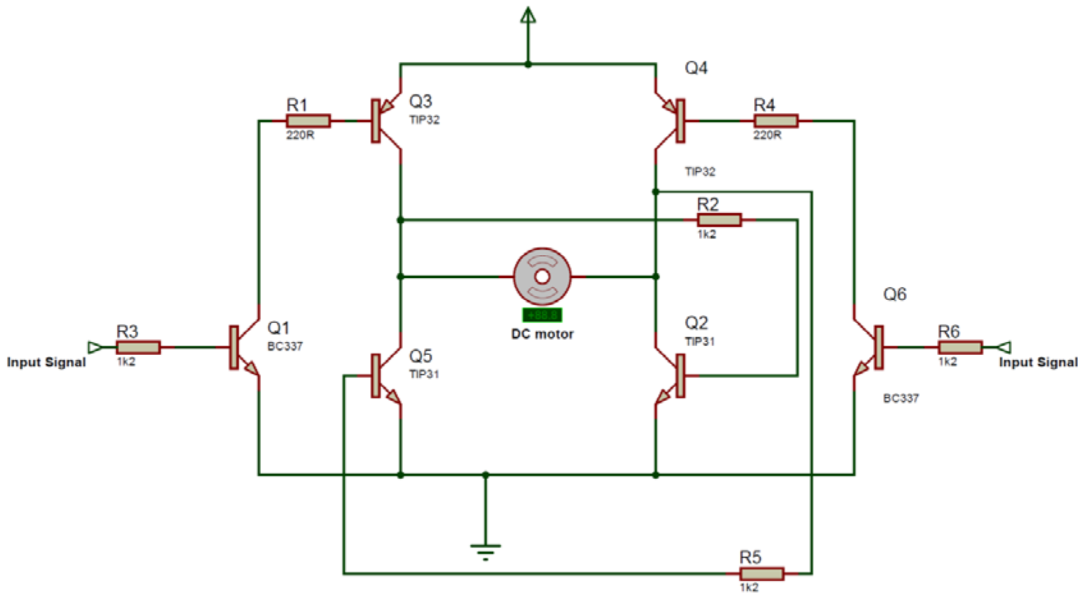


Fig 1 Complete full H-bridge circuit Diagram.

Video module selection

This section covers the camera selection, AV module section, and LCD monitor selection. All the components within this section are selected basically to save energy; hence they are low power devices. The system is also meant to be as portable as possible, hence during the selection only devices with portability are utilized. The Audio/video section of this Dissertation is meant to produce and retrieve live video coverage from the mobile system, basically the required video quality and coverage is the first step to designing the system, hence the importance of the camera to be utilized. The camera is required to produce NTSC video format, through RCA connectors, with a coverage area of about 4.69 x 3.45mm. This video signal is required to be transmitted wirelessly, hence the need for AV transmission and reception modules small enough for portability and capable of performing this action.

The Audio/Video transmitter receiver pair is to be capable of processing and transmitting composite video and audio over the airwaves on an undisturbed frequency band at medium range. Hence the selection of the 2.4 GHz Transmitter / Receiver pair selection, which also operates in the ISM band. The display monitor is chosen to be small at 4.7 inches and easily integrate-able to the remote control system. The circuit connections are illustrated in Figs 3.3a and 3.3b.

