Proceedings of 2015 IEEE
International Conference on Mechatronics and Automation
August 2 - 5, Beijing, China

Characteristic Evaluation on Land for a Novel Amphibious Spherical Robot

Liguo Li[1], Jian Guo[1]

[1]Tianjin Key Laboratory for Control Theory & Applications in Complicated Systems and Biomedical Robot Laboratory
Tianjin University of Technology
Binshui Xidao 391, Tianjin, China
(liliguo126@sina.com;jianguo@tjut.edu.cn)

Shuxiang Guo[1,2]

[2] Intelligent Mechanical Systems Engineering Department
Faculty of Engineering
Kagawa University
Takamatsu, Kagawa, Japan
guoshuxiang@hotmail.com

***Abstract* –In recent years, people have attached great importance to the development of amphibious robots that are used to develop marine resources and implement marine missions. This paper presents a new type of amphibious spherical robots. The robot includes four drive units. Each drive unit consists of two servo motors, a water-jet propeller, a DC motor and a wheel. The robot can constitute 3 movement structure ways according to the environment. When the robot enters water, it adopts water jet propulsion. According to different land conditions, there are two movement patterns to switch. One is a quadruped movement pattern which is available to climb over obstacles; the other is a driving wheel movement pattern which is used to speed up the movement of robot under the flat terrain. The paper focuses on characteristic evaluation on land for a novel amphibious spherical robot. Based on two movement patterns, experiments were conducted under the condition of different terrains and different loads on land. From the results, the robot moving speed decreases with the load increasing in the same terrain. Without load, the maximum velocity of the robot is 8cm/s at the frequency of 1.25Hz on the title floor under quadruped movement pattern. Without load, the maximum velocity of the robot is 36.7cm/s at the duty of 100% on the title floor under wheel movement pattern. So compared with the quadruped movement speed, wheel movement speed of the amphibious spherical robot has greatly improved.**

***Index Terms* –Amphibious Spherical Robot, Movement pattern, Characteristic evaluation**

I. INTRODUCTION

Underwater robots, as a kind of intelligent tool, are applied to perform underwater tasks including sea cruise, maritime search, and other implementation of underwater tasks [1].

Spherical shape has many excellent properties. In 1996, Helsinki University of Technology bred the world's first spherical robot named Rollo whose designers are the Aame Halme, et al [2]. Then spherical underwater robots more and more get the welcome of scholars. In 2012, the University of Manchester developed a Micro-Autonomous Underwater Vehicles which had a diameter of 150mm and 4 DOF. DC motor/propeller thruster units were selected as the means of propulsion in both planes [3].

In 2011, based on the principle of coanda effect, Massachusetts Institute of Technology puts forward the concept of pump-flow valve. They developed a novel device for water drive [4]. Since then, they have developed a series of underwater robots. The robots adopt symmetrical structure, no cable control, without appendages, small volume. The interference of external water environment can be effectively avoided. They are suitable for underwater nuclear pipeline detection. But the robots are difficult to achieve accurate controlling [5]-[7].

In 2013, McGill University developed an amphibious robot which can work both on land and in water. A new class of multi-purpose leg is used to for walking and swimming [8].

Professor Guo et al, at the Kagawa University put forward the concept of Father-son robot system. Amphibious robot carries micro-robot made by intelligent materials for driving device. When meeting narrow underwater environment, amphibious robot emits Micro-robot to complete tasks. Amphibious robot provides power and sends signals to micro-robots with cables [9]-[15].

In China, underwater robot research started relatively late. However, there are also some institutions that are engaged in this field, such as Harbin Engineering University and Beijing University of Post and Telecommunications. Harbin Engineering University developed spherical robots based on the principle of vector propulsion. The robot can achieve 3 DOF movements in water [16]. Beijing University of Post and Telecommunications also developed their own spherical robots [17].

Legs and wheels are two widely adopted methods utilized on the ground locomotion. Wheel movement has excellent performance of power efficiency and movement speed, which can hardly be completed by legs. Thus, the study of a leg-wheel hybrid platform more and more get the welcome of scholars. Leg-wheel hybrid platform is suitable for general indoor-outdoor environments.

