Semi-Autonomous Robot for Landmine Detection and Removal

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***Abstract*— Since the times of war, landmines still pose a significant threat to many, especially in war affected areas. Further, 70 to 85 percent of these victims are composed of civilians, peace keepers and aid workers [2]. Landmines have a devastating impact on economy, lead to loss of biodiversity, ecological crisis, soil contamination, loss of productivity, threat to food security, community health, poverty and social marginalization [4].**

This paper aims to implement a semi-autonomous robot for land-mine detection and removal. It is achieved by applying the principles of passive IR thermography for land-mine detection and a custom adapted tree transplanter mechanism for demining. The area to be surveyed is navigated by a remote controlled robot. In this process, it avoids detonating any anti-personnel land-mines owing to its light weight framework.

The detection of land-mine is performed by using the fact that the thermal signature of land-mines is different from the surrounding soil. An IR camera is used to obtain an approximate location of the land-mine. Once detected, the mine is dug out by three spades (actuated by a linear actuator) forming a triangular prism inside the soil as in a tree transplanter. The idea was validated through a prototype designed and implemented for land-mines of 10 cm in diameter placed at 7 cm depth below ground with radiations from a land-mine stimulated using IR LEDs.

I. INTRODUCTION

A land-mine is a bomb that blasts usually due to exertion of pressure on the trigger.

Fig. 1. Anti-personnel land-mine [3]

Since the mid-14th century, land-mines pose a major threat to soldiers and civilians, leaving large areas of land uninhabitable. There are more than 100 million anti-personnel or anti-tank land-mines in more than 70 countries at present. It has been estimated that more than 26,000 people are killed or maimed by mines every year, which is one victim every 20 minutes [16] [17].

Currently, these land-mines are being removed manually by humans. This poses great threat to their lives and hence we aim to solve this by introducing a semi-autonomous technique to remove these land-mines.

This paper is organized as follows. Firstly, Section 2 describes the broad classification of land-mines. Followed by a brief idea about existing land-mine detection techniques in section 3. Further, section 4 and 5 illustrates the method used for digging and lifting in the model. Finally, section 6 concludes with future scope of this project.

II. TYPES OF LANDMINES

Land-mines can be classified into two types:

1) Anti-tank mines (ATM)
2) Anti-personnel mines (APM)

ATMs are designed to detonate at the pressure of large vehicles and are hence larger than APMs. Thereby, detection of ATMs are safer and easier to detect by humans as compared to APMs.

APMs like the one shown in figure 1 are more difficult to locate and remove and hence most civilian casualties are caused due to these. They are mostly made of non-metallic material adding to the difficulties in its detection. APMs can be further divided into three types; blast, bounding fragmentation, and directional fragmentation based on how they detonate [5].

Since their mechanism is simple and their material is cheap, small military groups have been able to manufacture this type of mine. This fact has resulted in serious mine problems for some poor countries that cannot afford the investment for demining work.

III. LAND-MINE DETECTION TECHNIQUES

Currently, there are various techniques available for detection of the presence of landmines. Some of the methods are discussed below.

A. *Ground Penetrating Radar (GPR)*

GPR actively emits electromagnetic waves through a wideband antenna and collects the signal reflected from its surroundings. When the signal meets a surface between two electrically different materials, it is reflected. Since, during reflection of a signal, it can get either diffused or reflected back at an equal angle, the intensity and direction of the

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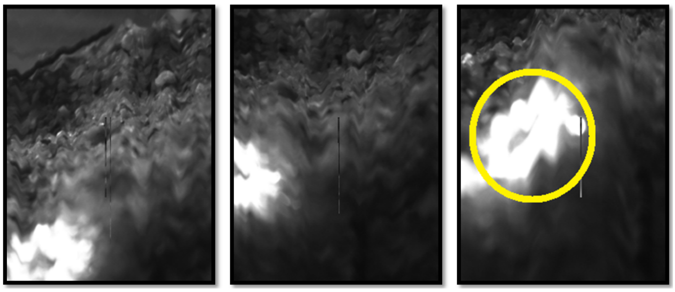


Fig. 2. IR radiations as seen through our IR camera and detection of simulated landmine (last image)

reflection depends on the roughness of the surface and the electric property of the medium material [5] [14].

If the reflecting surface is smooth, the reflected signal will be at the same angle as the incoming signal with respect to the surface normal. However, a rough surface reflects the incoming radiation in a diffused manner. Further, the electric property of the medium determines the refraction and absorption level of the EM waves and subsequently affects the direction and intensity of the reflection [5].

