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An Investigation Of New Trends In Sensing For Controlling A Landmine Detection ROV

A. M. S. Abbas[1], T. A. Khalil[2]

[1]Department of Mechanical Engineering, Higher Technological Institute, Tenth of Ramadan City, Egypt
[2]Dept. of Mechanical Engineering, Shoubra Faculty of Engineering, Zagazig University, Egypt

Abstract :

Abstract- ROVs in today's modern society are playing a very pivotal role in many onshore and offshore operations by commercial, governmental and military users. A very important application of ROVs, particularly in Egypt, is the detection and demining of landmines laid out in vast areas of the Western Desert. Landmine detection is characterised by the high cost of conventional methods, the need for imported advanced technology, and the lack of clear accurate maps of landmine locations. The objective of this paper is to investigate new trends in sensing for controlling ROVs in terms of navigation and location with focus on the application in landmine detection. An early prototype of a landmine detection ROV has been developed to demonstrated the feasibility of the mechanical construction and reasoning control mechanism. Various alternatives of sensors used in navigation associated with ROVs are identified together with their applicability in the landmine detection prototype ROV. GPS is identified as an economical starting option for location of landmines.

Keywords - ROV, navigation sensors, landmine detection, ultrasonic sensor, laser guided sensor, GPS, artificial vision.

دراسة فى المحسات الحديثة المستخدمة فى التحكم فى مركبة اكتشاف الألغام

د/ أيمن صلاح الدين عباس　　　　د/ تامر عبد الفتاح خليل

الطرق التقليدية لاكتشاف الألغام ليست ذو كفاءة عالية في مصر نظرا للتكلفة العالية لاستيراد التقنية ولعدم وجود خرائط دقيقة لمعظم مواقع الألغام و حيث أن اتساع رقعة الأراضي المنزرعة وتنوع الألغام يعتبر عائقا كبيرا في اكتشاف اللغم وتحديد مكانه ولهذا فإن المركبات ذات التحكم عن بعد لها استخدامها في اكتشاف وإزالة الألغام الأرضية. تم تصميم وتنفيذ النموذج الأولى للمركبة لرصد الطرق الحديثة في التحكم في توجيه وتحديد موقع المركبة عن طريق المجسات الحديثة وأيضا لدراسة جدوى التصميم الميكانيكي ودقة التعرف على اللغم. استخدم هذا النموذج في تجربة أربعة أنواع من المجسات الحديثة هي: التوجيه بالموجات فوق الصوتية، التوجيه بالليزر، تحديد المواقع بالقمر الصناعي، و الرؤية الاصطناعي ، و تمت دراسة و تطبيق هذه المجسات الأربع في المركبة الأولية لتحديد موقع لغم، و اتضح من واقع هذه الدراسه أن نظام تحديد المواقع بالقمر الصناعي هو بداية جيدة للتجربة الأشمل وذلك من حيث الدقة مقابل الجدوى الاقتصادية.

I. INTRODUCTION

A Remotely Operated Vehicle (ROV) is a mobile robot which is operated and controlled by an operator in a safe and comfortable environment while the ROV works in a difficult or hazardous environment. ROVs have varying forms and sizes starting from small vehicle equipped with simple sensors for observation, up to complex work systems equipped with several dextrous manipulators.

A typical ROV system is composed of four components; the vehicle, the launch system, sensors, and data communication. The vehicle is the main part responsible for motion of the ROV. The launch system is in charge of the actuation and power of the vehicle while sensors are in charge of data collection. The fourth component, which is data collection, whether wired or wirelesses, is responsible for carrying control signals, status and sensory data between the vehicle and the human operator.

II. ROV OPERATIONS

ROVs in today's modern society are playing a very pivotal role in many onshore and offshore operations by commercial, governmental and military users. There are many practical applications of ROVs that have made significant contributions to the acceleration of the technical development of our world. One of the most important and hazardous operations of ROVs is in nuclear power generation plants. The ROV is used to inspect and repair the inside of the nuclear reactor. To conduct such a task without the use of an ROV is practically impossible.

Another major operation of ROVs is the exploration of minerals in remote geographical locations such as deserts, mountains or deep seas and oceans. In a country with vast deserts and a long coastline, an ROV equipped with appropriate sensors and probes could be used for exploration and location of petroleum and other minerals deep underground or under the seabed. Related to this, is the extensive operation of ROVs in the oil and gas industry [1]. The ROV is used in platform and pipeline inspection, drilling and construction support as well as sub sea installation and repair.

A related area of ROV operation is in the field of land surveying. An ROV equipped with suitable probes is used to mark and plot lands in new areas marked for urban or agricultural development. It may also be used to accurately control the directional navigation of diggers during the construction of water canals and irrigation systems. Possible cases of particular interest in Egypt include; the South Valley Development project (Toshka and Ewaynat), and the Sinai Development project. In both projects an ROV equipped with appropriate advanced sensors can be used to accurately pinpoint the course of the irrigation canals during construction and to locate the drilling position of subterranean water wells.