National Taiwan University developed a leg-wheel hybrid robot Quattroped in 2009. This robot was implemented with a transformation mechanism which directly changes the morphology of wheels (i.e. a full circle) into 2 degree-of-freedom legs (i.e. combining two half-circles as a leg)[18]. Roller Walker [19] incorporates a passive wheel on the foot of each 3 DOFs leg. And the locomotion can be switched from quadruped walking into roller skating on the flat ground. But those robots only can work on land.

According to the status quo at home and abroad, the paper put forward a new type of amphibious spherical robots. The robot includes four drive units which can constitute 3 movement structure ways according to the environment, including wheel structure movement or quadruped walking movement adopted on land and water jet propulsion in water. The ground is relatively flat; wheel structure pattern is adopted by the robot to improve movement speed. While the ground is more rigorous, the robot can use quadruped movement pattern to climb over obstacles. And the paper mainly states characteristic evaluation on land for a novel amphibious spherical robot.

This paper consists of four parts. Section II introduces structure design of novel amphibious spherical robot. Then section III illustrates two kinds of land movement gait of amphibious spherical robot. In section IV, land movement experiences are carried out; analysis of experimental results is given. Finally, we come to conclusions and bring forward future work in section V.

II. Structure Design of the Novel Amphibious Spherical Robot

A. *Structure of the Novel Amphibious Spherical Robot*

The novel amphibious spherical robot mainly consists of a sealed upper hemisphere shell, a plastic circular plate and four drive units. The structure diagram of the robot is shown as figure1.Four drive units are symmetrical installed on the plastic circular plate. Each drive unit includes two servo motors, a water-jet propeller, a DC motor and a wheel. Figure 2 shows the links between various components. The control circuits, sensors and batteries are installed inside the sealed upper hemisphere shell so as to achieve the waterproof effect.

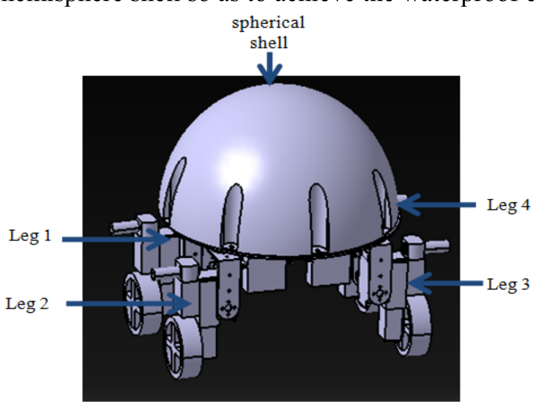


Fig.1. Structure of the novel amphibious spherical robot

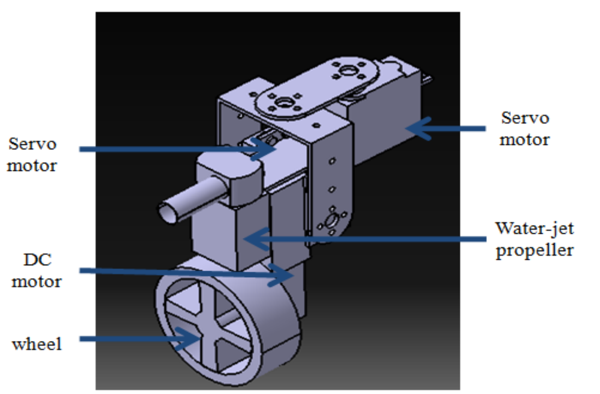
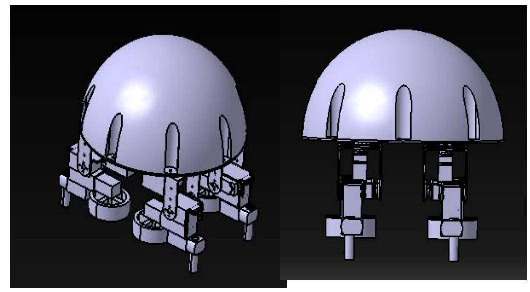
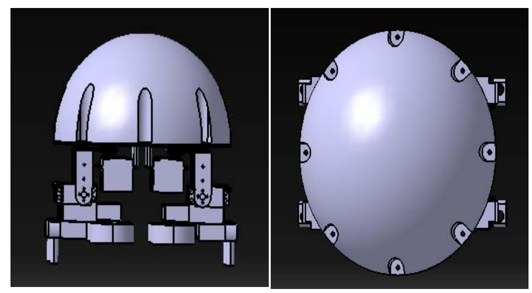


Fig.2. Structure of the drive unit

Figure 3and 4 show the two movement patterns that the novel amphibious spherical robot will adopt according to land status information. Figure 3 indicates the initial gait of quadruped movement. Figure 4 indicates the initial gait of wheel movement. According to land terrain conditions, two kinds of way can switch freely. Switch between the two modes is achieved by controller controlling eight servo motors.