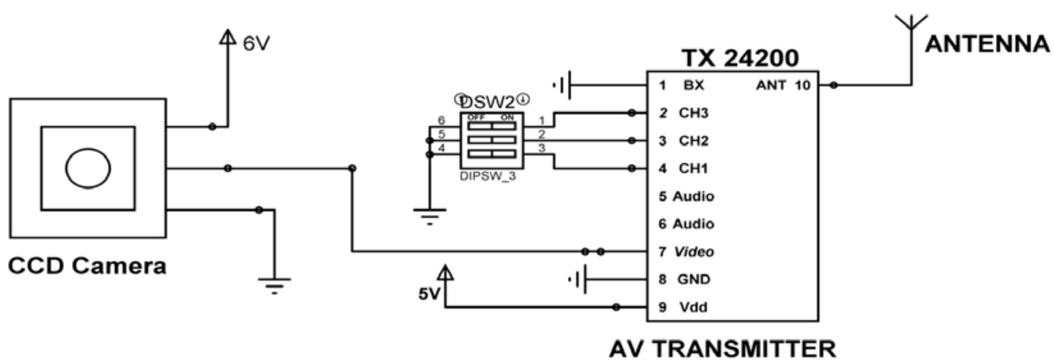


Fig 2 CCD Camera to Video Transmitter Module Circuit Diagram

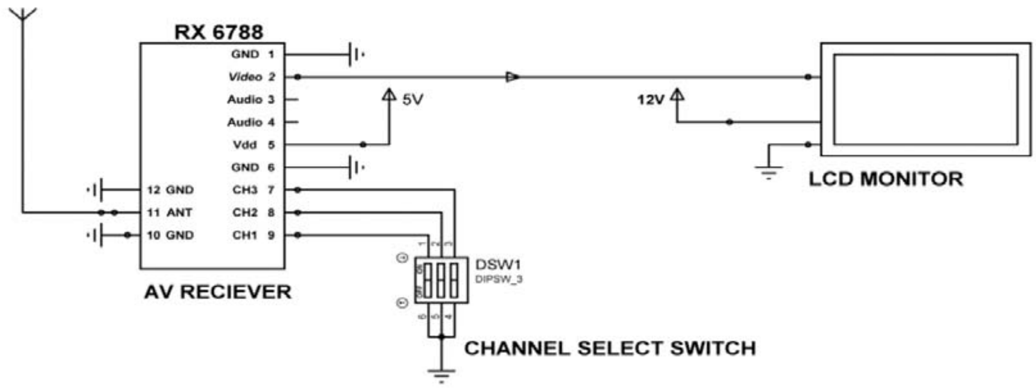


Fig 3: Video Receiver module to Monitor Circuit Diagram

RF module selection

This section comprises the radio frequency transmitter and receiver modules design.The module selection is based on the following criteria

1. Range of coverage = 100 meters minimum
2. Operating frequency = 433 MHz (ISM)
3. Type of modulation = Digital
4. Type of data transmitted = Serial Data
5. Size of module = Miniature
6. Power consumption = below 50mW

$L_m = \frac{\lambda}{4}$, but $\lambda = \frac{V}{f}$ where , V = speed of light ($2.8 \times 10^8 ms^{-1}$)

F = operating frequency = 433 MHz

Therefore, $\lambda = \frac{2.8 \times 10^8}{433 \times 10^6}$ = 0.646 m

$L_m = \frac{0.646}{4}$ = 0.162 m

L_m = 16cm

Utilizing the above requirements, searching manufacturers datasheets for available RF transceiver modules, KYL500S Smart Transceiver Module, by Shenzhen KYL Communication Equipment Co., Ltd

Were readily available and met the required specifications, which are required to transmit serial data (1's and 0's) from the encoding microcontroller over the airwaves and receive this data for the decoding microcontroller, within a minimum distance of 100 meters. This process of transmit and receive of digital data is done at 433MHz, utilizing Frequency Shift Keying (FSK) digital modulation.