Another application of ROVs is in the field of archaeological excavation either underwater or on land. Recently publicised cases include the discovery of Hellenic era monuments buried in the sea off the coast of the ancient port of Alexandria [2] and the excavation of the air vents in the King's chamber of the great Pyramid at Giza using an ROV [3].

Agricultural operations of ROVs have been well developed in recent years. This is due to the fact that automated mechanisation increases the productivity of farmland. Intensive farming is characterised by demanding manpower, repetitive tasks and accurate location in all phases of the farming process from marking fields to lining, seeding, harnessing and harvesting. An ROV have made significant contributions to all of these tasks [4,5,6,7].

Another very important application of ROVs, particularly in Egypt, is the detection and demining of landmines laid in vast areas of the Western Desert left over by the warring British and German armies during World War II. By some estimates some 20 million landmines are buried in the desert between Alexandria and the Libyan border [8]. These landmines are a major cause of death and handicap for many Bedouins living in these areas, especially young children. Landmine fields in these areas are a key obstacle in the economic development of North West Egypt due to the loss of potential reclaimed agricultural land. Unfortunately, any effort to remove these landmines is hindered by three problems. The first of these is the severe shortage of funds allocated to landmine detection and removal due to the extremely high cost of conventional methods. The second problem is the need for imported advanced technology for detection and location of these buried landmines. The final problem which is directly related to the two previous problems is the lack of clear accurate maps of landmine locations. In addition, natural elements during the many years since the end of the war have definitely relocated many of the landmines. Due to this particular problem, an ROV equipped with modern sensors and operated safely from a distance is a good target for a locally developed ROV.

In all of the mentioned operations, and indeed in many others, there is a need for an accurate and reliable control system. The control system is divided into three components; the mechanical structure, the reasoning mechanism, and the sensors. The mechanical structure is the hardware of the ROV responsible for generation of motive power for operation and navigation of the vehicle and manipulators and supporting all components of the ROV. It is in charge of tasks such as start-up of the ROV, driving and steering, and providing variable modes and speeds of motion. Most of these tasks are fully automated and are commercially exploited as in modern manufacturing plants and robotic assembly work cells. An initial prototype of a landmine detection ROV has been developed in order to evaluate the efficiency and viability of such an approach.

The second component of the ROV control system is the reasoning mechanism which is responsible for initiating action signals and receiving feedback control signals. Computer technology is the current standard manifestation of the reasoning mechanism. This technology is well studied and established and modern computerised control systems are very stable. Another advantage of digital computer control is that it allows the effective interfacing of the ROV drives and digital sensors with the computer technology. This component has been applied with a skeleton PC based computer control system in the initial prototype.

The final component of the control system is the attached sensors. The function of these sensors is to collect real time data about the ROV work environment. In the operation of a landmine detection ROV as a case study, a form of sensing which accurately locates landmines buried in the sand, clearly marks the location, and navigates around them, is required. It is this sensing task which is presented in detail for the developed prototype in this paper.

III. AIMS OF RESEARCH

The objective of this research is to investigate new trends in sensing for controlling ROVs in terms of navigation and location with focus on the application in landmine detection. The aims are:

- Investigating new modern trends in controlling mobile robots;
- Comparing between different trends and understanding the suitability of each trend
- Examining the applicability of trends locally in the Egyptian environment;
- Proposing a cost efficient design of a sensing unit based on modern technology which is affordable to developing countries;
- Applying this sensor choice to the landmine detection ROV.

IV. AN INITIAL ROV PROTOTYPE

An early prototype of a landmine detection ROV has been developed. The mechanical construction of the robot is based on a low bed triangular configuration. This aimed at lowering the centre of gravity of the ROV in order to improve it's stability on unlevelled landscapes and to reduce the complexity of the design. This structure also simplifies the steering mechanism required in the ROV. The chassis is made of hollow steel tubes in order to be rigid but relatively lightweight. Solid threaded rubber tyres are used to improve the grip on the desert terrain. A mine detection sensor is fitted at the front of the ROV and swivels in an included angle of 120o in order to provide a large coverage area. The layout of the first prototype is illustrated in fig1.

