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SILO6: A Six-Legged Robot For Humanitarian De-Mining Tasks

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ABSTRACT

Detection and removal of antipersonnel landmines in infested fields is an important worldwide problem. Around 100 million landmines have been deployed over the last two decades, and demining will take several more decades, even if no more mines were deployed in future. A high mine-clearance rate can only be accomplished by using new technologies such as improved sensors, efficient manipulators and mobile robots. This paper presents some basic ideas on the configuration and controller of a mobile system for detecting and locating antipersonnel landmines in an efficient and effective way. The whole system has been configured to work in a semi-autonomous mode with a view also to robot mobility and energy efficiency. The paper outlines the main features of the overall system and focuses on some aspects of the controller.

1. INTRODUCTION

Full clearance of antipersonnel-landmine infested fields is at present a serious political, economic, environmental and humanitarian problem. Politicians have shown a real interest in solving this problem, and solutions are being studied in different engineering fields. The best solution, albeit perhaps not the quickest, would be to apply a fully automatic system to solve this problem. However, any such solution still appears to remain a long way from succeeding. First of all, efficient sensors, detectors and positioning systems would be needed to detect, locate and, if possible, identify different mines. Then, adequate vehicles would have to be provided to carry the sensors over the infested fields.

There are many potential vehicles that can carry sensors over infested fields; wheeled, tracked and even legged vehicles can accomplish demining tasks effectively. Wheeled robots are the simplest and cheapest, and tracked robots are very good for moving over almost all kinds of terrain, but legged robots also exhibit interesting potential advantages in demining [2].

The idea of using legged mechanisms for humanitarian demining has been under development for at least the last five years, and some prototypes have been already tested. TITAN VIII, a four-legged robot developed for general purposes at the Tokyo Institute of Technology, Japan [4], was one of the first walking robots adapted for demining tasks. AMRU-2, an electropneumatic hexapod developed by the Free University of Brussels and the Royal Military Academy, Belgium [1] is one more example of walking robots used as test beds for humanitarian demining tasks. COMET-1 was perhaps the first legged robot developed on purpose for demining tasks [7]. It is a six-legged robot developed by a Japanese consortium, and it incorporates different sensors and location systems. The COMET team is currently engaged in developing the third version of its robot [5]. These four robots are based on insect configurations, but there are also different legged robot configurations, such as sliding-frame systems, being tested as humanitarian demining robots [3]. To sum up, there is a great amount of activity in developing walking robots for this specific application field.

The IAI-CSIC holds experience in the design, development and control of walking robots, gait generation, terrain adaptation, robot teleoperation, collaborative control and other fields. All these technologies are mature enough to be merged in order to produce efficient robotic systems. This paper, thus, presents the SILO6 walking robot's ongoing results under development at IAI-CSIC, which has been configure on purpose for demining tasks.

2. SYSTEM DESCRIPTION AND MAIN REQUIREMENTS

The SILO6 whole system has been configured with the aim of putting together different subsystem. These subsystems are (see Figure 1):

- 1. **Sensor head**. The sensor head is configured to detect potential alarms but also to allow the controller to maintain the sensor head at a given height over the ground using simple range sensors. It is based in a commercial metal detector (see Figure 2).
- 2. **Scanning manipulator**. The sensor head is basically a local sensor and so the system needs to use a manipulator to move the sensor head and to adapt it to terrain irregularities (see Figure 2).
- 3. Locator. After detecting a suspect object, the system has to mark the object's exact location in a database for subsequent analysis and deactivation. We considered that an accuracy of about ± 2 centimetres is adequate for locating landmines. This accuracy can be obtained with commercial systems such as DGPS (Differential Global Positioning Systems).
- 4. **Mobile robot**. A mobile platform to carry the different subsystems across infected fields is of vital importance for thorough demining. In our case, the platform is based on a legged robot. The following requirements are the starting point for configuring the walking robot:
- The legged robot was based on a hexapod configuration. Section 3 explains why this choice was made.



Figure 1. DYLEMA system

being balanced through detailed design.