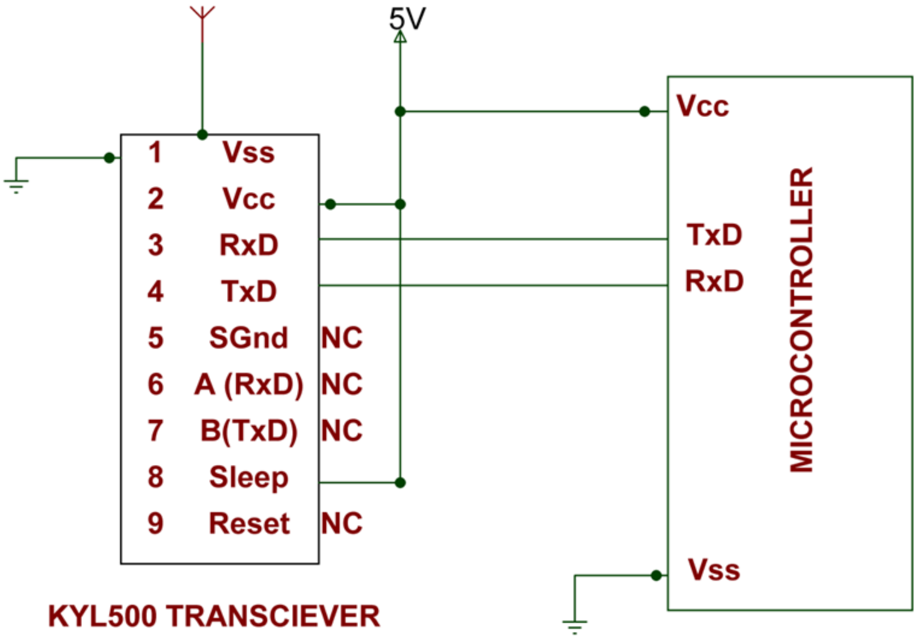


Fig 4: RF Transceiver Circuit Diagram

Microcontroller selection

The PIC 16F877 microcontroller was used for both the remote control device and the mobile surveillance system because it contain the required ports and contains extra ports capable of allowing upgrade of the system and complete interface.

Control switch design

The system uses a hand portable remote control device, which Comprises button types and arrangements.

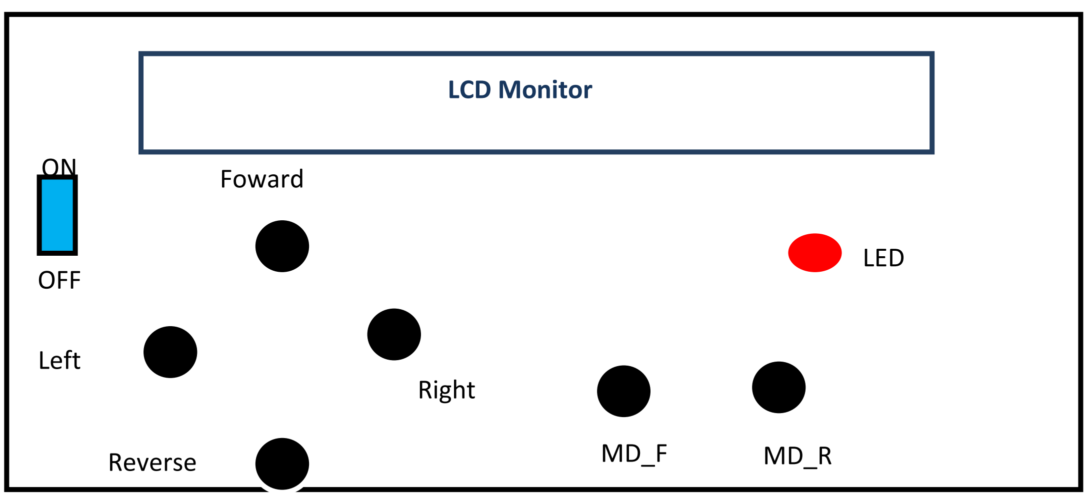


Fig 5: Control Buttons Arrangement for the handheld device

Metal detector design

The metal detecting system uses a square wave oscillator coupled with a search inductor coil, which is meant to produce a difference in frequency in the audio frequency range of 3Hz – 30kHz operating. When a metal is introduced to the coil, it causes a change in the electromagnetic field around the coil which further leads to a change in inductance and frequency of oscillation. The signal is collected over a low pass filter to ensure within the audio frequency rate of coil.

