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Walking Hexapod Robot in Disaster Recovery: Developing Algorithm for Terrain Negotiation and Navigation

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***Abstract*—**In modern day disaster recovery mission has become one of the top priorities in any natural disaster management regime. Smart autonomous robots may play a significant role in such missions, including search for life under earth quake hit rubbles, Tsunami hit islands, de-mining in war affected areas and many other such situations. In this paper current state of many walking robots are compared and advantages of hexapod systems against wheeled robots are described. In our research we have selected a hexapod spider robot; we are developing focusing mainly on efficient navigation method in different terrain using apposite gait of locomotion, which will make it faster and at the same time energy efficient to navigate and negotiate difficult terrain. This paper describes the method of terrain negotiation navigation in a hazardous field.

***Keywords*—**Walking robots, locomotion, hexapod robot, gait, hazardous field.

I. INTRODUCTION

THE catastrophic cyclone Sidr that wrecked havoc Bangladesh in 2007, tsunami hit most of the countries of Asia around Indian ocean in 2004, Katrina hit Arkansas in 2005, and the terrorist attacks on the World Trade Centers in 2001 are clear indication that we are not prepared for disaster recovery at all. In all cases the infrastructure could not withstand the fury of nature, even in the case of WTC the NYPD was not prepared for such gigantic task of rescue mission. The conventional reaction to such disaster is not adequate; a new paradigm shift is needed to address such calamities utilizing all resources at hand. Disaster recovery is defined to be the emergency response function which deals with the collapse of man made structures [1]. In any disaster either man made or due to Mother nature, the elementary tasks at hand are: (i) to reach the affected hazardous field (ii) find and get information about victims, and (iii) rescue as many of them as possible.

Hexapod robots can play significant role in disaster recovery mission. It is possible for robot to reach any hazardous field unlike who have limited mobility in such missions. Nowadays many legged and wheeled robots are involved in this mission [6]-[9]. In terms of hazardous field navigation for disaster recovery mission, hexapod robots have advantages over wheeled robots. Given sufficient intelligence hexapod robots may discover and negotiate any kind of terrain over wheeled robot.

Wheeled robots are the simplest and cheapest and tracked robots are very good for moving, but not over almost all kinds of terrain. Many manned wheeled vehicles [6] and [7] or robotic systems [8] and [9] have already been tested. Navigate over obstacles and ditches and even on stairs is one of the foremost advantages legged robots hold over their wheeled or tracked counterparts. It shows that legged robots can operate in both even and rough terrain. The hexapod provides additional degrees-of-freedom for the robot's sensors and onboard equipment. Some general-purpose robots were tested for this application at the first but nowadays specific prototypes developing special features are being built and tested. The TITAN VIII walking robot, a four-legged robot developed as a general-purpose walking robot at the Tokyo Institute of Technology, Japan [10]. COMET-I is maybe the first legged robot purposefully developed for rescue missions. It is a six-legged robot developed at Chiba University, Japan, and incorporates different sensors and location systems [11] and [12]. This robot weights about 120 kg and results very heavy for real search and rescue missions. The Chiba University group has developed the fourth version of this robot, COMET-IV, which weighs about one ton. ARIEL is another hexapod robot, developed by the robots Company, for mine-recovery operations. The Defense Advanced Research Projects Agency (DARPA) and the US Office of Naval Research (ONR) are exploring methods for using this robot for underwater missions [13]. This robot uses six 2-DOF legs with limited mobility to perform omni directional motions. The legged robots working group at the Industrial Automation Institute (IAI-CSIC) has long experience in the development of walking robots [14], [15] and [16] and since 1999 it has been working on the application of the RIMHO-2 walking robot for detecting and locating unexploded ordnance. The hexapod robot could be used in agricultural field also, though wheel robots already are being existed in this field [17]. But the wheel robot can move only directed even terrain. In this case hexapod robot can navigate even and uneven terrain. In this navigation the hexapod consider the gait of locomotion for