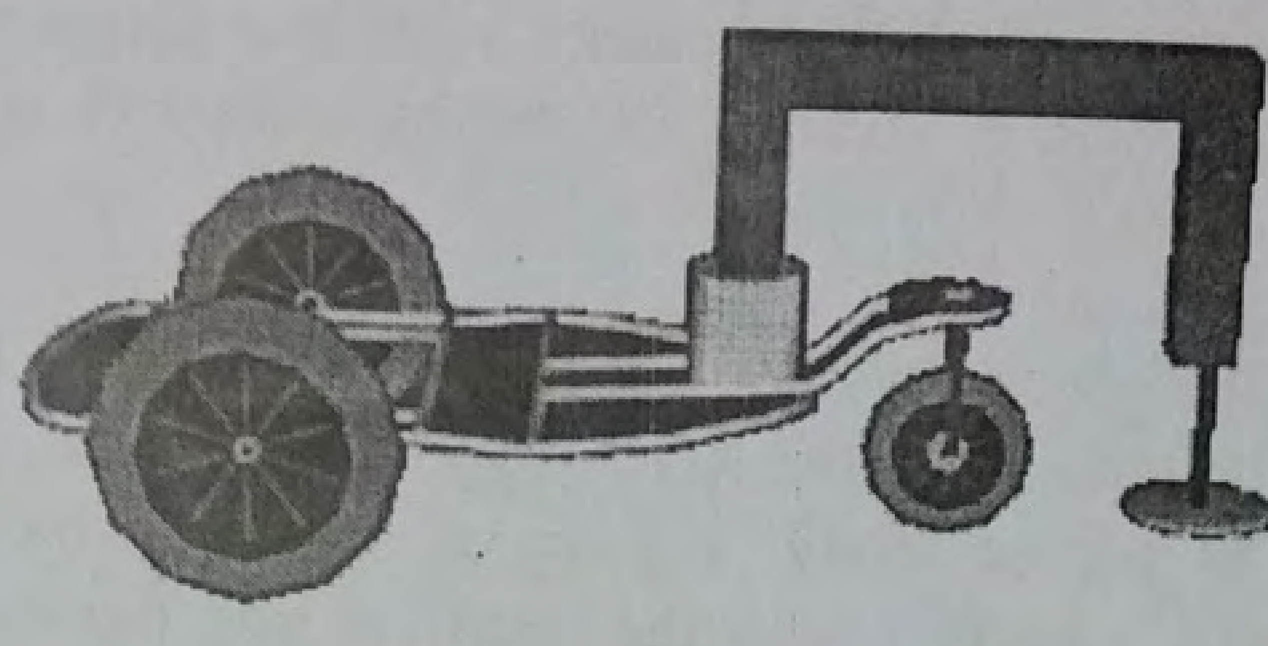

Fig. 1. General layout of the mechanical construction of the ROV prototype.

The reasoning mechanism of the early prototype ROV is based on a system of relays controlling the operation of the various drive motors in the ROV through signals generated by the software running on the PC fitted to the vehicle frame. It is this PC which also receives and interprets the feedback signals from the motors. The PC software is also in charge of activating the sensors fitted to the ROV and processing the return signal from them to precisely locate the position of the ROV thus marking the location of the buried landmine. The reasoning mechanism is illustrated in fig. 2.