Software design

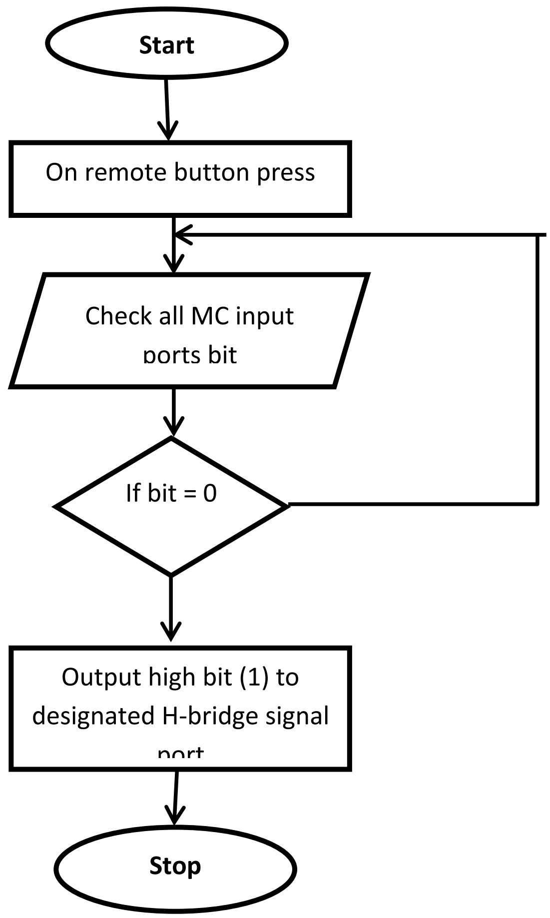


Fig 6: Wheel Control Flow Chart

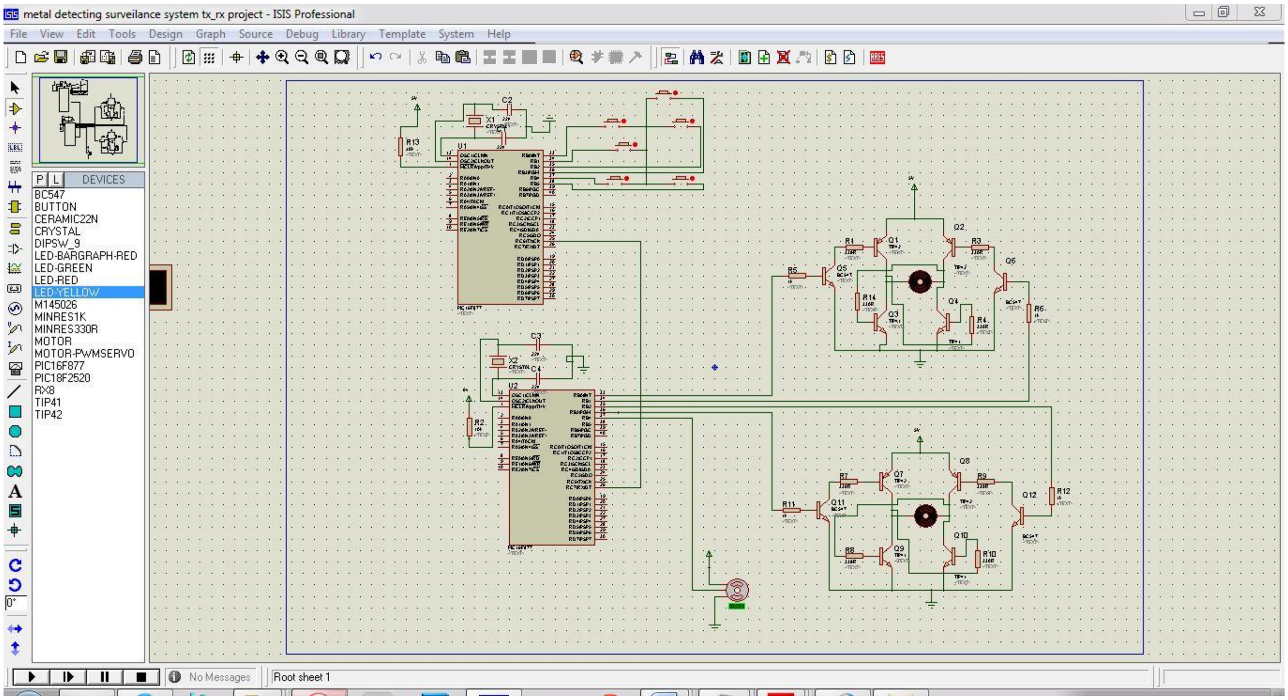


Fig 7 Button Control Trials on Proteus 8 Computer Software GUI

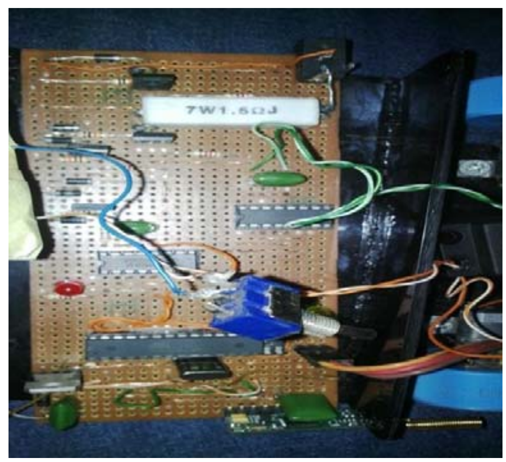


Fig 8 Different Completion Levels and Circuits of the Device

Test and measurements

The system was tested to ensure proper functionality. Waveforms snapped from each stage of the circuit test point were displayed, showing characteristics of the signal; voltage amplitude and frequency. The oscilloscope was used not only to view wave forms but to determine voltage magnitude (amplitude) with the vertical axis settings in V/divisions and time related measurements (period, frequencies) with the horizontal axis settings in ms/divisions

The remote control system was tested to ensure appropriate response on the press of control buttons. This proves that the mobile surveillance unit can be fully controlled by the handheld device.