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terrain negotiation, to avoid to place legs on uneven terrain, the proposed gaits are adaptive gaits [2], FTL gaits [3], graph search method [4], free gaits [5]. Hexapod robots appropriate for disaster recovery mission. Disaster recovery mission refer to be the crisis rejoinder task, in this case workers feel an uncomfortable to work in this hazardous work environment [18], [19]. Often, there are substantial risks involved in field work due to the hazardous environment. The main application of robots in the mission has been concerned with the substitution of manual human labor by robots or mechanized systems to make the work more time efficient, accurate, uniform and less costly [20], [21].

The main focus of this research is to develop an efficient terrain negotiation & locomotion for a spider robot. The focus is to negotiate hazardous field of even and uneven terrain.

In Section II, we will discuss methodology, different gaits for locomotion and details of the algorithm developed followed by control system design in section III. Finally we present conclusion and future direction in section IV.

II. METHODOLOGY

A. Hexapod Body Configuration

A hexapod robot is a perfunctory medium that walks on six legs. Since a robot can be statically secure on three or more legs, a hexapod robot has a great deal of suppleness in how it can move. If legs become disabled, the robot may still be able to walk. Furthermore, not all of the robot's legs are needed for stability; other legs are free to reach new foot placements or manipulate a payload. A hexapod, can achieve higher speed than a quadruped, and it is well known that a hexapod achieves its highest speed when using a statically stable gait. However, the robot's static stability margin is not optimum when using gaits, for instance, five-leg support patterns present better stability. Nevertheless, a hexapod configuration using alternating tripods has been chosen just to try to increase the machine's speed, albeit at the cost of slightly jeopardizing stability. To navigate in the hazardous field, it will rotate in any direction; heavy legs with powerful servo motors are chosen over other types as they can withstand heavy loads. It contains the required subsystems, such as an onboard computer, electronics, drivers, a PIC Microcontroller, LCD and batteries. Walking robots body shape can determine key features such as static stability, as studied in [22]. Fig. 1 depicts the spider configuration.

Fig. 1 Body of Hexapod agent

B. Hexapod Leg Configuration

Hexapod robots require legs that touch the ground only at certain contact points. Legs have been designed keeping in mind weight consideration mechanisms because their weight is part of the robot's total weight, which must be supported by the legs themselves. Spider-like leg configurations are typical for walking robots. It is known that a spider configuration is the most efficient leg configuration from the energy point of view because it requires lower torques. 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 outdoor mobile robots). So, we used a leg system that can be used in the spider configuration. By reducing servo motors size we can allow motions in two joints simultaneously. This configuration gives the benefit of using small servo motors if we impose some constraints on the possible trajectories. Two servo motors are used vertically for joints 2 and 3. Joint 1 is configured around a typical rotary joint with horizontally constructed servo motor. With each leg configuration we have all three servo motors confined within a very small volume near the body. This gives additional advantages because the expensive leg components are away from the foot, the most dangerous point in the leg. This decreases the cost of replacing parts in the case of an accident. Fig. 2 shows a leg indicating the main parts and components.

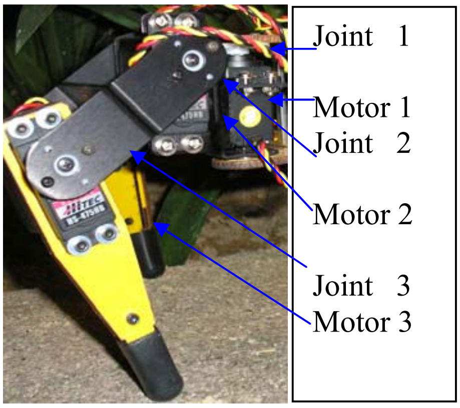

Fig. 2 Leg configuration

C. Hexapod Locomotion

For the hexapod locomotion, we would like to configure it by using two types of gait system. As this robot is able to navigate all kind of terrain in the hazard field, so it can move faster when it will get into even terrain, and in the event of uneven terrain, it will navigate very leisurely. Bump sensor helps it to detect any obstacle like hill or ditch which it may encounter in the hazardous field. This obstacle refers to uneven terrain. Thus we have used two types of gaits for different terrain as shown in Fig. 3.