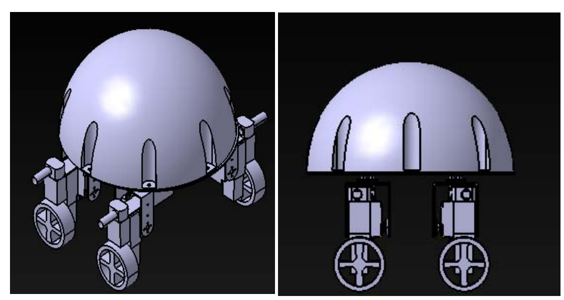


(a)overall structure (b) side view

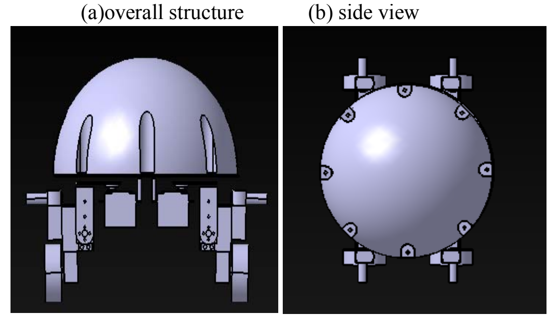


(c) front view (d) top view

Fig.3. Initial gait of quadruped movement



(a)overall structure (b) side view



(c) front view (d) top view

Fig.4. Initial gait of wheel movement

B. *Control System and Energy system*

We chose Atmega2560 as core controller. Eight channels of PWM signals control eight servo motors. Using eight input/output ports control four water-jet propellers. Using eight input/output ports control four DC motors.

For the energy system, two LI-PO batteries are used. The voltage of the battery is 7.4V. Battery capacity is 5000amh. One is used to supply for microcontroller; the other one is used to supply for servo motors, DC motors and water jet propellers.

III. Land Movement Gait Analysis of Amphibious Spherical Robots.

A. Prototype of a Novel Amphibious Spherical Robot

Figure 5 shows prototype novel amphibious spherical robot. The robot is small in size. Maximum diameter is less than or equal to 40cm. The robot consists of two parts. The upper part of the robot is control mechanism; the lower part is actuating system. The two servo motors on the same drive unit are mutually perpendicular. Each drive unit can realize two degrees of freedom movement. We chose to use waterproof servo motor (Fig.6) produced by Raboesch Company and HS-5646WP Water-jet propeller (Fig.7) made by Hitec Company. The waterproof servo motor is 41.8mm in length, 21mm in width, 40mm in height. The water-jet motor is sized21*31*56mm with nozzles.

