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22

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

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1. 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 (G. Nejat, 2006). In any disaster either man made or due to Mother nature, the elementary tasks at hand are: (i) reach the affected hazardous field (ii) find and get information about victims, and (iii) rescue as many of them as possible.

It is possible for robot to reach any hazardous field unlike who have limited mobility in such missions. Nowadays legged and wheeled robots are involved in such mission (Habib, 2000), (Y. Mori, 2005), (Rizo J, 2003), (Y. Baudoin, 1999). In terms of hazardous field navigation for disaster recovery mission, legged robots have advantages over wheeled robots.

Wheeled robots are the simplest and cheapest and tracked robots are very good for moving, but not over almost all kinds of terrain. Manned wheeled vehicles (Habib, 2000), (Y. Mori, 2005) or robotic systems (Rizo J, 2003), (Y. Baudoin, 1999), have already been tested. Navigate over obstacles and ditches and even on stairs 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. Some general-purpose robots were tested for this kind of application, nowadays specific prototypes having special features are being built and tested for specific mission. The TITAN VIII walking robot, a four-legged robot was developed as a general-purpose walking robot at the Tokyo Institute of Technology, Japan (Hirose S, 1998). COMET-I 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 (Nonami K, 2000), (Q.J. Huang, 2003). This robot weighs about 120 kg. 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 (D. Voth, 2002). 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 (P. Gonzalez, 1995, 2000, 2003) and since 1999 it has been working on the application of the RIMHO-2 walking robot for detecting and locating unexploded ordnance. Hexapod robot could also be used in agricultural fields, though wheel robots already are being used in this field (Philip J., 2005). The wheel robot can move only directed even terrain, when hexapod robot can navigate even and uneven terrain. In navigating hexapod considers different gaits namely adaptive gaits (C.-L. Shih, 1993), FTL gaits (F. Ozguner, 1984), graph search method (P. K. Pal, 1991), free gaits (R. B. McGhee, 1979). Hexapod robots are appropriate for disaster recovery mission for its versatile properties.

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

2. Hexapod Configuration

2.1 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, all of the legs are not needed for stability. 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. 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 hazardous field, it will rotate in any direction; heavy legs with powerful servo motors are chosen over other types so that 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 (Schneider A, 2000). Figure 1 depicts the spider like hexapod configuration.

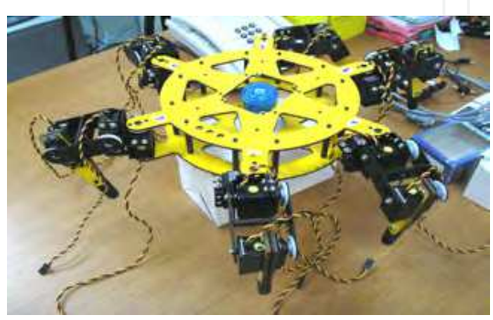

Fig. 1. Body of Hexapod agent

2.2 Hexapod Leg Configuration

Hexapod robots require legs that touch the ground only at certain contact points. Legs have Legs have been designed taking into consideration weight of the robot along with its subsystems as well as the weight of the legs. Spider-like leg configurations are typical for walking robots. It is known that a spider-like leg configuration is the most efficient one from the energy point of view and it requires less torques. However, it is not very efficient in terms of stability. Energy efficiency being a very important factor for outdoor mobile robots, spider-like leg configuration is chosen for accomplishing its job with both stability and energy efficiency. Three servomotors are used in each leg as shown in Fig. 2. The servomotors at joints 2 and 3 are able to rotate about two horizontal axes; however, the third one used at joint 1 is able of rotating about a vertical axis only.

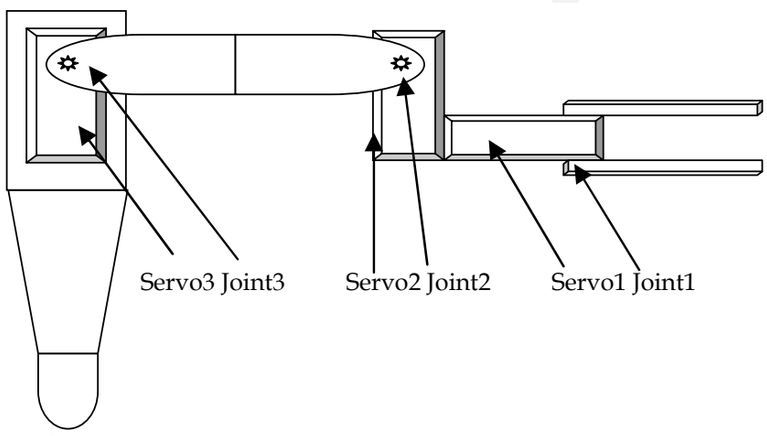

Fig. 2. Leg configuration

3. 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 Figure 3.