The GPR can provide information about the presence and location of an object. If the signal is interrupted, it indicates the presence of an object. The time delay (δt) incurred between emitting the signal and receiving the reflected signal can give details about the location of the object.

B. IR Cameras as sensors

This idea revolves around the concept of passive IR thermography. This technique is based on the thermal radiation contrast of objects with respect to their background. This enables us to detect the abnormality (presence of a landmine) in the soil. All objects at temperatures greater than absolute zero emit electromagnetic (EM) radiation at wavelengths from 3m to 100m referred to as the thermal IR radiation [6].

The difference of thermal characteristics, i.e., heat capacity c, thermal conductivity k and thermal diffusivity α , between buried objects and the background is the base of using IR technique for detecting land-mines [7]. The radiations emitted by the buried landmines is characteristically different from those emitted by the surrounding soil [14]. Further, the radiations emitted by the land-mine lies in the infrared range due to the chemical composition of the landmines. Hence, when these radiations are captured by an IR camera as shown in figure 2, the presence of the land-mine can be detected.

C. US Sensors

The principle of US (Ultra Sonic) is very similar to GPR except for the signal. Both sensors emit an active signal and collect reflections from the surroundings. [8] In a uniform homogeneous medium, the US wave propagates along a straight line and is reflected and refracted when the wave encounters a boundary between two different media. [5]

At the boundary hence, this behavior of the US wave is decided by the speed of the wave and the media's density. Then the location of the landmine can be determined by measuring the frequency of the US signal as low frequency waves penetrate further than ones with higher frequency.

D. Analyzing the available techniques

1) As current mines do not have metallic material as much as older types, it is difficult to detect mines by the current employed technologies like the metal detector [9]. Further, in this detection technique, the number of false positives is high as any metallic rubble in the soil that can trigger an alarm.
2) Some recent research has reported that GPR can recognize targets buried at about 30 cm in clay [5]. But, the penetration depth is comparatively less due to its high frequency which also increases clutter. Its performance is sensitive to complex interactions between mine casing material, soil texture and moisture, wave frequency and soil surface roughness. Another limitation is the detection of small shallow mines because the reflection at the soil surface masks the response of such mines [15]. Hence, this along with its high cost makes it a less often used technique for demining.
3) US may be used in different situations than other sensors. The main advantage of US waves is that it can propagate well in humid environment. It can even be used to detect underwater landmines where other means of detection will not be very effective. Further, it would be the best method to be used in floods or rice swamp areas, that are common in mine afflicted areas.
4) However, IR Thermography is the easiest method to visualize data in 2D image format considering that the maximum burial depth has been estimated at about 10-15 cm [5]. The depth of the mine can also be found by using image processing techniques on the IR intensity variations coming from the mines at different depths. Also, this holds for every type of mine and other buried objects, despite the amount of metal content, if any, making possible the detection of small plastic antipersonnel mines [10]. Further, this provides a simple implementation that provides commendable accuracy in detecting the mine using the IR radiation from the mine. Hence, taking the advantages into consideration, this method was choseen for implementation.

IV. LANDMINE REMOVAL: DIGGING

When a machine moves and digs into the soil using working tools, the tool is subject to digging resistance. This resistance is much higher than the resistance to machine movement hence digging resistance forms a more significant factor in calculating net resistance [11].

Digging resistance consists of cutting resistance (R_1) and displacement resistance of dug soil (R_2), which is different for different tool type. Cutting resistance is the tangential component of overall digging resistance that can be formulated as:

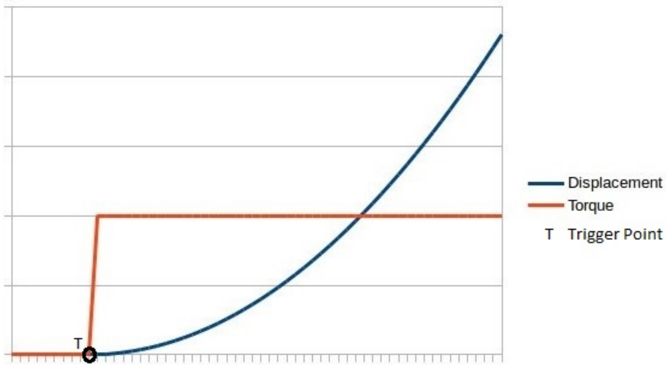


Fig. 3. Torque provided Vs Distance dug into soil

$$R_1 = k_1 * L * h \tag{1}$$

where,
k_1 : Specific Cutting Resistance (N/m^2)
L : Cutting Tool Width (m)
h : Soil Cutting Depth (m)

Cutting resistance is dominant in relation to machine movement resistance. Cutting resistance depends on the type of working tool (flail, tiller) and working conditions. According to soil categorization, specific soil resistance (k_1) can range from 25 kN/m^2 to 320 kN/m^2 in the first and fourth soil category respectively.