Metal detector test and measurements

All measurements taken were based on specific test configurations and points shown in fig 10. The sensitivity of the metal detector was tested using three (3) different metallic substances of different sizes to show its response at different distances between the metal detector coil and these metals.

Functionality and proximity test

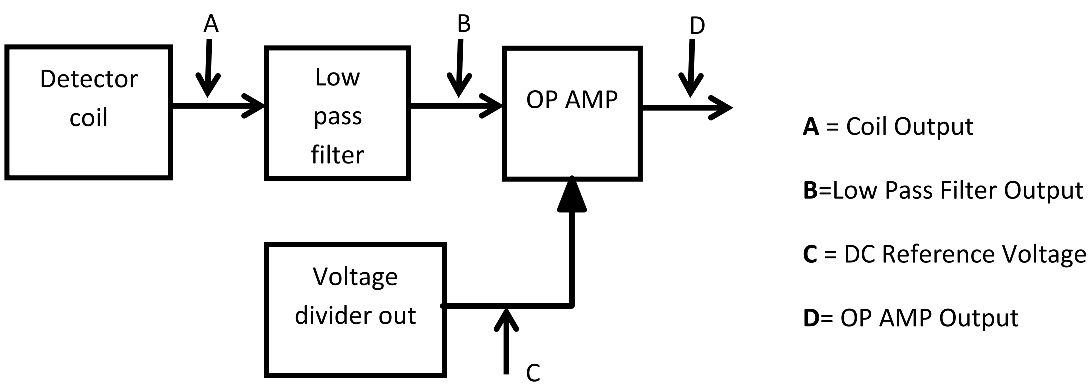


Fig 9 Voltage and Frequency Test Points

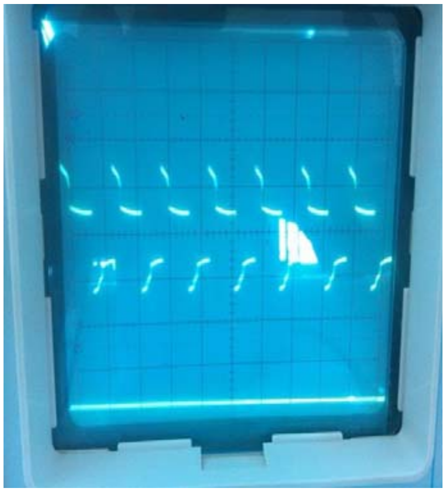
During Testing, measurements were taken when the metal detector was not in the vicinity of any metal and later in the presence of ferrous and non-ferrous metals.

Results

Snapshots of Wave forms and measured test values showing the acquired results from all test points are illustrated.

Point A: Detection coil

Measurements were taken initially without the presence of metals



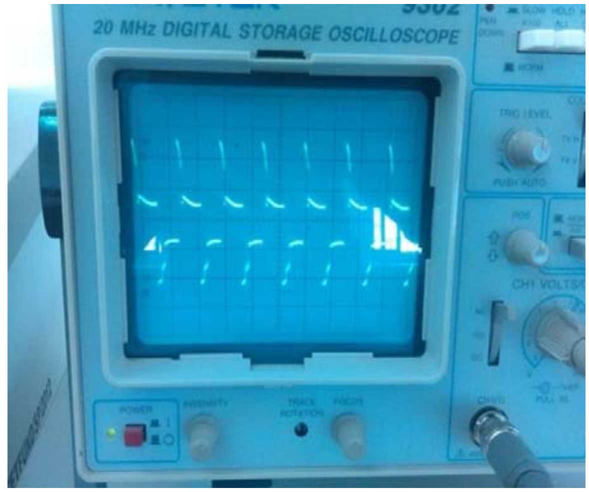


Fig 10a Detection coil Output Waveform operating at 3.333 kHz

Fig 10b Coil waveform in the presence of ferrous metal 3.125 kHz

Fig 10a shows the metal detecting coil output waveform operating at about 1.5 div by 0.2ms, giving a period of about 0.30ms. Hence the operating frequency which is the reciprocal of period is 3.333 kHz, with a peak voltage of about 5.97 Volts.