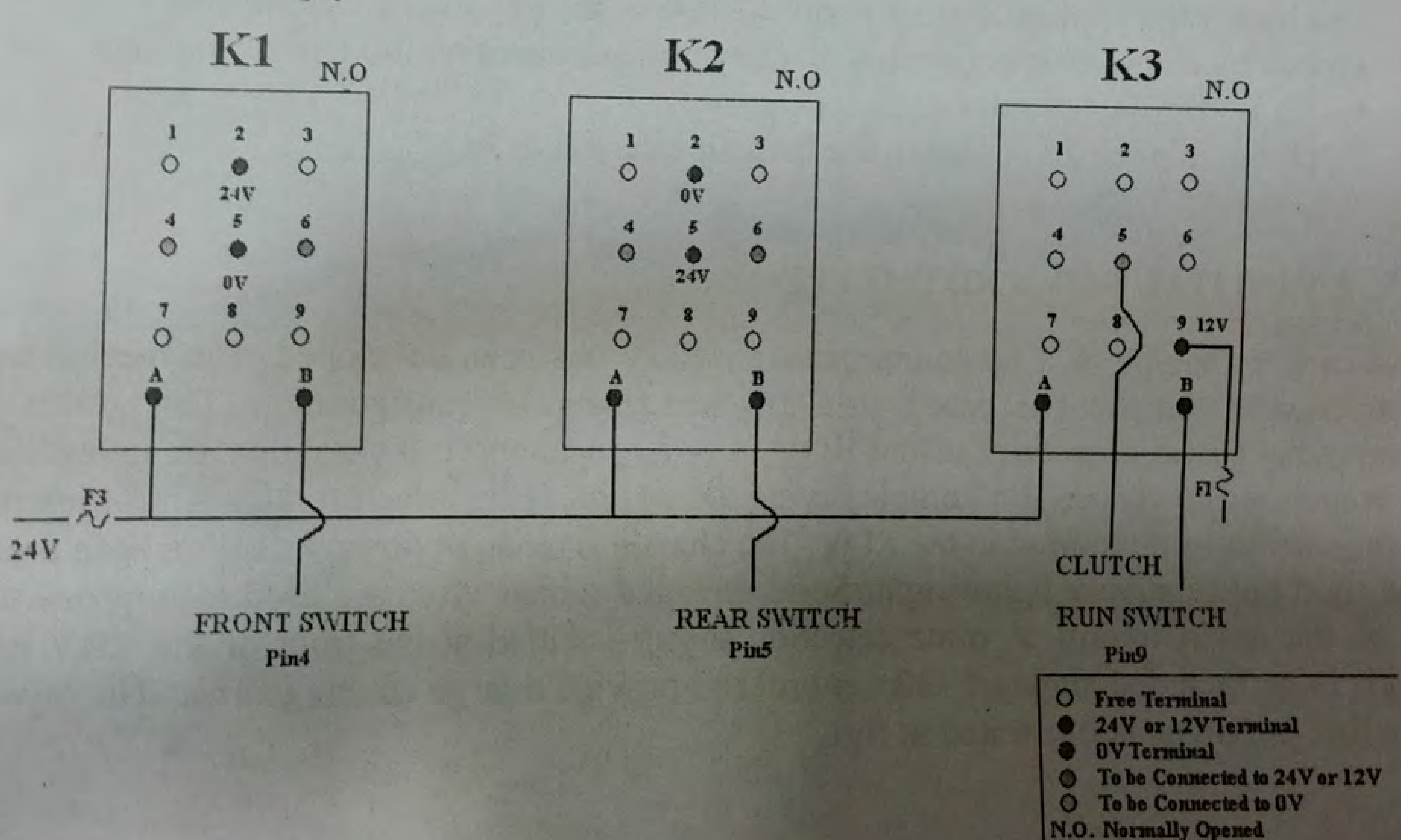

Fig. 2. Relay diagram for reasoning mechanism.

V. NEW TRENDS IN ROBOT SENSING

In this paper, we discuss the various alternatives of sensors used in navigation associated with ROVs. These sensors are classified into four categories:

- Ultrasonic sensors;
- Laser guided sensors;
- Global Positioning System;
- Artificial vision.

Each is discussed in detail as applied in the operation of an ROV. The advantages and disadvantages of each category are discussed together with the usability of the sensor. The suitable of each category for the developed landmine detection ROV is discussed.

1. Ultrasonic Sensors

Ultrasonic sensors are relatively simple and easy to interface with and are very suitable for robot applications. The working principle of the sensors is based on emission of a series of sound waves in a cone shaped pattern and waits for the returned echo reflecting off an object, fig. 3. The pulse is generated by an electrostatic or piezoelectric transducer which converts electrical energy to mechanical energy to sonic energy. The sensor measures the time interval between transmission and reception of the signal and converts it into a distance measurement based on the speed of sound. However, variations in the speed of sound due to environment elements such as wind speed and temperature, affect the accuracy of the sensor. Microprocessor technology compensates these factors into the calculation of the distance.

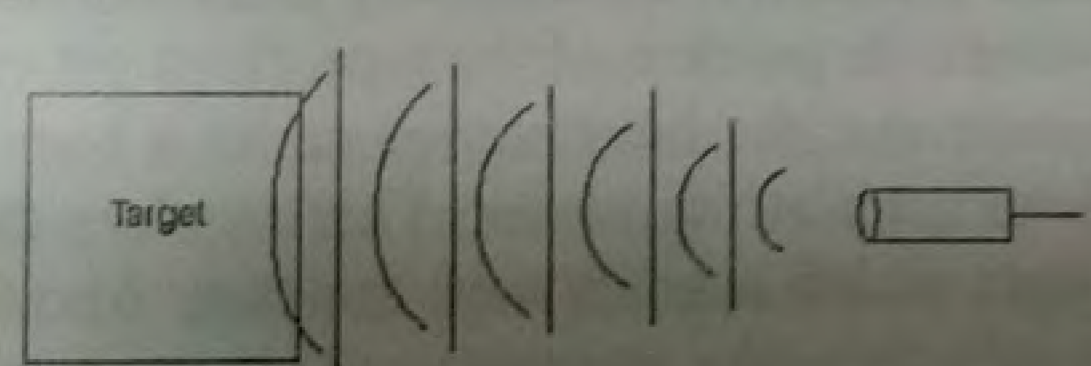

Fig. 3. Operation of an ultrasonic sensor.

Ultrasonic sensor technology provides many advantages over other sensing technologies. They may be used to measure the precise distance to both stationary and moving objects. They are not affected by target material, surface, colour or translucency.

They are also resistant to external disturbances such as vibration, radiation and ambient noise. Ultrasonic sensors function well in harsh environments as they are not affected by dust, dirt or high moisture. Another advantage is the fact that they are reliable sensors which require little or no maintenance.

On the other hand, ultrasonic technology has many drawbacks. The main limitation in the application of these sensors in the designed landmine detection robot is the relatively short range possible (up to 12 m). Also, since the pulse emitted is cone shaped, any encountered object will return an echo signal to the sensor which may cause a misleading location, in particular in the case of a detection ROV which is required to locate a landmine precisely. Also ultrasonic sensors are not capable of uniquely identifying object types, although this issue may be addressed by using multiple or rotating sensors. The final limitation of ultrasonic sensors is that they usually fail in detecting openings and channels but this may not be relevant in the context of the developed landmine detection robot.