Cutting resistance increases more with increase of cutting depth (h), then with increase of cutting width (L). In order to achieve required efficiency on certain soil category, machine operator should adjust cutting depth h and regularly inspect tool blades.

Cutting Resistance for a single spade in the model can be calculated from equation 1 using integral form as:

$$R_1 = k_1 * \int_0^h l * dh \tag{2}$$

In the model proposed, the dimensions of triangular part of the spade are:
base - 25 cm
height - 10 cm
By substituting the value of the length of the spade 'l' in contact with the soil when the spade is at depth 'h' into the soil, for a total digging depth of 7 cm, the equation 2 becomes:

$$R_1 = k_1 * \int_0^7 3.43 * h * dh = 210.0875N \tag{3}$$

Hence, equation 3 gives the final value of cutting resistance required. The graph obtained by plotting the torque provided by the linear actuator versus the distance the spade digs into the soil is as depicted in the graph in figure 3.

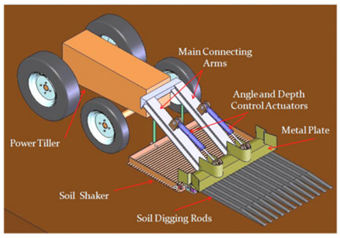


Fig. 4. The potato digger mechanism for landmine removal [13]

Fig. 5. Tree Transplanter mechanism [1]

V. LANDMINE REMOVAL: DEMINIG WITHOUT DETONATION

The mechanisms considered for land-mine removal are as follows:

A. *4 DOF Excavators*

Generally, excavators are used where there is a need of simple digging and soil transferring operations through machine control. But the use of hydraulic actuators makes it bulky and increases the weight of the vehicle increasing the chances of detonation of land-mines while traversing the area of inspection. Secondly, this mechanism includes the risk of the mine toppling and hence causing detonation during the process of lifting the land-mine above ground.

B. *Potato Digger Mechanism*

This mechanism as depicted in figure 4, is inspired by the potato digger, which is used for gentle lifting of the tubers and soil separation over a vibrating sifter [13]. It uses the vibratory blade which is inserted into the soil and the mine is dug out soil free. This mechanism is highly dangerous since the mine is in direct contact with the soil. Secondly, these cannot cover more than 7 to 10 cm of depth and hence not suitable for all types of minefields.

C. *Tree Transplanter Mechanism*

A typical tree transplanter [1] consists of a number of blades (generally 3 or 4) that encircle the tree, digging into the ground and then lifting the entire tree, including its roots and soil, out of the ground and re-planting or transplanting the whole tree in the designated area. This mechanism can be seen in figure 5. A similar idea can be implemented in removing the land-mine along with some amount of soil surrounding it. This ensures that there is no direct contact of the blades with the mine and there is no relative motion