5. **Controller**. The global control system will be distributed into two main computers, the onboard computer and the operator station. The onboard computer is in charge of controlling and co-ordinating the manipulator and leg joints, communicating with the DGPS, the detector and the operator station via radio Ethernet. The operator station is a remote computer in charge of defining the mobile robot's main task and managing the potential-alarm database.

Hence, the walking robot is to be configured as a six-legged autonomous robot carrying a scanning manipulator, which handles the sensor head. The system will be controlled through teleoperation and collaborative techniques. The sections below give an overall view of the robot's configuration.

• The legged robot should be lightweight enough to be handled by two adults. This requirement is important so the robot can be rescued from technical o logistic problems.

• The robot should be autonomous from the energy point of view. Tethers should be avoided.

• The robot should be semiautonomous from the control point of view. Thus, a remote operator should be in the loop to control the system through teleoperation and collaborative control.

The robot is being configured to optimise power consumption, mobility and stability. These are antagonistic conditions which are

3. WALKING ROBOT CONFIGURATION

Walking robots are intrinsically slow machines, and machine speed is well known to depend theoretically on the number of legs the machine has. Therefore, a hexapod can achieve higher speed than a quadruped, and a hexapod achieves its highest speed when using a wave gait with a duty factor of $\beta = 1/2$, that is, using alternating tripods [8]. Although stability is not the optimum when using alternating tripods, a hexapod configuration has been chosen just to try to increase the machine's speed.

3.1 Body structure

The main tasks of a walking robot's body are to support legs and to accommodate subsystems. Therefore, the body must be big enough to contain the required subsystems, such as an onboard computer, electronics, drivers, a DGPS and batteries.

"Alternating tripods" means that two non-adjacent legs on one side and the central leg on the opposite side alternate in supporting the robot. That means that, for a given foot position, the central leg in its support phase is carrying about half the robot's weight, whilst the two collateral legs in their support phase are carrying about one-fourth of the robot's weight. This is especially significant in traditional hexapod configurations, where legs are placed at the same distance from the longitudinal axis of the body. If the robot has similar legs, then the non-central legs will be over-sized, and to optimise the mechanism the central leg's design should differ from that of the rest of the legs. However, using just one leg design has many advantages in terms of design cost, replacements, modularity and so on. A satisfactory force distribution and homogenisation of the system can be accomplished by displacing the central leg a little bit from the longitudinal body axis. In this case the central legs support a lower weight and the corner legs increase their contribution in supporting the body (see [2] for further details).

3.2 Leg structure

Walking robots need leg configurations that provide just contact points with the ground, so a 3-DOF device is sufficient to accomplish motion. Legs have to be designed to be lightweight mechanisms and have to support the robot's weight. Therefore, the load carried by each leg is very heavy and must be supported with the leg in different configurations. A mammal configuration is the most efficient leg configuration from the energy point of view (lower torques are required). However, it is not very efficient in terms of stability. Insect-like legs seem to be more efficient stability-wise, but power consumption increases extraordinarily in an insect-like configuration. The idea is to provide a leg configuration that can accomplish its job with both stability and energy efficiency (a very important factor for



Figure 2. Scanning manipulator and sensor head



Figure 3. Leg configuration

outdoor mobile robots). Development has therefore been focused on a leg that can be used in both the mammal and the insect configuration.

Feet can be designed in two basic configurations, a ball fixed to the ankle or a flat sole with articulated passive joints. The first design is the simplest and can work for applications in loose terrain if the radius of the ball is big enough.

4. CONTROL SYSTEM

The control system is distributed between the operator station and the onboard controller. Both of them are based on PC-based computers (see Figure 1). The operator station runs under the Windows XP operating system, and the onboard controller (the robot's controller) runs under QNX, a UNIX-like real-time multitasking operating system. Communication between operator station and onboard computer is performed by radio Ethernet. The main hardware and software aspects are discussed below.

4.1 **Operator station**

The operator station consists of the following modules:

- 1. Man-machine interface.
- 2. Alarm database manager.
- 3. Station-robot communication.