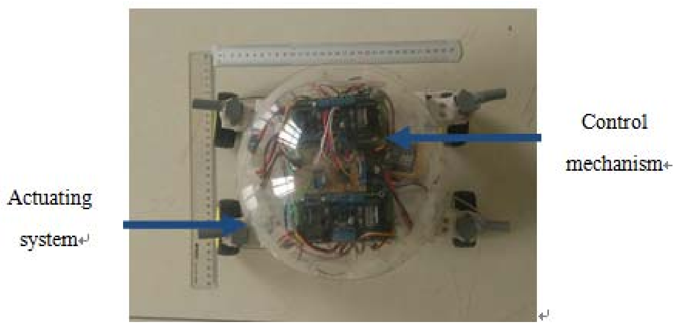


Fig.5. Prototype novel amphibious spherical robot


Fig.6.Servo motor


Fig.7.Water-jet propeller

B. Quadruped Movement Gait

There are four kinds of gaits when quadruped robot move on land, including trotting gait, crawling gait, gallop gait and hoof slipped gait. Considering the system stability and feasibility, the robot in this paper adopts crawling gait to walk on land. Experience results will be analyzed in the next section. Crawling gait is that the robot's four legs walk on the ground in a certain order. From figure 8, motion sequence of the robot's legs is leg1, leg3, leg4 and leg2. In figure 8, 0 indicates that leg contacts with the ground and 1 indicates that leg departs from the ground. So duty ratio of crawling gait is B=0.75 in a cycle T. That is to say, at any one time, there are three legs on the ground; the fourth leg is of the ground. We regard the leg contacting the ground as supporting leg. The leg off the ground is named swing leg [20].

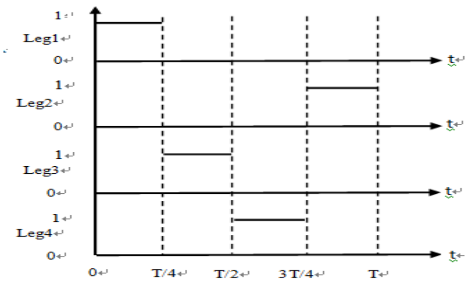


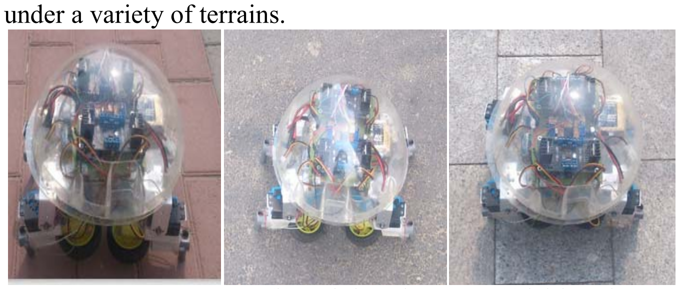
Fig.8. Crawling gait

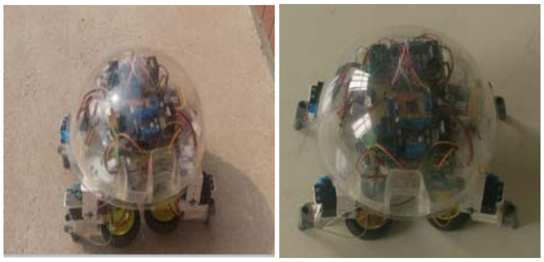
C. Wheel Movement Gait

Wheel movement is another way that novel amphibious spherical robot can choose. When the ground is flat, the robot can choose this way.Because it can improve movement speed of the robot. Four wheels of the robot are respectively controlled by a DC motor. So it is a system of Four-Wheel-Independent. The movement direction of the robot not only can be controlled by servo motor of each drive unit, but also can be changed by the output of the DC motor rotational speed difference. When conducting land experiment, we set the four wheels running state.

IV. Experiences and Results

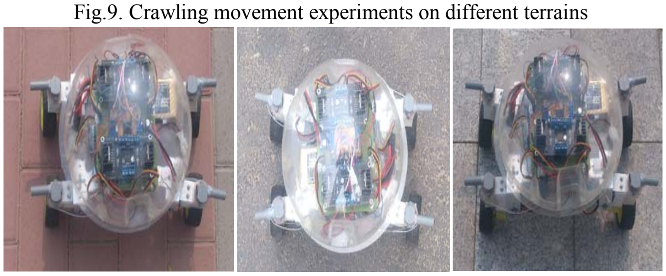
In order to evaluate character on land for a novel amphibious spherical robot, we conduct many experiences. Based on two movement patterns, Figure 9 shows experiments of quadruped movement crawling gait were conduct under the condition of different terrains and different loads on land. Figure 10 shows experiments of wheel movement gait were conduct under the condition of different terrains and different loads on land. Terrains in the experience include pavement, asphalt road, brick road, cement floor and title floor. These terrains can be characterized by different coefficients of friction. Different loads on the robot we choose are respectively 0g, 204g and 403g. Finally, we get the data graph under a variety of terrains.