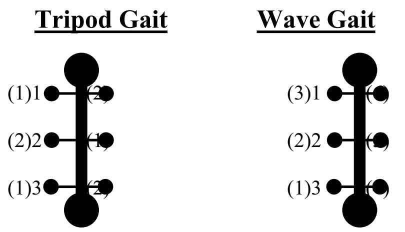

Fig. 3 Different types of gait

D. *Tripod Gait for Even Terrain*

The Tripod Gait is the best-known hexapod gait. A tripod consists of the front-back legs on one side and the middle leg on the opposite side. For each tripod, the legs are lifted, lowered, and moved forwards and backwards in unison. During walking, a hexapod uses its 2 tripods not unlike a bi-pad stepping from one foot to the other - the weight is simply shifted alternately from one tripod to the other. Since 3 legs are on the ground at all times, this gait is both "statically" and "dynamically" stable. The movement scheme is easily visualized by examining the Fig. 4; the numbers adjacent to the legs in the body diagram correspond to time points on the graph. The leg coordination of walking spiders appears to be quite regular too, and is described by the so-called tripod gait. In the tripod gait three legs, front and rear leg of one side and the middle leg of the other side, perform their swing movements at the same time.

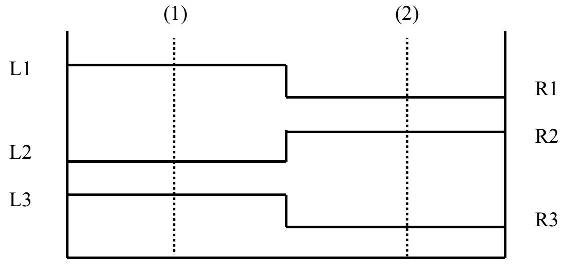

Fig. 4 Stepping patterns of swing movement

The tripod gait appears when the animals walk fast and the load is small. The occurrence of this gait may indicate that leg movement is controlled by a hierarchical superior system which determines the temporal sequence of the movements of the different legs [23].

E. *Wave Gait for Uneven Terrain*

In the Wave Gait, all legs on one side are moved forward in succession, starting with the rear most leg. This is then repeated on the other side. Since only one leg is ever lifted at a time, with the other five being down, the animal is always in a highly-stable posture. One conjecture is that the wave gait cannot be speeded up very much. Wave gaits are a group of gaits in which a wave motion of foot falls and foot lifting's on either side of the body move from the rear to the front, one after another with constant intervals, and in which the laterally opposing legs differ in phase exactly half of a leg cycle. Each wave gait is characterized by a forward wave of stepping actions from the back to the front on each side of the body. The wave gait pattern is chosen in this system because it provides the maximum stability margin for uneven terrain navigation. The control algorithm is used for the control action of wave gait locomotion with an angular position input and torque command output [24]. The foot is commanded to move forward a constant length as viewed from the main body at each integration time interval. The numbers adjacent to the legs in the body diagram correspond to timepoints for the wave gait is showing in the Fig. 5.