1. Peak Voltage, V_P = 6 V
2. Peak-peak voltage, V_{P-P} = 12V
3. Period, T = 0.3 ms
4. Frequency, F = 3.333kHz

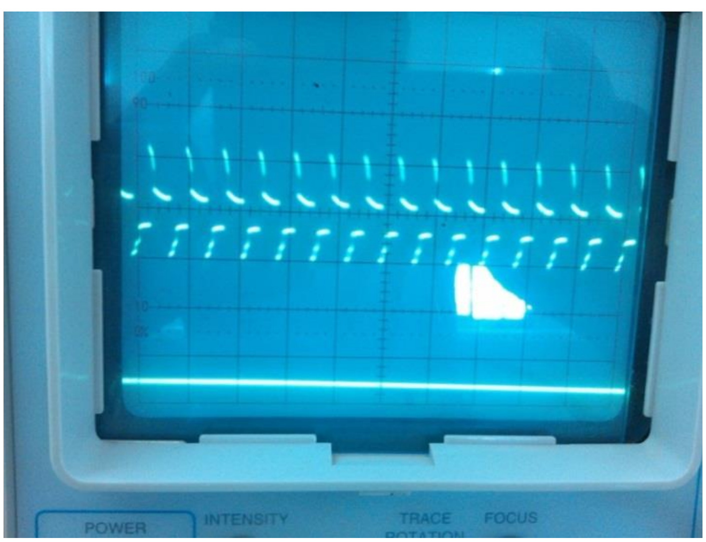


Fig 10c Coil Waveform In the Presence of a Non-ferrous Metal at 3.57 kHz

Point B: Low pass filter output

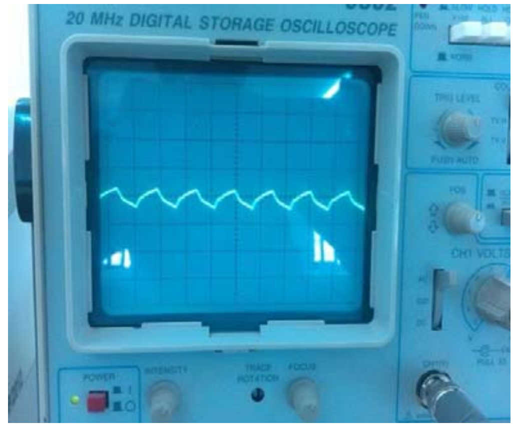


Fig 11a Rippled DC output of low pass filter at 1.95V

Fig 11b Low Pass Filter Waveform showing the AC ripples at 3.334kHz

The results recorded from the metal detector without the presence of a metal (free running)

1. DC voltage, Vdc = 1.95 V
1. AC ripple peak voltage, Vacr = 0.08 V
2. Peak-peak ripple voltage, Vrp-p = 0.16 V
3. Period, T = 0.28 ms
4. Frequency = 3.334 kHz

The 3.334 kHz filter waveform is a 1.8Volts DC wave with ripples. The peak to peak ripple voltage is about 0.16 V. The ripple size varies with frequency change; increase in operating frequency decreases the ripple voltage and vice versa.

Point C: Voltage divider output

The signal from this point is a DC voltage waveform gotten from the voltage divider network which is to act as the reference voltage.