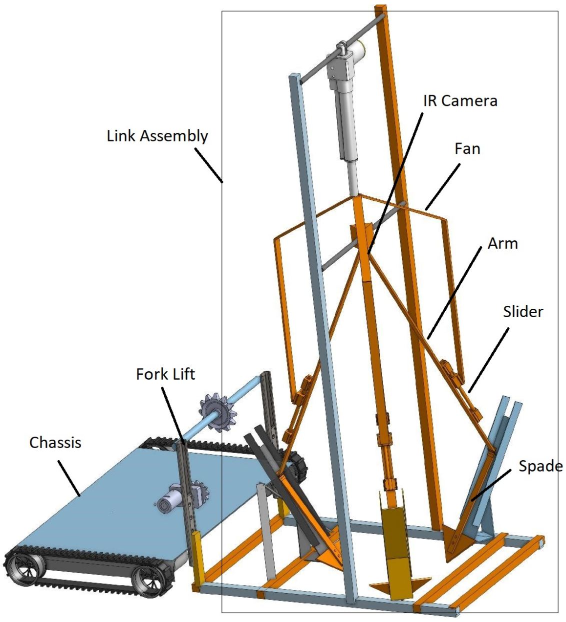


Fig. 6. CAD Model

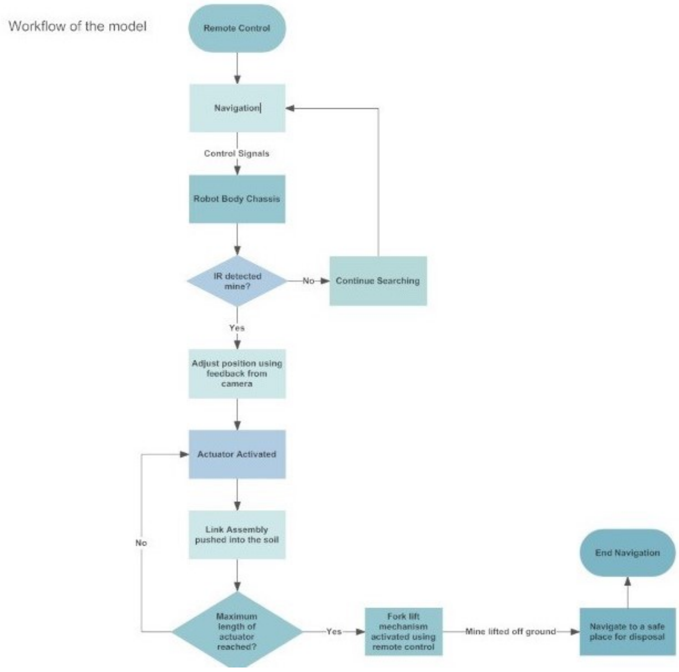


Fig. 7. Implementation Work Flow

between the mine and its surrounding soil, thus making it a safe method of removal. Hence, in this project the above mechanism is implemented.

VI. RESULTS AND IMPLEMENTATION

The robot implementation can be divided into six modules; them being remote controller, robot body, IR camera, actuator, links assembly and the fork lift mechanism. The CAD model of our design is depicted in the figure 6. The entire robot is powered by three Lithium Polymer (LiPo) batteries. It is controlled using a simple joystick control system for semi-autonomous traversal of required area. The implementation work-flow is as depicted by the figure 7.

Each of the modules in the robot can be explained as follows:

A. Remote Controller

The robot is done using Radio Frequency (RF) based remote control mechanism. It consists of an RF transmitter and receiver module for wireless communication. The receiver module is connected to the motor drivers which in turn actuate the motors attached to the wheels. The wavelength of an electromagnetic signal is inversely proportional to the frequency; the higher the frequency, the shorter the wavelength. RF communication between the transmitter and the receiver works by the creation of electromagnetic waves at the transmitter and the pick up those electromagnetic waves at a particular destination by the receiver. It is widely used for wireless communication since it is cost effective, and does not require line of sight.

B. Robot Chassis

The robot chassis was made out of a rectangular piece of high grade steel. Each chassis is supported with four wheels with a facility to attach belts to decrease pressure exerted due to the weight of the robot on over it. Each of the chassis is attached to the fork lift mechanism as indicated by the figure 6.

C. IR Camera

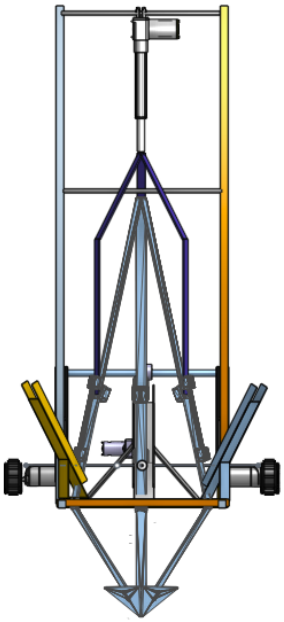
The detection is performed using an IR camera module interfaced with an arduino and a single chip computer (Raspberry Pi). The radiations from the landmine are simulated using IR LEDs. Simple image segmentation algorithm is applied on the feed obtained from the IR camera module.The radiations from the IR LED is detected as a bright spot on the image as shown by the figure 2. This then triggers the linear actuator via an interrupt.

D. Linear Actuator

The linear actuator has a maximum length of 100mm (4 inch stroke) , operating at a voltage of 24V, it can provide a force equivalent to 4000N. This force is equally distributed along the length of the three spades. This force is enough to reach the digging force (as calculated in section 4) required. To ensure the spades meet at the pinnacle of a triangular pyramid when dug into the soil, the angle at which force is applied on it has to be regulated. To do so, a custom made link assembly is designed.
Before digging the orientation of the mechanism is as shown in figure 6.