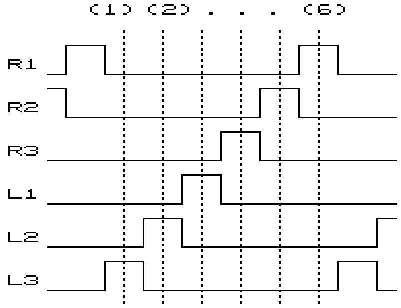

Fig. 5 Stepping patterns of swing movements for wave gait [25]

F. *Algorithm for Movement of Hexapod*

TABLE I
SET OF ELEMENTARY REACTIONS

Behavior 1	Go forward
Behavior 2	Rotate right
Behavior 3	Rotate left
Behavior 4	Go backward

From the Table I, the steps of hexapod movement control system with elementary behaviors are summed up as follows-

Steps of progress:

1. *the hexapod stands for forward movement with tripod gait until grasps obstacle.*
2. ***if** perceive obstacles then wave gait with*
    a) *timer on for t seconds*
    b) *terrain consider as uneven*
    c) *go backward in the terms of behavior4, then it uses it's behavior 3 & 2 to rotate left or right **(90° angle)** according to the opposite direction of the obstacle.*
    d) *use behavior1 until grasp obstacle*
3. ***else** tripod gait with behavior 1.*

G. *Sensors Edifice*

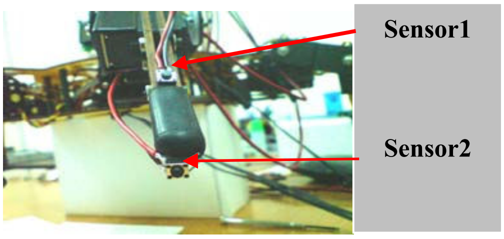

Fig. 6 Construction of the Sensors

The hexapod contains 8 bump sensors. Only the front two legs' consist of 4 sensors (2x2=4). Fig. 6 shows one front legs with sensors' construction. Sensor 2 is attached at the bottom of the leg and sensor1 is attached with the rubber band of the leg. On the other hand, rest of the 4 sensors is attached with other 4 legs as sensor2 shown in Fig. 6.

H. Obstacle and Collision Avoidance

We have designed two types of obstacle for the hexapod robot, such as 'hill' & 'ditch' type. Thus the hexapod robot will detect these obstacles during the navigation period.

Sensor1 is used for the detection of 'hill 'obstacles and sensor 2 is used for 'ditch' obstacles.

Table II shows the method of different types of action during obstacle detection.

TABLE II
DIFFERENT OPERATION

Behavior 1	No obstacle
Behavior 2	Left obstacle
Behavior 3	Right obstacle
Behavior 4	Front obstacle

I. Terrain Negotiation

The hexapod will negotiate two different types of terrain: even terrain & uneven terrain. Terrain negotiation always comprises safety aspects on the motion execution in order to protect living creatures as well as the robot's hardware. Especially rough terrain capabilities require the robot to distinguish traversable from hostile locations. Obstacles make sense to the hexapod robot about the types of the terrain.

J. Scenarios of Hexapod

Fig. 7 shows the state diagram of random scenarios of the hexapod robot. We have a state table in Appendix, and we have constructed the state diagram from this state table. We need to examine it further and construct a stable state table. In all the states, the actions to get to the robot and the action performed by it. For example, when hexapod turns on, it puts itself in the turned on state. From here, it is allowed to conduct various movements.

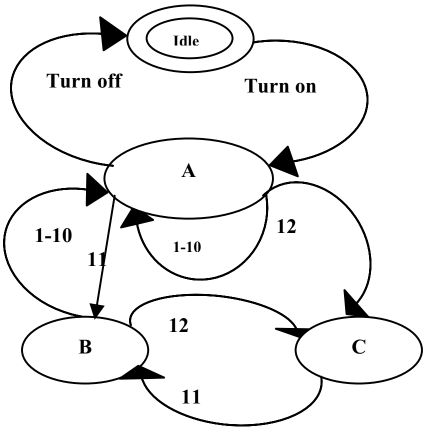

Fig. 7 State diagram for Random Scenarios

Steps of Algorithm:

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1.  idle mode
2.  call turn_on procedure.
3.  Active state: able to do all operation sequentially
    (a). move_forward
    (b). move_backward
    (c). turn_left
    (d). turn_right
    (e). sensor_1(on/off)
    (f). sensor_2(on/off)
    (g). t_gait
    (h). w_gait
    (i). timer_on
2.  Un even terrain state: if sensor_1(on) or sensor_2(off)
    then
        (a) timer_on
        (b) w_gait
        (c). move_forward
        (d). move_backward
        (e). turn_left
        (f). turn_right
3.  Even terrain state: else
        (a). t_gait
        (b). move_forward
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K. Control System

Fig. 8 shows the control environment currently implemented. The user interfaces have control over the running of the microcontroller and are fed back information about the status of the robot. The onboard controller is a PIC Microcontroller system. In test phase, communication between operator station and onboard computer is performed by a data cable. The microcontroller reads the information and controls the movements of the robot. The drive system consists of servo motors. The motor is driven by a high powered PWM (Pulse Width Modulation) controller board; it gets the signal from the microcontroller. The servo motor controller has its own soft start and stop facilities allowing smooth stopping and starting with no processing time required for the microcontroller. The 0-5v analogue signal input also allows the microcontroller to control the speed, acceleration and declaration. Computer module shows the user relevant information on the robots status and allows the user to control the robot directly with ease.

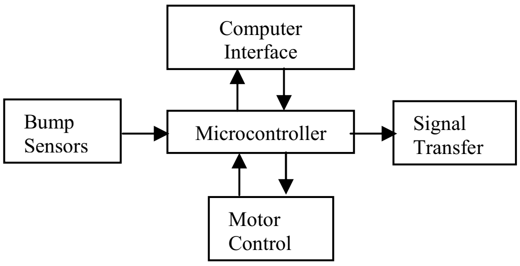

Fig. 8 Control environment of the developed system

III. CENTRAL OPERATOR

The central operator station is situated at a distance from the walking robot and is in charge of human–machine interface, database management and system communication to take the corrective action in the hazardous field. The human–machine interface is a component anticipated to fulfill main requirements of assignment designation for taking corrective action against disaster our environment. The user has the ability to control robot motion remotely, with real-time visual information on what the robot is doing. Communication between the operator computer and the onboard computer is conducted by means of a data cable.

IV. CONCLUSION AND FUTURE WORK

We have developed a method to perform obstacle avoidance terrain negotiation in a dynamic uncertain environment by using different gait locomotion. The novelty of the method we have developed consists of the explicit consideration of uncertainty in the perception system, to negotiate the terrain of the environment from sensors bumping. The developed method can be able to take the decision of the locomotion in accordance with the terrain. The case of hexapod robot's different navigation system in the hazardous field has been analyzed in this paper. The algorithm we have developed for hexapod robots that may overcome many of the shortcomings of previous legged robots developed for hazardous field.

APPENDIX

STATE TABLE FOR RANDOM SCENARIOS

State	Event	Actions	Comment	Caused By	Will Effect
A. Active	1.turnOn	Boot Up	Hexapod is turning on		2-10
	2.bootUp	Activity	Allow various activities	1	3-8
	3.forward movement	Walk Forward	Hexapod will begin to walk forward	2	11,12
	4. backward movement	Walk Backward	If obstacle is in front, hexapod will begin to walk backward		12
	5. right rotation	Rotating in right side	If obstacle is left side, hexapod will turn by 90* angle in right direction		12
	6. left rotation	Rotating in left side	If obstacle is right side, hexapod will turn by 90* angle in left direction		12
	7. sensor2 press	Button on	No ditch obstacle		11
	8. sensor2 not press	Button off	Ditch obstacle found		12
	9. sensor1 press	Button on	Hill obstacle found		12
	10. sensor1 not press	Button off	No obstacle		11
B. Even terrain	11. tripod gait	Fast movement	Hexapod will walk or rotate very fast until it gets an obstacle	7, 10	3
C. Uneven terrain	12. wave gait	Slow movement	Hexapod will walk or rotate at a snail's pace for **t** seconds.	8, 9	3,4,5,6

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