(a) pavement (b) asphalt road (c) brick road

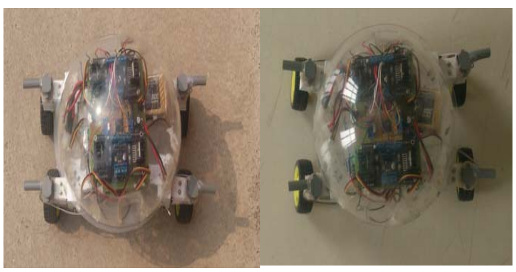


(d) cement floor (e) title floor

Fig.9. Crawling movement experiments on different terrains



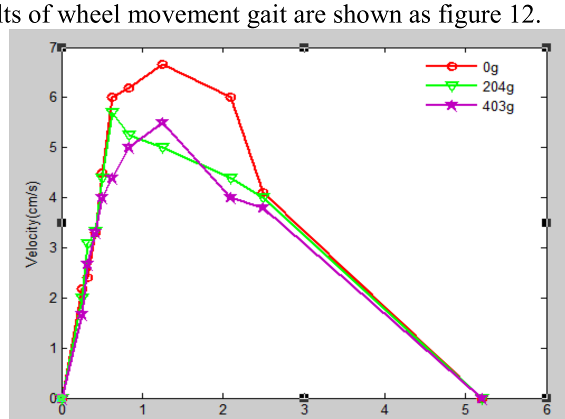
(a) pavement (b) asphalt road (c) brick road



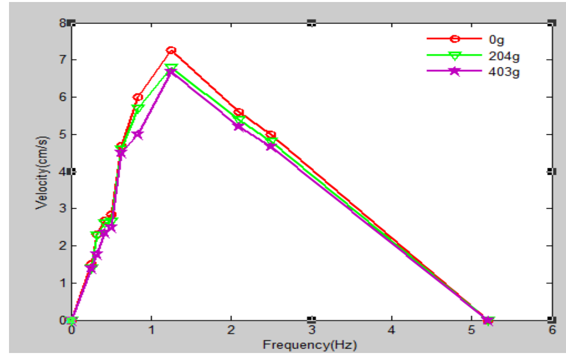
(d) cement floor (e) title floor

Fig.10.Wheel movement experiments on different terrains

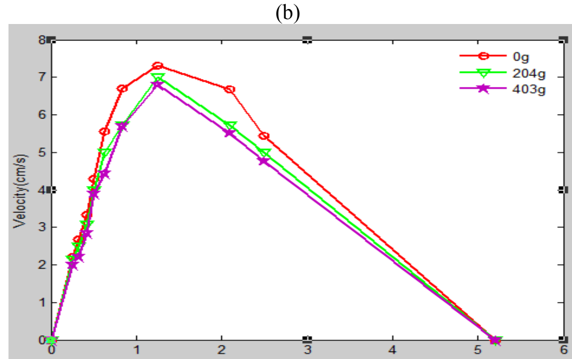
All experiments were repeated several times to achieve an average velocity. When the robot walked in crawling gait, the robot was programmed to move straight forward for 1m. By measuring the time, average velocity was calculated. When the robot walked in wheel movement gait, the robot's movement speed is faster. In order to make accurate measurement, the robot was programmed to move straight forward for 8ms. By measuring the distance, average velocity was calculated. At last, the experience results of quadruped movement crawling gait are shown as Fig.11. The experience results of wheel movement gait are shown as figure 12.



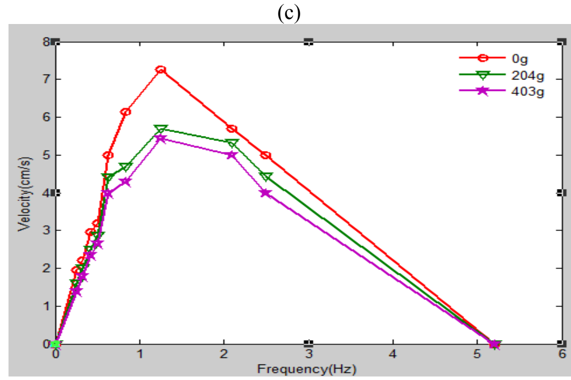
(a)