2. Laser Guided Sensors

Laser guided systems were introduced in the early 1980's. These systems are based on target triangulation to keep the vehicles on course. The vehicle is equipped with a laser beacon mounted at the front of the vehicle and at a suitable height. This beacon scans around the vehicle for laser targets mounted on fixed reflective objects. The reflections from these targets are measured relative to angles from the vehicle and triangulated to allow the vehicle to determine its position. The target objects are typically located at equidistant from each other, on both sides of the path to provide sufficient navigation resolution, fig. 4. Laser navigation accuracy is in the order of 2 cm.

There are many types of laser guided sensors. The most simple is the stationary linear beam in which the laser is transmitted in a fixed straight line. It is usually used in assembly and packing lines in automated factories. The second type of laser sensors is the rotating beam in which the laser beam follows a scanning angular trajectory. This type is usually used in military applications. Regardless of the type, the most common configuration of the laser guided sensor is such that the laser source emits a beam which is reflected off the target object and received back at the sensor. This requires that the surface of the target object be reflective to light which is not always the case. Another configuration is to place the laser receiver separately from the transmitter. This configuration is not practical in an open-area environment for the application in a landmine detection ROV.

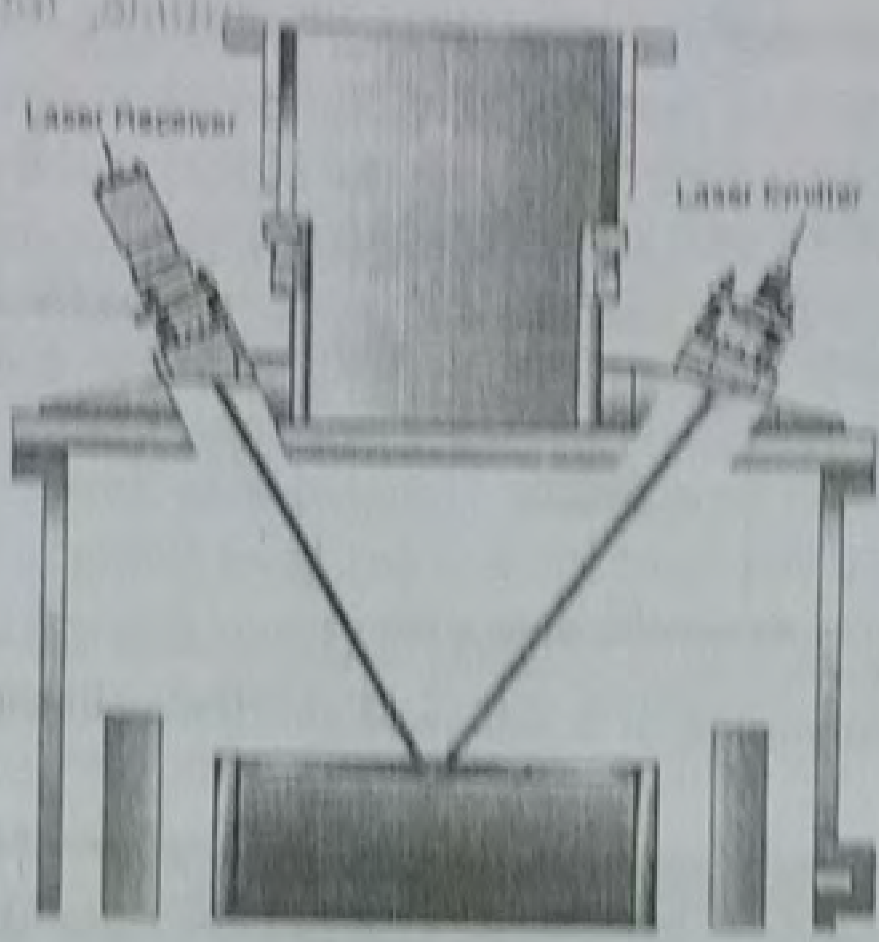

Fig. 4. Basic operation of a laser sensor.

3. Global Positioning System (GPS)

The Global Positioning System (GPS) is a constellation of 27 satellites (24 active and 3 standby) orbiting the earth at an altitude of 19,300 km setup by the US military. The orbits are arranged so that at any given time anywhere on earth, there are at least four satellites visible in the sky. Each satellite completes its orbit in 12 hours. A GPS receiver is used to determine the exact location on earth in terms of longitude, latitude and altitude. The receiver does this by attempting to locate the four current satellites in view and calculates the distance to each, using this information to deduce its own location. This operation is based on a mathematical principle called trilliteration. In order to apply this principle, the location of each satellite and the distance from the receiver to each must be known. Each satellite transmits a pseudo-random code which is picked up and matched by the GPS receiver with a lag time. Using the speed of light, the receiver converts the lag time into the distance from the receiver to the satellite, fig. 5. This process is repeated with each of the maximum four satellites in view. The receiver clock is constantly resynchronised with the satellite atomic clocks in order to maintain accuracy. The location of each of the maximum four satellites at a given time is extracted from an almanac of all GPS satellite locations at all times stored in the GPS receivers. The culmination of applying the trilliteration principle is that the GPS receiver accurately determines the latitude, longitude and altitude at its current location, fig. 6.

