DEVELOPMENT OF A MOBILE ROBOT CONTROLLED BY THREE MOTORS FOR HOSTILE ENVIRONMENT

D.G.Gweon, Y.Y.Cha and H.S.Cho

Department of Production Engineering
Korea Advanced Institute of Science and Technology
373-1 Kusong-Dong Yusong-Ku,
Taejon, Korea

Abstract : In this study a hybrid legged / wheeled mobile robot,KAMOBOT,is developed. The mobile robot has a six-legged, cylindrical configuration,each leg of which is equiped with a wheel at the bottom. The robot can go up and down stairs,go over obstacles, move along curvilinear paths and rotate around its geometric center. Such maneuverability can be achieved by using only three electric motors.In this study several gate modes are analyzed and algorithms for gate control are presented.

1. Introduction

Since the advent of industrial robots at the end of 1950's, robots working in a fixed position have taken leading role in automation. In order that robots can be used successfully under such working conditions as under-water,nuclear power plant and other hostile environments, mobility should be however added on them. That is the reason why a mobile robot comes into existence. A mobile robot can be divided into two types according to driving mechanism ; wheeled type and legged type. Although the wheeled mobile robot is more energy-efficient, easier controllable and faster than the legged one, it can not overcome obstacles like stairs. While the legged mobile robot can operate well even in hostile environment,it has demerits of complex structure, poor controllability and slow speed. TO-ROVER was developed in 1983 at Tokyo university, Japan [1]. It is a wheeled-type mobile robot which has the adaptability to hostile environments. This machine is however greatly restricted in the heights and widthes of stairs it should go over and it has poor maneuverability in plane curvilinear motion. A study on hybrid locomotion vehicle (HLV) was achieved at Hitachi in 1984 [2].The robot has 15 motors for lifting five legs and for driving and steering wheels at the bottom of each leg.Because of many motors cost for controlling and manu-facturing are very high.Besides these machines there is a crawler type mobile robot [3]. In this case, if obstacles are not quite rigid enough to bear its weight, obstacles will be damaged.Also the floor will be marred in case of steering.Our research is concerned with the development of a HLV which has a six-legged,cylindrical configuration. It is equipped with only three motors for lifting the legs and for driving and steering the wheels at the bottom of each leg. The robot developed in this research has merits in cost, speed and maneuverability. In this paper,structure of the robot,its driving modes and motion control algorithm are discussed.

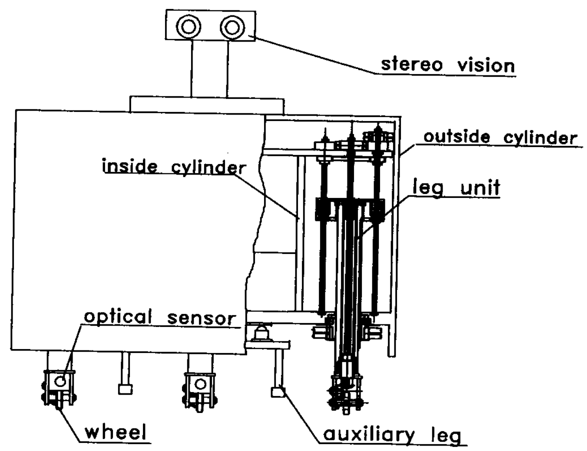

Fig.1 Structure of HLV

2. Structure of HLV

2.1 Overall Structure

Fig 1 shows the overview of HLV developed in this study. The frame of the HLV is constituted of upper plate, lower plate and inside cylinder. As a protective cover an outside cylinder will be attached. Between inside and outside cylinders, six legs are installed. The cross-section of one of the six legs is illustrated in figure. Leg and wheel-driving mechanism are constituted of three main parts:wheel-driving unit,wheel-steering unit and leg-lifting unit.Each structure and working principle will be explained in next paragraphes.Outside cylinder measures 70 Cm in diameter and inside cylinder 38 Cm. The greatest possible stroke of leg is 42 Cm. The inner part of the inside cylinder is loaded with battery,motor drivers, control boards and so on. For recognizing obstacles in front of wheels an optical sensor is installed on each wheel.Each wheel must come into contact with surface with enough contact force in order to move without slip. For this reason compression spring is installed under each ball screw nut. In order to detect the spring forces (contact forces) piezo-electric sensors are inserted at the bottom of the spring.Also three dimensional measuring system like stereo vision will be installed for finding the path of robot.