4.1.1 Man-machine interface

This module is a Java-based program intended to fulfil three main requirements: (a) robotstate monitoring, (b) robot teleoperation and (c) task definition. The user will have the ability to govern robot motion remotely, with real-time visual information on what the robot is doing. The man-machine interface also allows the user to define the task, a process that involves the definition of mine-field features (field dimensions, roughness, etc.), robot path and autonomous navigation strategies.

4.1.2 Alarm-database manager

Each time the robot detects an alarm, the spatial position of the suspect object is stored in a relational database. This database will enable mines to be removed by a specialist team in a posterior step. The user can access every alarm location found in a given field of a given country. Field and available mine features are also stored.

4.1.3 Station-robot communication

Communication between the operator computer and the onboard computer is conducted by means of a radio Ethernet card. The operator computer runs under the Windows XP operating system, whilst the onboard controller runs under the QNX operating system. Because different operating systems are used. the communications protocol has to be compatible with any operating system. One such protocol is the TCP/IP (Transmission Control Protocol/Internet Protocol) used world-wide for Internet connection. A client-server architecture was chosen for inter-process communications, where the operator computer is the server and the onboard computer is the client.



Figure 4. SILO6 hardware architecture.



Figure 5. Software architecture

4.2 Onboard computer

4.2.1 Hardware architecture

The onboard controller is a distributed hierarchical system comprising a PCbased computer, a data-acquisition board and eight three-axis control boards based LM629 microcontrollers, on the interconnected through an ISA bus. The LM629 microcontrollers include digital PID filters provided with a trajectory generator used to execute closed-loop control for position and velocity in each joint. Every microcontroller commands a DC motor-joint driver based on the PWM technique. An analogue dataacquisition board is used to acquire sensorial data from the range of external equipment (sensors, locators, etc.). A radio Ethernet card is provided for network communication with the operator station. Additional electronic cards for interfacing with the detector are also provided, as well as communication with the DGPS systems via RS232. A general diagram of the SILO6 hardware architecture is shown in Figure 4.

4.2.2 Software architecture

The onboard computer is in charge of the walking robot's gait and trajectory generation, manipulator control, signal processing and communications, as well as coordination of the microcontrollers. These tasks are distributed in a software architecture that consists of layers developed on a bottom-up basis. These layers can be mainly divided into:

- Hardware interfaces: These layers contain the software drivers for both the walking robot and its manipulator.
- Axis-control layers: These layers control the individual joints for both the walking robot and its manipulator. Individual joints are controlled through a dedicated microcontroller, which runs a PID control algorithm.
- Leg control: This layer is in charge of coordinating all three joints in a leg to perform coordinated motions.
- Leg kinematics: This layer contains the direct and inverse kinematic functions of a leg.
- Trajectory control: This module is in charge of coordinating the simultaneous motion of all four legs to perform straight-line or circular motions.
- Stability module: This layer determines whether a given foot-position configuration is stable or not.
- Gait generator: This layer generates the sequence of leg lifting and foot placement to move the robot in a stable manner. Dynamic stability is guaranteed by the stability module. The SILO6 gait generator will be based on three gaits: a tripod gait, a spinning gait and a turning gait.
- Communications: This layer handles communications with the operator interface through radio Ethernet via the TCP/IP protocol.

- Manipulator kinematics: This layer is in charge of solving the manipulator kinematics.
- Equipment and sensor-data acquisition layer: This layer provides interfaces with external equipment.

Figure 5 diagrams the different software modules and their interconnections.

5. 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. There is international interest in eradicating landmines, and solutions are coming from new, emerging engineering fields.

New sensors are required in order to detect landmines efficiently, but existing sensors can be carried by mobile robots over infested fields. Legged locomotion provides many advantages for moving on natural terrain and appears to be a good solution for carrying mine sensors efficiently.

Some preliminary work has been done to study the potential of using walking robots for demining. This paper addresses the development of a walking robot endowed with a manipulator able to scan areas with a sensor head based on a metal detector. This paper introduces the main system and provides some details of the configuration of the walking robot and the manipulator, and it outlines the hardware and software architecture as well.

6. ACKNOWLEDGEMENT

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