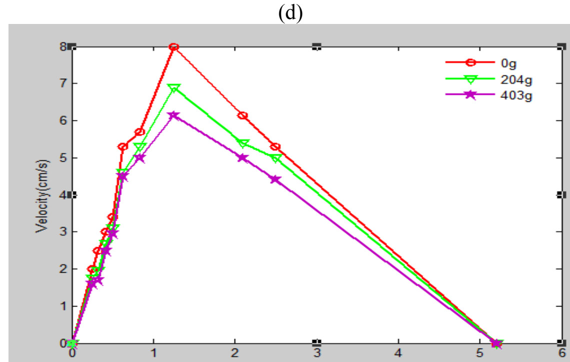
(b)



(c)



(d)

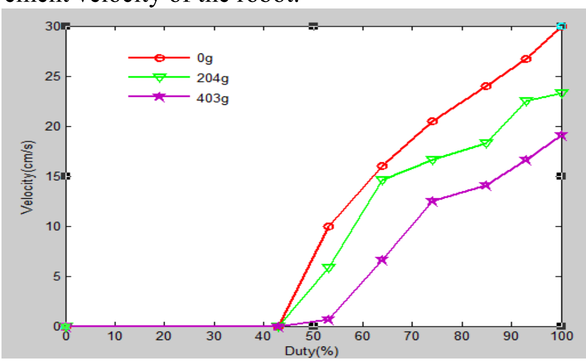


(e)

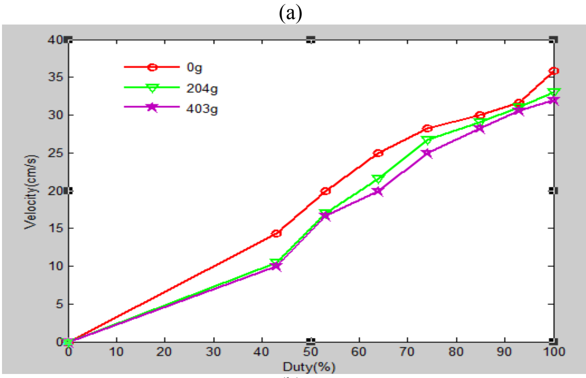
Fig.11. Results of crawling movement experiments on different terrains: (a) pavement, (b) asphalt road, (c) brick road, (d) cement floor, and (e) title floor

When the novel amphibious spherical robot walked in quadruped movement crawling gait, we can get the relationship figure between the frequency and speed of the robot. It is shown in figure 11.

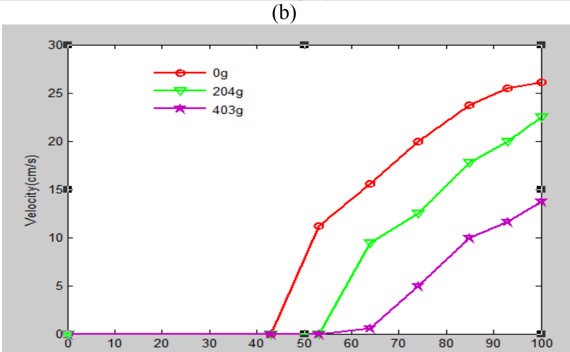
Fig.11 shows that without load, the maximum velocity of the robot is 8cm/s at the frequency of 1.25Hz on the title floor under quadruped movement pattern. Figure 11 also shows that with the frequency increasing in less 1.25Hz, the walk velocity of the robot increases and when the frequency is more than 1.25Hz, with the frequency increasing the walk velocity of the robot decreases. In the vicinity of the band 1.25HZ, with the increase of load weight, the velocity of the robot has relatively large attenuation. Thus, increased load on the robot has more effect on movement velocity of the robot. However, in the low or high bands, increased load on the robot has less effect on movement velocity of the robot.