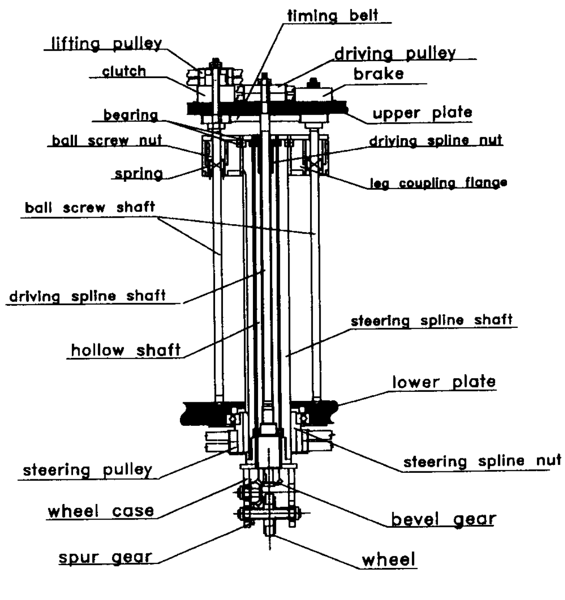

Fig.2 Cross-section of a leg and wheel unit

2.2 Wheel Driving Unit

Wheel driving unit is a driving mechanism which make it possible for HLV to move in every derection in plane motion.Fig 2 is a cross-section of one leg. Six driving pullies are connected with one driving motor(not shown in the figure)through timing belt.The power of driving motor is transmitted into wheels through driving pulley,driving spline shaft,hollow shaft,bevel gear and spur gear. While hollow shaft is rotated with driving spline shaft, it moves up and down relative to spline shaft . The power source of the up-down motion will be explained in paragraph 2.4 .

2.3 Wheel Steering Unit

Like wheel driving unit, one driving motor (steering motor: not shown in the figure) of wheel steering unit revolves six steering pullies at the same time (Fig 2). The rotation of steering pulley rotates steering spline shaft and wheel case which is fixed at the lower end of the shaft determining the wheel direction. The reason spline shaft is used is to transfer steering power into wheel case even in down position of leg.

2.4 Leg Lifting Unit

The power of one leg lifting motor operates six lifting pullies at the same time through timing belt (Fig 2). The power transmitted into lifting pulley is sent into left ball-screw shaft through clutch and into right ball-screw shaft through timing belt. The simultaneous revolution of two ball-screw shaft makes leg-coupling flange which contains ball-screw nuts move up or down. In consequence the parts of leg, that is, hollow shaft, steering spline shaft and wheel case will move up or down. Though the power of lifting motor is transmitted into six lifting pullies at the same time, a leg can move up or down,only when the corresponding clutch is coupled. Fig 3 shows a down position of the leg.

2.5 Body Steering Unit

Though HLV can move to any position on a plane by means of wheel driving unit and steering unit, it is impossible to change the orientation of HLV body because six driving pullies and six steering pullies are operated equally and simultaneously.For the rotation of HLV body a

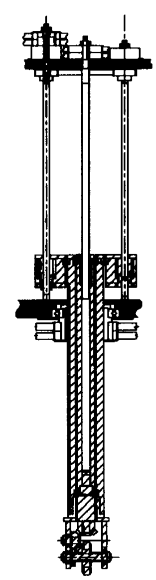

Fig.3 Down position of leg

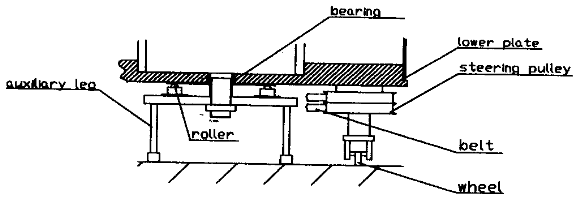

Fig.4 Auxiliary leg for body rotation

body steering unit shown in Fig 4 is necessary. It is designed to support body only with auxiliary legs when all of six legs are detached from surface.The body supported by the auxiliary leg can rotate when only one leg is landed and the direction of its wheel is in the circumference. In figure the auxiliary leg seems to have only two supporting points, but it has three supporting points separated 120 degree apart making the body stable. Fig 5 shows a photograph of the HLV designed in this study.