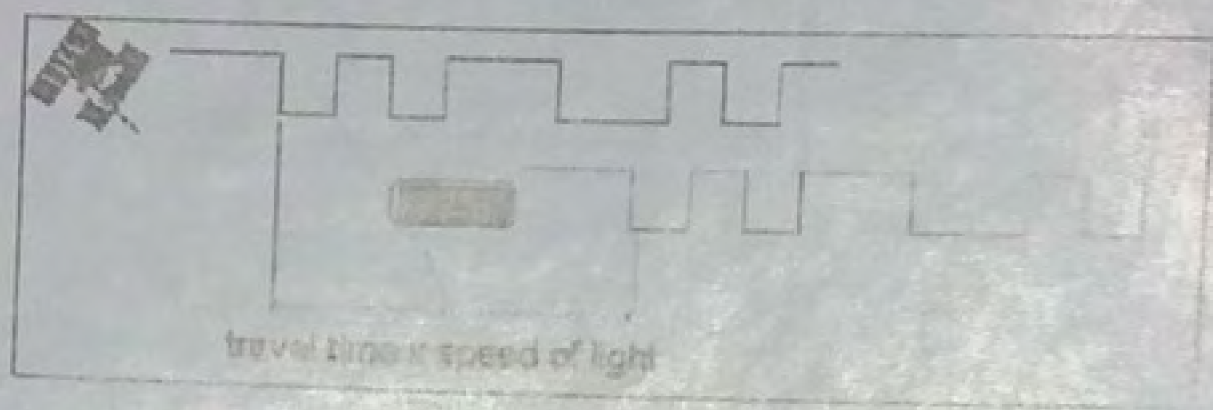

Fig. 5. Determination of distance between GPS satellite and receiver.

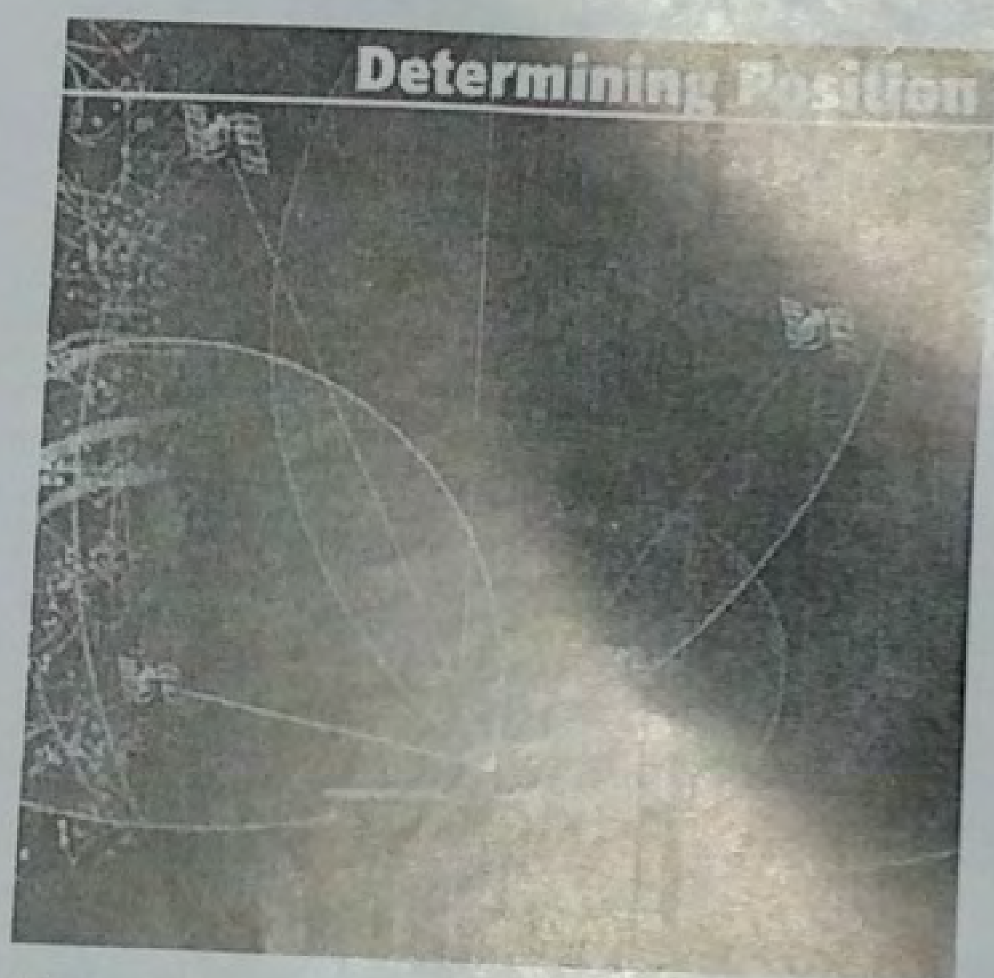

Fig. 6. Determination of location using GPS

Although the GPS system was originally intended, designed and implemented for US military applications, the US has allowed the free use of the GPS data for civilian application fields with less accuracy. These applications include aviation, maritime navigation, surveying and recreation.