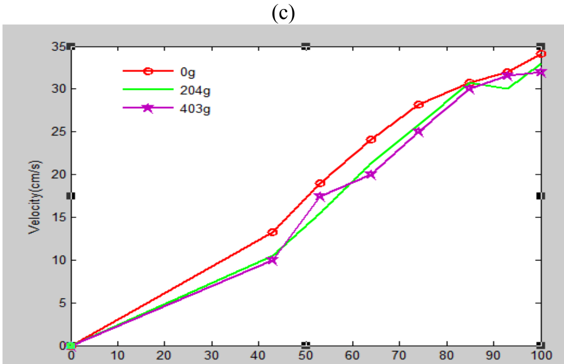
(a)



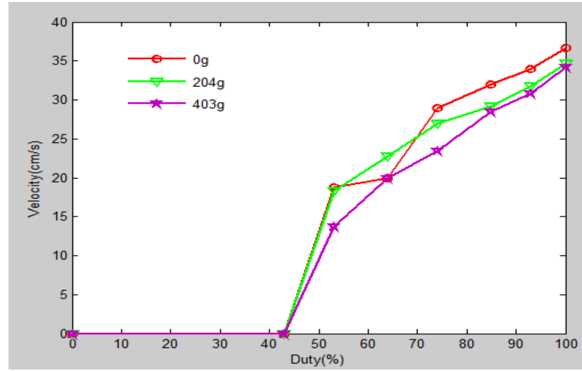
(b)



(c)



(d)



(e)

Fig.12. Results of crawling movement experiments on different terrains: (a) pavement, (b) asphalt road, (c) brick road, (d) cement floor, and (e) title floor

When the novel amphibious spherical robot walked in wheel movement gait, we can get the relationship figure between duty ratio and speed of the robot. It is shown in figure 12.

Fig.12 shows that without load, the maximum velocity of the robot is 36.7cm/s at the duty of 100% on the title floor under wheel movement pattern. Fig.12 also shows that with the duty increasing, the walk velocity of the robot increases. With the increase of load weight, the velocity of the robot has relatively small attenuation. Thus, increased load on the robot has little effect on movement velocity of the robot.

Figure 11 and 12 both show that in two movement patterns, robot moving speed decreases with the load increasing in the same terrain.

V CONCLUSION AND FUTURE WORK

We put forward a new kind of the amphibious spherical robot which includes four drive units in this paper. The robot can constitute 3 movement structure ways according to the environment, including wheel structure movement or quadruped walking movement adopted on land and water jet propulsion in water. According to different land conditions, there are two movement patterns to switch. The ground is relatively flat; wheel structure pattern is adopted by the robot to improve movement speed. While the ground is more rigorous, the robot can use quadruped movement pattern to climb over obstacles. And the paper mainly states characteristic evaluation on land for a novel amphibious spherical robot in two movement patterns that include quadruped movement crawling and wheel movement. Experiments based on two movement patterns were conducted under the condition of different terrains and different loads on land. We can draw some conclusions.

1) In two movement patterns, robot moving speed decreases with the load increasing in the same terrain.

2) Without load, the maximum velocity of the robot is 8cm/s at the frequency of 1.25Hz on the title floor under quadruped movement pattern and the maximum velocity of the robot is 36.7cm/s at the duty of 100% on the title floor under wheel movement pattern.

3) Wheel movement improves movement speed of the amphibious spherical robot under the flat ground terrain.

As for the future work, accurate water test will be performed. Advanced control algorithm is applied to the control of the robot.

ACKNOWLEDGMENT

This research is partly supported by National Natural Science Foundation of China (61375094), Key Research Program of the Natural Science Foundation of Tianjin (13JCZDJC26200), and National High Tech. Research and Development Program of China (No.2015AA043202).

REFERENCES

[1] Ting M.C., M. Abdul Mujeebu, M.Z. Abdullah, M.R.Arshad, "Numerical study on hydrodynamic performance of shallow Underwater Glider Platform", *Indian Journal of Geo-Marine Sciences*, Vol.41, N0.2, pp.124-133, 2012.

[2] Aarne Halme, Torsten Schonberg, Yan Wang, "Motion control of a spherical mobile robot", *Proceedings of the 1996 4th International Workshop on Advanced Motion Control*, Vol.1, pp. 259-264, 1996.

[3] Simon A. Watson, Dominic J. P. Crutchley, Peter N. Green, "The mechatronic design of a micro-autonomous underwater vehicle (μAUV)", *Mechatronics and Automation*, Vol. 2,N0.3,pp.157-168,2012.

[4] Anirban Mazumdar, H. Harry Asada, "A Compact Underwater Vehicle Using High-Bandwidth Coanda-Effect Valves for Low Speed Precision Maneuvering in Cluttered Environments",*2011 IEEE International Conference on Robotics and Automation*,Shanghai,China,pp.1544-1550,2011.