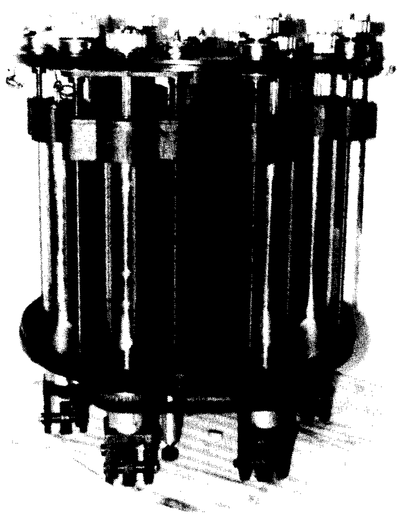

Fig.5 Photograph of HLV

3. Motion Analysis and Control Algorithm

3.1 Simple Plane Motion

The modes of plane motion can be divided into two types; simple plane motion and body rotation by auxiliary leg. Fig 6 shows three modes of simple plane motion. Because six wheels are operated at the same time, the orientation and the position of the body are not changed in case of steering.As structural characteristics of this HLV, wheel steering motion has an effect on wheel driving motion. In case of a) in Fig 7 actual driving angle will be driving angle minus steering angle. In case b) actual driving angle will be driving angle plus steering angle. In case of operating only steering motor as in case of c) driving motion occurs as much as steering angle. In this regards actural driving angle θ_{da} and angular velocity $\dot{\theta}_{da}$ can be obtained as follow;

$$\theta_{da} = \theta_d - \mathrm{sgn}[\theta_d, \theta_s]\theta_s$$

$$\dot{\theta}_{da} = \dot{\theta}_d - \mathrm{sgn}[\theta_d, \theta_s]\dot{\theta}_s$$

where, θ_d : driving angle

$\dot{\theta}_d$: driving angular velocity

θ_s : steering angle

$\dot{\theta}_s$: steering angular velocity

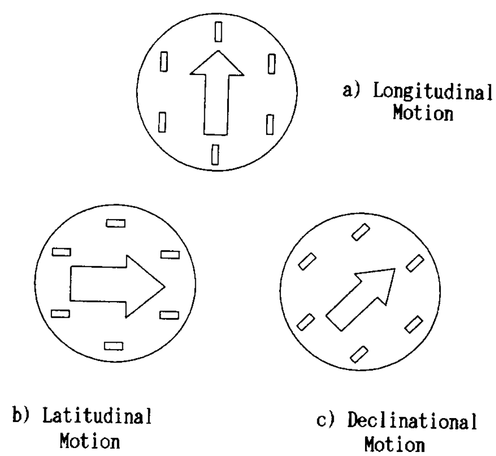

Fig.6 Mode of plane motion

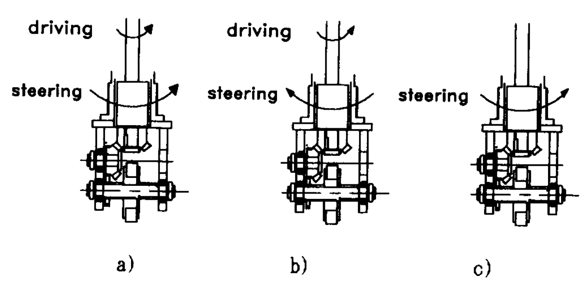

Fig.7 Relation between steering and driving of wheel

3.2 Body Steering Motion

Fig 8 shows working principle of body steering motion. In figure six wheels and one auxiliary leg with three pads can be seen. The black marks mean landed states. The sequence of body steering process is as follow;

a) Simple plane motion with six wheels landed
b) After raising six legs the body is supported by auxiliary leg.
c) Wheels are steered so that one of the wheels is in the direction of circumference.
d) After landing the wheel in the circumference direction, driving motion of the wheel occurs.
e) Accordingly, the body can be rotated.

3.3 Crossing Obstacle and Climbing Stairs

When HLV encounters obstacles or stairs in the process of plane motion, it can get over these troubles owing to leg-lifting function each leg has. Fig 9 shows the procedure of crossing obstacles. After detecting an obstacle by means of optical sensor fixed in each leg the leg faced with obstacle will be raised in a certain height, the body will be advanced and finally the leg will be lowered until the sensed value of piezoelectric senser fixed in leg coupling flange exceeds a given value. Following legs will repeat the above-mentioned processes. As a similar way mentioned above, HLV can climb stairs. Fig 10 shows the procedure of climbing stairs.