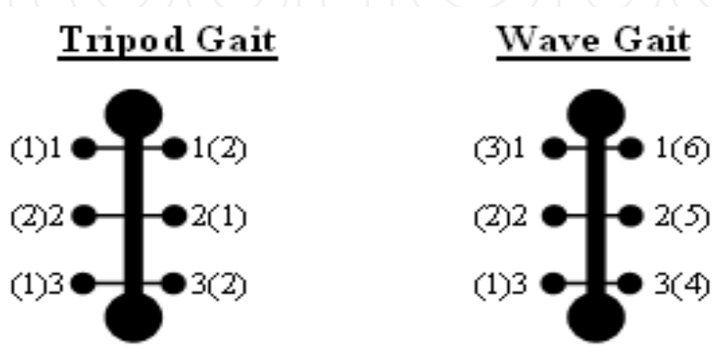

Fig. 3. Different types of gait

3.1 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.

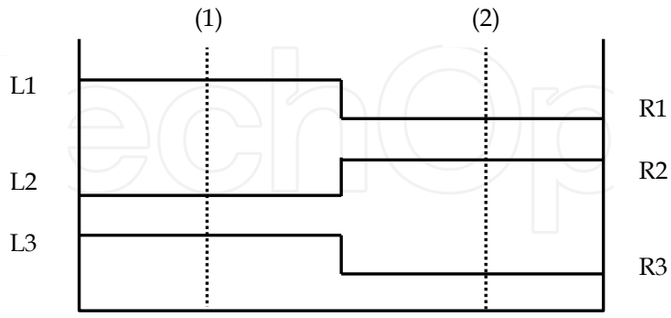

Fig. 4. Stepping patterns of swing movement

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 Figure 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. 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 (V. Holst).

3.2 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 (Katsuhiko I.). 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 Figure 5.

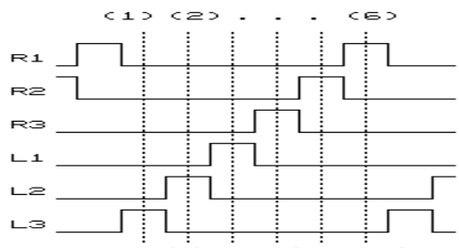

Fig. 5. Stepping patterns of swing movements for wave gait (Oricom T.)

4. Methodology

4.1 Movement of Hexapod

General behaviour of the hexapod is shown in Table. 1.

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

Table 1. Set of elementary reactions

From table 1, 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 detects obstacle.
2. **if** perceive obstacles then wave gait with
   a) timer on for t seconds
   b) terrain consider as uneven
   c) go backward in terms of behavior4, then uses behavior 2 or 3 to rotate right (90 angle) if the obstacle is in the left or right.
   d) use behavior1 until detect obstacle
3. **else** tripod gait with behavior 1.

4.2 Sensors Edifice

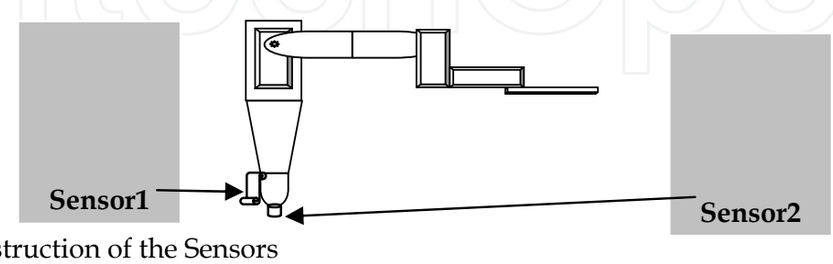

Fig. 6. Construction of the Sensors

The hexapod contains 8 bump sensors. Two sensors are attached to each of the front legs. Figure 6 shows one front leg with sensors. Each of the rest 4 sensors is attached with each of the 4 legs as sensor2.

4.3 Obstacle and Collision Avoidance

We have designed two types of obstacle for the hexapod robot, such as 'hill' & 'ditch'. Thus the hexapod robot will detect these obstacles during the navigation period. Sensor1 is used for the detecting of 'hill 'obstacles and sensor2 for 'ditch' obstacles. Table 2 shows different actions and scenario.