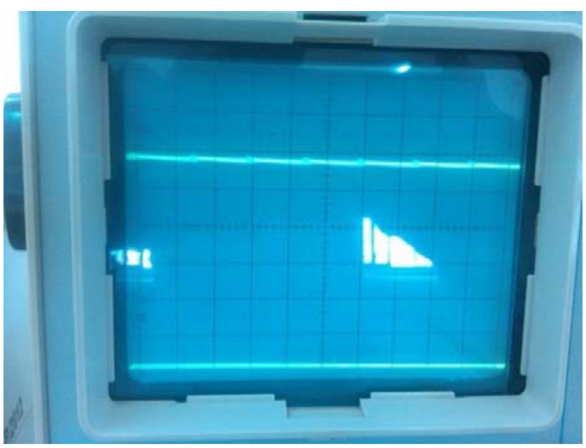
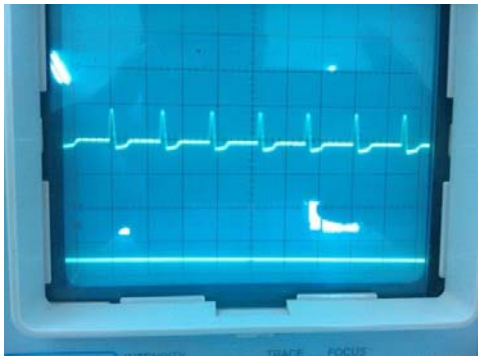


Fig 12 Voltage divider output DC wave form at 1.8V

No change in waveform frequency or amplitude noticed in and without the presence of a metal

Point D: OP amp output



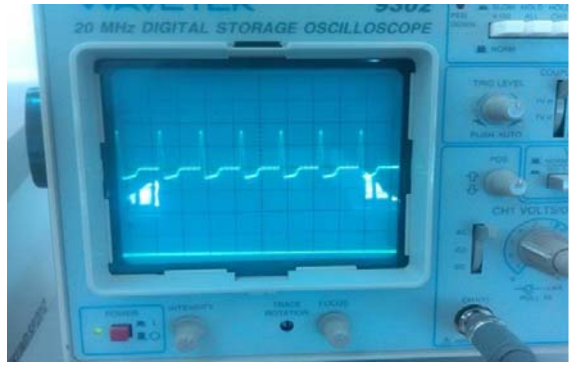


Fig 13a Operational amplifier output waveform at 3.333kHz and peak voltage 2V

Fig 13b Operational Amplifier output waveform at 2.778 kHz due to ferrous metal presence

1. Peak Voltage, Vp = 2 V
2. Trough voltage = 0.8 V
3. Peak –peak voltage = 2.8 V
4. Period, T = 0.28 ms, Frequency, F = 3.333 kHz

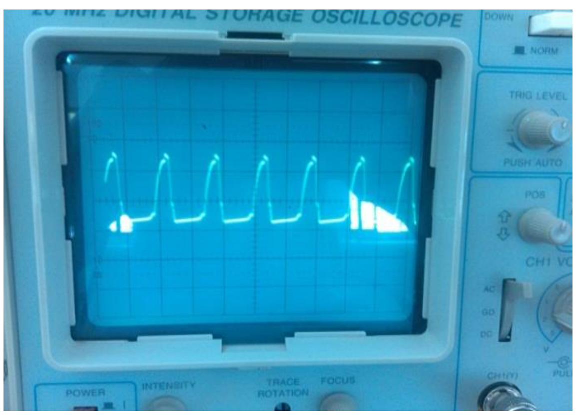


Fig 13c Operational Amplifier output at 3.700 kHz in the presence of non-ferrous metal

Conclusion

The aim of the paper has been achieved with the understanding of a simulated model of the major parts of the system using ISIS Proteus 8 electronics modeling software, which also provided an idea of the designed physical implementation.

Recommendations

Further work can be carried out on this system to provide better functionality. Like replacing the power system of the device with an embedded array of Photovoltaic (PV) solar cells to ensure continuous 12V/2.4 Ah power supply to the mobile unit, hence reduced size and improved use duration.

Robotic pickup arms could be added to the system for controlled pickup of items and samples on the field, to avoid direct human interaction with the device environment.

The metal detector can be completely replaced with Ground Penetrating Radar (GPR) for more advanced up-to-date and precise detection of metallic and non-metallic objects.

Applications

This system can be utilized for the following purposes

1. Security: it can be used to locate Unexploded Ordnance (UXO) or as a simple landmine locator, to detect heavy anti-tank and antipersonnel mines like the Egyptian HAMDY fragmentation mine Or 60 mm mortar shells, which contains a large quantity of cast iron. It can also be used as a surveillance device for Visual security searches and checks.

2. Industrial: it can be used to scan small tunnels, caves and trenches from a safe distance.

3. Construction: it can be used to search for metal pipes or rods in the ground, during renovations and building.

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