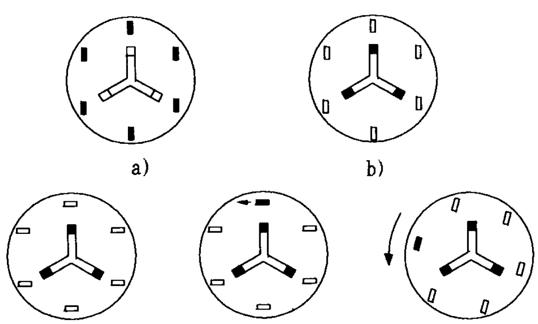

Fig.8 Sequence of body steering

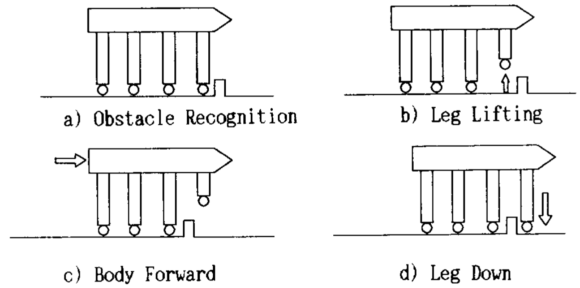

Fig.9 Procedure of crossing obstacle

3.4 Motion Control Algorithm

Fig 11 shows the flow chart of motion control algorithm. In figure "trajectory inform" is the information about the routine which HLV passes along. After HLV starts at initial position, the trajectory informations are compared with the informations produced by 3-dimensional vision system. In case these informations are different, the path along which HLV passes has to be modified in accordance with the vision informations. "Moving obs" means moving obstacle like walking man, in which HLV will come to a stand still until the obstacle vanishes. "Obs. crossed" means obstacles like stairs and projections which must be crossed over. There are two types of obstacles to be crossed over, that is, obstacles projected and obstacles sunken. In order to get over these types of obstacles the leg should be elevated up or down. "Obs. avoided" means obstacles like wall which can not be crossed over but can be avoided. "Goal" is destination at which HLV should arrive. After HLV arrived at the goal, docking with other facilities may be nesessary. The docking procedure is shown in the right part of flow chart.

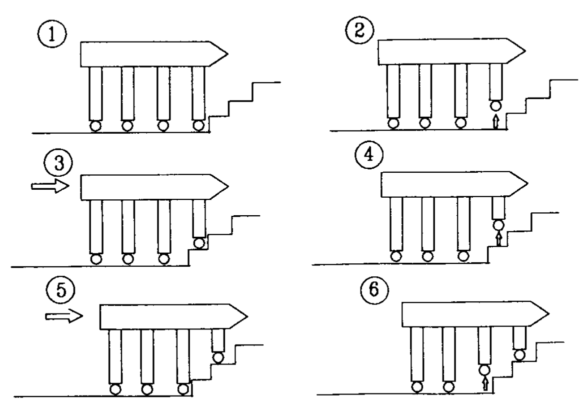

Fig.10 Procedure of climbing stairs

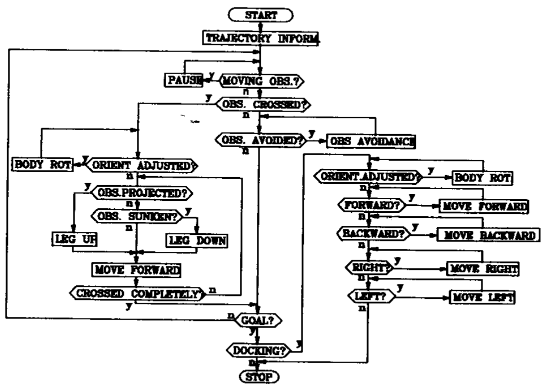

Fig.11 Flow-chart of motion control algorithm

4. Conclusion

In this paper a new concept of mobile robot (HLV) is introduced. The structure of the HLV is that six legs attached to the cylindrical body are equipped with wheels at the bottom. Also the HLV can go up and down stairs, go over obstacles, move along curvilinear paths and rotate around its geometric center. Such maneuverability can be achieved by using only three motors.Therefore the HLV can be simply controlled and constructed at very low cost. Also the HLV has following merits; high moving velocity due to wheeled type and high adaptability to the working environment with obstacles. On the other hand the cumulative error can be caused by the slip between wheel and ground surface.But the error can be reduced. Because in spite of uneven surface wheels can contact with surface with constant force due to the springs installed under the ball screw nuts. As an another demerit, a structural limitation occurs in geometric configuration of legs. If the width of overcomming obstacle is equal to that between legs of HLV (13 Cm or 26 Cm), three or four legs should be raised at the same time.In this case it is impossible to overcome obstacles because of the stability of body.Therefore width between legs should be determined in accordance with obstacles expected in working environment.

Reference

[1]. Masaharu Takano and Gotaro Odawara, " Development of new type of mobile robot TO-ROVER," Proceedings of 13th ISIR, vol.2, pp(20) 81-89, April 1983

[2]. Yoshiaki Ichikawa, Norihiko Ozaki and Kenichiro Sadakane,"A hybrid locomotion vehicle for nuclear power plants," IEEE Trans. Syst.Man.Cybern., vol.SMC -13, no.6, pp.1089-1093, Nov. 1983

[3]. G.Clement and E.Villedieu, "Mobile robot for hostile environments," Proc. of the Int. Nat. Meeting on Remote Systems and Robotic in Hostile Environment, pp.270-275,1987