Design and Control of a Manipulator for Landmine Detection

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Summary. Antipersonnel mines infest fields all over the world. According to recent estimates, landmines are killing and maiming more than 2,000 innocent civilians per month [1]. The problem of landmine detection and removal requires the co-operation of various engineering fields. For this purpose, new technologies such as improved sensors, efficient manipulators and mobile robots are needed. This paper describes the configuration and control architecture of a scanning manipulator to detect antipersonnel landmines. The main features of the system that consists of a sensor head able to detect some kind of landmines and a manipulator to move the sensor head over large areas, conveniently sensorized to scan irregular terrains in the presence of obstacles are presented. Experiments show the performance of the whole system.

1 Introduction

Detection and removal of antipersonnel landmines is a serious problem of today. There is a real need to solve it, and solutions are being explored in different engineering fields. The finest solution is to apply fully automatic systems to this relevant task. However, this solution seems to be still very far away from succeeding. Efficient sensors and detectors are required to detect and, if possible, identify different mines.

Based on previous experience in robotics, the IAI-CSIC has configured the DYLEMA system based on a legged robot for detection and location of landmines (see Fig. 1) [2, 3]. DYLEMA is a Spanish acronym that means: Efficient Detection and Location of Antipersonnel Landmines. The main aim of this project is to develop a whole system to integrate relevant technologies in the fields of legged locomotion and sensor systems in order to identify the needs of this integration for humanitarian demining activities. This paper presents the on going results about the scanning manipulator carried by the walking robot. Section 2 describes the configuration of the manipulator and its sensor head. Section 3 presents the control architecture of the scanning manipulator

Fig. 1. DYLEMA demining system

based on sensor information and finally, some remarks and conclusions are given in Section 4.

2 Description of the Scanning Manipulator

The scanning system is intended to detect antipersonnel landmines while a mobile robot traverses the infected area and is broken down into the following subsystems illustrated in Fig. 2(a):

2.1 Sensor head

This subsystem contains a commercial mine detector and additional elements to detect the ground and objects in the way. The sensor head is configured to detect potential alarms, but also to allow the controller to maintain the sensor head at a given height above the ground using simple range sensors (infrared sensors coupled by pairs). Touch sensors are also provided to detect objects in the sensor head's trajectory. Figure 2(b) shows the sensor head.

2.2 Scanning manipulator

The commercial mine detector is basically a local sensor. That means it is able to sense just one point. The efficiency of such a device can be improved

Fig. 2. Scanning system: a) Scanning manipulator; b) Sensor head

Fig. 3. The scanning-manipulator control architecture

by sweeping the sensor head through a large area. The simplest way to do this is by using a manipulator. Therefore, a 5-DOF manipulator is used to move the sensor head and to adapt the sensor head to terrain irregularities (see Fig. 2(a)).

3 Control Architecture

The scanning manipulator has to be controlled to seek for buried mines. The control architecture of the manipulator is shown in Fig. 3.

The manipulator-control architecture is a deliberative/reactive hybrid. Apart from the basic joint controller, three modules govern manipulator motion, which are:

The sweep-trajectory generator: This is the deliberative module that generates the sweep trajectory to ensure complete coverage of the swept area.

The object-contour tracer: This is a reactive module that moves the sensor head around an obstacle using information from the bumper.

The ground-surface tracer: This is a reactive module that keeps the detector head at a constant distance from the ground, controlling its attitude as well.

3.1 Sweep-Trajectory Generator

The sweep-trajectory generator calculates the trajectory of the sensor head that ensures the complete coverage of the swept area. This is done by means of a crossed sweep, explained below.

The crossed sweep is the most efficient way to scan for buried mines. It avoids overlapping scanned areas while ensuring complete coverage. The sensor-head trajectory referred to the manipulator's base reference frame is depicted in Fig. 4(a). It scans an area that covers the width of the mobile robot that carries it ($2y_d$) and a length of x_d along the x -axis. To coordinate the manipulator's motion with the walking robot's motion, certain conditions must be met:

- The walking robot moves along the x' axis in an external reference frame $\{x', y'\}$ at a constant speed of v_{CG} . The external reference frame is centered initially at the robot's CG position, and the x' axis lies along the robot's longitudinal axis.
- The crossed-manipulation motion, combined with the CG robot motion, results in zig-zag trajectories parallel to the x' and y' axis as Fig. 4(b) shows.
- The complete crossed manipulator's motion takes place in a walking-robot gait-cycle time (T_c).

Fig. 4. Crossed-sweep trajectory: a) In the manipulator's reference frame; b) In the external reference frame