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

Table 2. Different operation

4.4 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 robot's hardware. Especially rough terrain capabilities require the robot to distinguish traversable from hostile locations. Obstacles classification done through the sensors attach to the front two legs, obstacle classification algorithm is given in Appendix A.

4.5 Scenarios of Hexapod

Figure 7 shows the state diagram of the developed algorithm of the hexapod robot. We have a state table in Appendix A, 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.

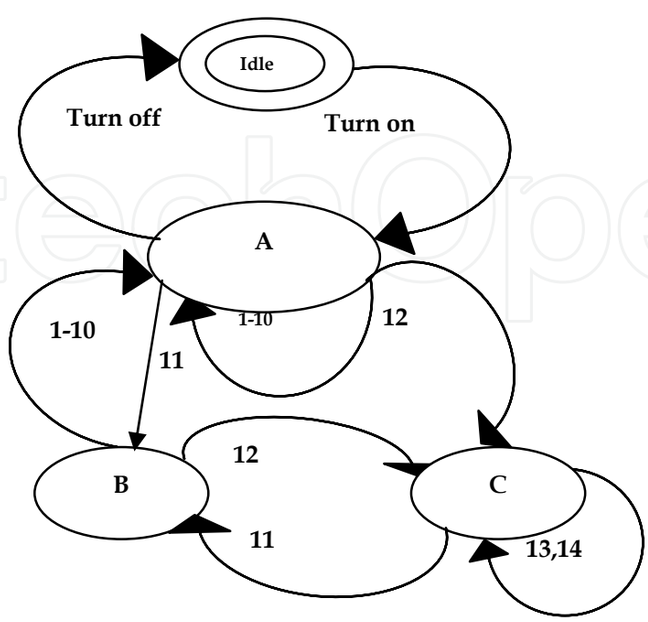

Fig. 7. State diagram for Random Scenarios

Steps of Algorithm:

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. **Uneven terrain state: if** sensor_1(on) or sensor_2(off) then
   (a) timer_on
   (b) w_gait
   (c). If hill type obstacle-
   move_backward then rotate opposite direction of the obstacle.
   (d). If ditch type obstacle-
   Stop & check again for depth;
   If depth more than 1″ move_backward then rotate opposite direction of the ditch.
   Else move_forward.

   (e). Gait Transition

3. Even terrain state: else
   (a). t_gait
   (b). move_forward

4.6 Control System

Figure 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.

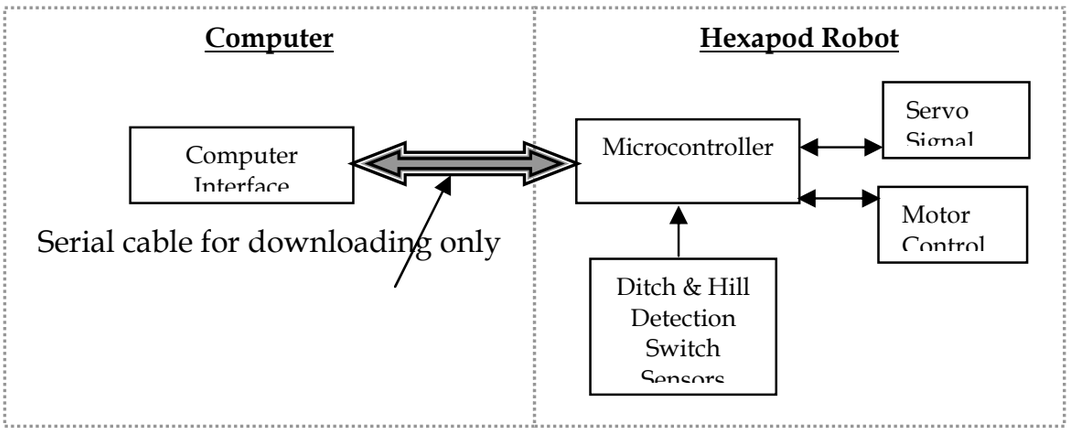

Fig. 8. Control environment of the developed system

5. Conclusion

We have developed a method to perform obstacle avoidance terrain negotiation in a static uncertain environment by using different gait of 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 bump sensors. This method is able to take decision in accordance with the terrain. The case of hexapod robot's different navigation system in the hazardous field has been tested successfully. Using this algorithm hexapod robot will be overcome many of the shortcomings of previous legged robots developed for hazardous environment.

Appendix A

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 left/right 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 fast forward 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
	13. stop & wave backward	No surface	Hexapod will walk backward & rotate	8	4,5,6
	14. stop & wave forward	Surface available with 1" dich	Hexapod will walk forward slowly	7, 8	3,12

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