The use of a GPS receiver in the landmine detection ROV has many advantages. The most apparent of these is the inexpensive cost of using the technology. The average cost if a receiver is $100 with no other costs involved as the high capital cost of initially installing the system and maintaining it is incurred by the US military. The accuracy of the system for civilian use has improved immensely since the discontinuity of Selective Availability [9] in May 2000 (currently about 10 m). Its accuracy is relative which means that all identified points may be referenced to a calibrated reference point. On the other hand, GPS systems have some drawbacks. The most important is that receivers can be used outdoors only and in a clear view of the sky as the radio signals transmitted from the satellites are of low energy. Also, the accuracy attained from the system may not be enough for the landmine detection application. Experimental work needs to be done to evaluate the usability of the achieved accuracy. With the introduction of the European Galileo project and its full operation in 2008 [10], competition in this type of sensing will definitely benefit civilian use.

4. Artificial Vision

The technology of artificial vision is based on using video cameras and computers to simulate human vision. An artificial vision system incorporates three components; an image acquisition device, the interface, and the image processing software. The image acquisition device may be one or more (in case of stereo vision) conventional video cameras, or more recently, digital video cameras responsible of capturing the image data within the scope of vision. If the ROV is to be used in badly illuminated environments, an infrared night vision camera may be used. The interface device is responsible for conversion of image data into a digital format usable by the image processing software. The image processing software is the component which processes the image data and deduces useful information to be utilised in pattern recognition of terrain navigation. The principle of operation is illustrated in fig. 7.

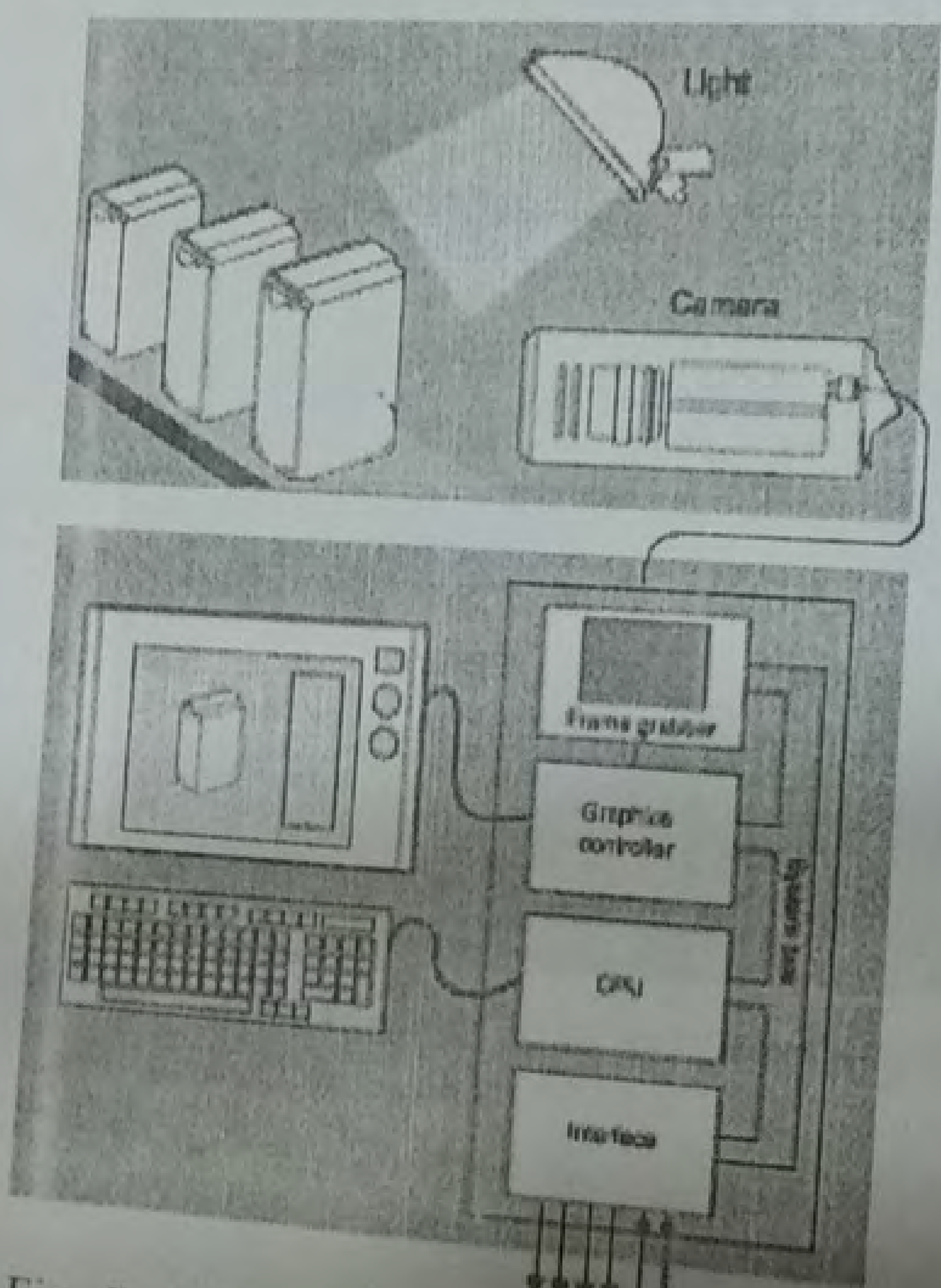

Fig. 7. Artificial vision operation diagram.