E. Link Assembly - Digging mechanism

In this model, we have chosen the tree transplanter mechanism powered by a linear actuator to implement landmine removal. The following explanation describes the



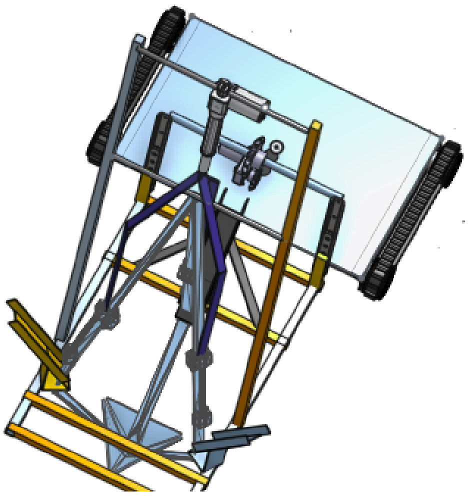


Fig. 8. Front view (above) and Isometric view (below) of the orientation after digging into the soil

movement of the spades into the soil. The three spades meet under the ground forming a triangular pyramid thus encapsulating the mine.

Parts of the link Assembly

1) Fan: The part directly attached to the linear actuator. As the linear actuator exerts force on the fan, it moves down transmitting the force onto the arms attached below via slider.
2) Slider: A 1 DOF slider which enables relative motion between fan and the arms. As the fan moves on the slider, the angles between the arms decrease, thereby enabling the spades move into the soil at a fixed angle to the surface.
3) Arms: Acts as a transmitter of force from the linear actuator to the spades. The angle between the arms changes from an initial 60 degrees to 48 degrees.
4) Spades: It consists of triangular part and a handle. The handle part is attached to the arms using a hinge joint. As the linear actuator exerts force on the fan and hence the arms, the triangular part of the spade is pushed into the soil, thereby enabling it to encapsulate the mine.

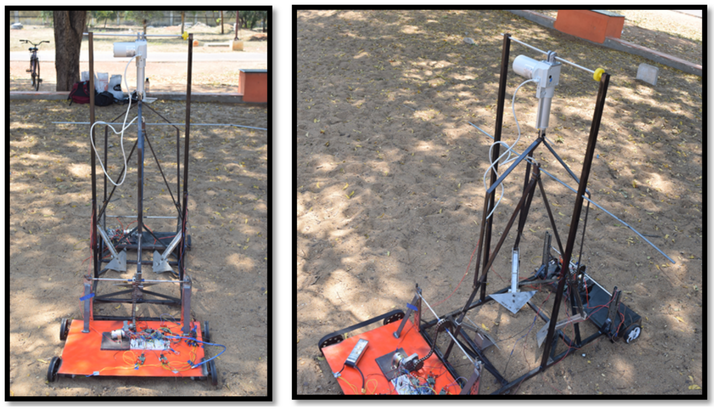


Fig. 9. Front view (left) and side view (right) of the working model of the proposed mechanism

overview of working of link assembly

The force from the linear actuator is split into three by using a fan like assembly that has three links placed at an angle of 120 degrees to each other. This system transfers the force to the links joined to the spade via a simple slider (or prism joint). Both connection of the links and connection of the link to the spade are hinge joints as indicated in figure 6, allowing the spade to move in a rough tangent to a curve of radius 'R' into the soil. Once the linear actuator has reached it's maximum extension length, another interrupt triggers the forklift mechanism.

After digging the orientation of the mechanism is as depicted in figure 8

F. Fork lift Mechanism

Once the pyramid is formed, the linear actuator stops on reaching its maximum limit, thus triggering the fork lift mechanism using which the entire link assembly is lifted above the ground to the height of the chassis. This ensures that the spades remove the landmine from the ground while remaining in their triangular pyramid formation.

Based on the above discussed mechanism, the implementation was done using high grade steel for the chassis and steel for the spades and link assembly. The final working model is as depicted in the figure 9.

VII. CONCLUSION

The presented design and implementation of a semi-autonomous landmine detection and removal robot aims to improve deminer safety through the use of efficient, reliable and cost effective mine detection equipment with minimum environmental impact. The choice of IR thermography for detection, eliminates many shortcomings faced by GPR and

US sensors and reduces pre-processing needs. The robot requires minimum technical knowledge to operate and can be easily deployed in regions with abundant buried landmines.

In the existing idea for landmine detection and removal, some modifications can be implemented to improve its accuracy and reduce even the minimal human intervention. One such method would be to implement simultaneous localization and mapping (SLAM) to make the robot completely autonomous instead of controlling the robot from a safe distance.

Further, a mechanism to avoid traversal over the landmine can be added to the robot instead of just depending on it being light weight to avoid detonation of landmine while moving over it.

Another addition would be implementation of active IR thermography. This will improve the detection mechanism by strengthening the strength of the radiation from the landmine and also significantly reducing false alarms.

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