To accomplish the first and second conditions, the diagonal span of the manipulator trajectory from P_1 to P_2 (see Fig. 4(a)) needs to travel back the same distance x_d traveled by the robot in the same interval $(t_2 - t_1)$, where t_i is the time at when P_i is reached (for $i = 1..4$), that is:

$$x_d = v_{CG}(t_2 - t_1). \quad (1)$$

To accomplish the third condition, the time interval of each trajectory span needs to be a fraction of the robot's cycle time. Additionally, to ensure complete coverage of the swept area, the distance from P'_0 to P'_1 has to equal the sensor head's diameter. So we have to determine the time intervals of the trajectory spans so that:

$$Dist(P'_0, P'_1) = D, \quad (2)$$

where D is the sensor head's diameter. Let us name $T_1 = t_1 - t_0$ and $T_2 = t_2 - t_1$. Let us also name d_R the distance traveled by the walking robot during T_1 and d_M the distance traveled by the manipulator during T_1 . The problem equations are:

$$x_d = v_{CG}T_2 \quad (3)$$

$$D = d_R + d_M \quad (4)$$

$$T_c = 2(T_1 + T_2) \quad (5)$$

As a solution of this system of equations, we finally obtain the time intervals T_1 and T_2 that assure complete coverage of the scanned area:

$$T_1 = \left(1 - \frac{x_d}{D}\right) \frac{T_c}{2} \quad (6)$$

$$T_2 = \frac{x_d}{D} \frac{T_c}{2}. \quad (7)$$

Now, the manipulator trajectory can be described in four steps, starting at $P_0 \equiv (0, -y_d)$:

Step 1: Linear trajectory from $P_0 \equiv (0, -y_d)$ to $P_1 \equiv (x_d, -y_d)$ in the x -direction, that is

$$x = \frac{x_d}{T_1}(t - t_0); \quad y = -y_d. \quad (8)$$

Step 2: Linear trajectory from $P_1 \equiv (x_d, -y_d)$ to $P_2 \equiv (0, y_d)$ such that

$$x = x_d - \frac{x_d}{T_2}(t - t_1); \quad y = -y_d + \frac{2y_d}{T_2}(t - t_1). \quad (9)$$

Step 3: Linear trajectory from $P_2 \equiv (0, y_d)$ to $P_3 \equiv (x_d, y_d)$ in the x -direction, that is

$$x = \frac{x_d}{T_1}(t - t_2); \quad y = y_d. \quad (10)$$

Fig. 5. Scanned area in the external reference frame using (a) a circular sweep; (b) a crossed sweep

Fig. 6. Experimental obstacle detection

Step 4: Linear trajectory from $P_3 \equiv (x_d, y_d)$ to $P_0 \equiv (0, -y_d)$ such that

$$x = x_d - \frac{x_d}{T_2}(t - t_3); \quad y = y_d - \frac{2y_d}{T_2}(t - t_3). \quad (11)$$

This crossed-manipulation motion, combined with the CG robot motion, results in zig-zag trajectories parallel to the robot's x' and y' axes in the external reference frame as Fig. 4(b) shows. The crossed-sweep trajectory is generated as a function of the speed of the walking robot's CG (v_{CG}), and one crossed sweep is performed per robot cycle. To show the advantages of applying the proposed sweep motion, a comparison between a circular sweep and a crossed sweep has been performed. Figure 5(a) shows the experimental results of applying a complete-coverage circular sweep and compares it with

the results of applying the crossed sweep (Fig. 5(b)) using the SILO6 robot. The dotted line shows the trajectory of the sensor head's base center, while solid lines depict the total scanned area. As can be observed, in order to obtain complete coverage with a circular sweep, overlapping areas must exist (shaded areas in Fig. 5(a)), which make the method inefficient. However, the crossed sweep generates complete-coverage trajectories without overlapping areas and is therefore demonstrated to be an efficient scanning method.

3.2 Object-Contour Tracer

An array of 12 bumpers around the sensor head detects obstacles in the mine field (see Fig. 6). This is done by moving the manipulator such that the bumper constantly detects the obstacle while the x coordinate (in the field reference frame) of the manipulator position varies. This module and the sweep-trajectory generator are mutually exclusive; that is, only one of them can be active at a time.

3.3 Ground-Surface Tracer

While performing a crossed-sweep motion, the sensor head adapts to the terrain profile reactively. Three range sensors arrayed at 120° -degree intervals around the sensor head (see Fig. 7) measure the sensor-head distance and orientation to the ground. The ground-surface tracer computes the error from the desired distance and orientation and modifies the reference trajectory to compensate for it.

4 Conclusions

Human operators handling manual equipment are, at present, detecting and locating antipersonnel landmines. However, human community can obtain many benefits by the robotization of this activity. New sensors are required in order to detect landmines efficiently, but existing sensors can be carried by robots over infested fields.

This paper addresses the development of a manipulator able to scan areas with a sensor head based on a metal detector and other sensors required to scan irregular ground in the presence of obstacles. The scanning system has been described and the control architecture has been presented. This architecture allows the manipulator to adapt to terrain irregularities and avoiding obstacles in a reactive manner. A new sweep method enabling the scanning manipulator to search efficiently for buried mines has also been proposed. The improvement obtained with the crossed-sweep algorithm has been proved experimentally.

The scanning manipulator will contribute to the autonomous antipersonnel-landmine detection process.

Fig. 7. Experimental ground adaptation

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References

1. P. Kopacek, "Demining robots: A tool for international stability," in *15th Triennial World Congress IFAC*, 2002, pp. 1–5, Barcelona, Spain.
2. E. Garcia, J. Estremera, and P. Gonzalez de Santos, "A control architecture for humanitarian-demining legged robots," in *Proc. Int. Conf. Climbing and Walking Robots*, September 2003, pp. 383–390, Catania, Italy.
3. P. Gonzalez de Santos, E. Garcia, J.A. Cobano, and A. Ramirez, "Silo6: A six-legged robot for humanitarian de-mining tasks," in *10th International Symposium on Robotics and Applications, World Automation Congress*, June 2004, Seville, Spain.