Conventional artificial vision systems lack the accuracy of modern developments in image capturing and processing. They do not convey the full features of the objects as they merely condense the image onto a 2D or 3D matrix based on a predefined threshold of light intensity. On the other hand, modern artificial vision systems are capable of capturing and analysing full features of the objects met and their surroundings. Appropriate hardware, together with advanced software, is sensitive to additional features such as colour, shading, texture, focus and motion. This is particularly useful in the application of artificial vision in ROVs.

The use of artificial vision as a sensor in an ROV has many advantages. The most clear is that the technology is equally usable both indoors and outdoors with the same accuracy and reliability. Also the accuracy of the technology is guaranteed if object pattern recognition and matching techniques are used based on prior storing of these patterns. Finally, advanced artificial vision technology allows the vehicle to sense and navigate 3D terrains which is very useful in the detection of landmines and navigation in a constantly shifting desert terrain. Artificial vision has proved its success in the guidance system of inter ballistic missiles. On the other hand, this technology as applied in ROVs has many limitations. The most understandable of these is the high capital cost of artificial vision systems including hardware and software. Secondly, image processing software carries out a highly mathematical modelling process which requires extensive computational processing power which is not normally attainable in an economical ROV. Also, it is common that a misinterpretation of the captured image occurs due to out-of-context processing of the data. Another disadvantage is the abstraction of location in space without focusing upon details of the wider surroundings. Finally, artificial vision suffers from the segmentation phenomenon. That is, the image processing software is ambiguous about which pieces of neighbouring images should be recognised as such [11]. This is a very important issue in the location of points of reference in an open-air landscape where no obvious landmark features are present which is the case of ROV operation in the vast Egyptian Western Desert.

VI. DISCUSSION

The study of available sensors for controlling the navigation of a landmine detection ROV has revealed the existence of four types of new technologically advanced trends. Each of them has its advantages and disadvantages when applied in the prototype ROV. All of them provide an acceptable level of accuracy for the required application with good reliability. Also, the four categories of sensors provide location data which allows the ROV to determine its location on the ground and thus improves navigation. All of the sensors are easy to implement and interface with the existing mechanical structure of the initial prototype ROV and the developed computer reasoning mechanism. The ultrasonic sensor provides an accurate location with a relatively cheap and simple to interface method but is disadvantaged with its limited work range. On the other hand, laser guided systems with their long range of measurement, are not practical in the landmine detection ROV due to the need to install a transmitter/receiver configuration. This is not possible in a vast open-area like deserts. Also, laser emitting devices are classified according to their power. High classes are difficult to attain and are very expensive. Artificial vision may be a good choice for navigational sensing unit but is disadvantaged by the possibility of misinterpretation of the sensed data. A GPS based system is an excellent and cost efficient choice compared to the other sensors which require high capital cost. Unfortunately, it works only outdoors and its accuracy currently is less than the other methods. At this initial stage of research, the GPS approach with be adopted to illustrate the concepts involved in sensing location and navigation. The limitations of the approach can be tackled at a latter stage of research by using a combination of sensor types simultaneously to improve precision and reliability [12]. Fixed landmarks as reference points can also be used to improve location accuracy.

Several of the sensors have been successfully used in recently publicised projects. During the construction of the Cairo Underground Line 2 in Egypt, the bored sections of the tunnel were dug using two tunnel boring machines starting at both ends of the tunnel. A computerised guidance system supported by laser guides was used for alignment control until the two machines met [13]. Also in the field of tunnelling, the two machines used to bore the Channel Tunnel between Britain and France also used computerised laser guidance systems in addition to radar waves to keep the machines at course [14]. Even in space, the Mars surface rover, Sojourner, included special artificial vision sensors to investigate and relay the first ever images of the Martian terrain to reach earth [15].

Each of these cases implemented off-the-shelf effective and efficient sensors. The investigation presented in this paper has highlighted the availability and practicality of these sensors. The study has indicated that the GPS approach can be a good starting point for implementation in the next phase of the landmine detection ROV.

VII. CONCLUSION

Based on the work presented in this paper, we conclude the following:

- The need for an accurate and reliable sensing unit for a landmine detection ROV is presented;
- Four new trends in sensing for controlling ROVs have been identified;
- These trends have been described together with their advantages and disadvantages as applied to the landmine detection ROV;
- The GPS approach to sensing has been selected as the most cost efficient method able of achieving an accurate determination of landmine locations using an ROV;
- A preliminary description of a GPS based sensing unit for the ROV is proposed.

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