[5] Anirban Mazumdar, Martin Lozano, Aaron Fittery, and H. Harry Asada, "A Compact, Manoeuvrable, Underwater Robot for Direct Inspection of Nuclear Power Piping Systems",*2012 IEEE International Conference on Robotics and Automation*, Minnesota, USA,pp.2818-2823,2012.

[6] Anirban Mazumdar,H. Harry Asada ,"Pulse Width Modulation of Water Jet Propulsion Systems Using High-Speed Coanda-Effect Valves", *Journal of Dynamic Systems, Measurement, and Control* ,Vol.135,2013.

[7] Anirban Mazumdar, Aaron Fittery, Wyatt Ubellacker, and H. Harry Asada, "A Ball-Shaped Underwater Robot for Direct Inspection of Nuclear Reactors and Other Water-filled Infrastructure",*2013 IEEE International Conference on Robotics and Automation*, Karlsruhe, Germany,pp.3400-3407,2013.

[8] Bir Bikram Dey, Sandeep Manjanna and Gregory Dudek."Ninja Legs: Amphibious One Degree of Freedom Robotic Legs",*2013 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*,Tokyo, Japan,pp.5622-5628,2013.

[9] Shuxiang Guo, Juan Du, Xiufen Ye, et al, "Real-time adjusting control algorithm for the spherical underwater robot", *Information*, Vol. 13, No.6, pp.2021-2029, 2010.

[10] LiWei Shi, Shuxiang Guo, Shilian Mao, "Development of an amphibious turtle-inspired spherical mother robot", *Journal of Bionic Engineering*, Vol.10, No.4, pp.446-455, 2013.

[11] Shuxiang Guo, Maoxun Li, Chunfeng Yue, "Underwater performance evaluation of an amphibious spherical mother robot", *Proceeding of the IEEE International Conference on Information and Automation*, pp. 1039-1044, 2013.

[12] Shuxiang Guo, Shilian Mao, Liwei Shi, "Development of an amphibious mother spherical robot used as the carrier for underwater microrobots", *Proceedings of the 2012 ICME International Conference on Complex Medical Engineering*, pp.758-762, 2012.

[13] Shuxiang, Guo, Shilian Mao, Liwei Shi, "Development of a Spherical Amphibious Mother Robot", *Proceedings of the 2013ICME International Conference on Complex Medical Engineering*, pp.614-619, 2013.

[14] Shuxiang Guo, Maoxun Li, Chunfeng Yue, "Performance evaluation on land of an amphibious spherical mother robot in Different Terrains", *Proceedings of 2013 IEEE International Conference on Mechatronics and Automation*, pp.1173-1178, 2013.

[15]Maoxun Li, Shuxiang Guo, Hideyuki Hirata, Hidenori Ishihara, "Design and Performance Evaluation of an Amphibious Spherical Robot", *Robotics and Autonomous Systems*, Vol.64 pp.21-34, 2015.

[16] Shuxiang Guo, Juan Du, Xiufen Ye, et al, "The computational design of a water jet Propulsion spherical underwater vehicle", *Proceedings of the 2011 IEEE International Conference on Mechatronics and Automation*, pp. 2375-2379, 2011.

[17] Xiaojuan Lan, Hanxu Sun, Qingxiang Jia, "Principle and dynamic analysis of a new-type spherical underwater vehicle", *Journal of Beijing University of Posts and Telecommunications*, Vol.33, No.3, pp.20-23, 2010.

[18]Shuan-Yu Shen, Cheng-Hsin Li, Chih-Chung Cheng, et al, "Design of a Leg-Wheel Hybrid Mobile Platform", *The 2009 IEEE/RSJ International Conference on Intelligent Robots and Systems,* pp.4682-4687,2009.

[19]G. Endo and S. Hirose, "Study on roller-walker," *IEEE International Conference on Robotics and Automation*, Vol.1, pp. 2032–237, 1999.

[20] Fu Wan, Shuxiang Guo, Xu Ma, et al, "Characteristic Analysis on Land for an Amphibious Spherical Robot", *Proceedings of 2014 IEEE International Conference on Mechatronics and Automation*, Tianjin, China, pp.1945-1950, 2014.