Journal of Energy Research and Reviews

Volume 14, Issue 3, Page 65-73, 2023; Article no.JENRR.102919
ISSN: 2581-8368

Application and Prospect of Wave Energy in Marine Robots

Liu Chuan [a*] and Yuan Shifeng [a]

[a] *North China University of Water Resources and Electric Power, Zhengzhou, China.*

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JENRR/2023/v14i3287

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/102919

Original Research Article

Received: 01/05/2023
Accepted: 01/07/2023
Published: 02/07/2023

ABSTRACT

Marine robots are an important tool for developing and exploring the ocean, which can adapt and work in the harsh marine environment. However, energy supply is one of the important factors that limit the operational capabilities of marine robots, and obtaining energy from the marine environment is an important way to improve the operating time and scope of marine robots. Wave energy is the most widely distributed in the ocean, with high energy flow density and easy to develop renewable clean energy. Therefore, wave energy can be used to provide energy for marine robots. Wave energy provides the possibility to solve the problem between the basic endurance and limited energy of marine robots. This paper introduces wave energy, summarizes the application of wave energy in marine robots, and analyzes its development trend, so as to provide reference for energy research of marine robots.

Keywords: Wave energy; marine robot; new energy; energy supply.

**Corresponding author: E-mail: lxcjxjy@163.com;*

1. INTRODUCTION

So far, due to the emergence of the global resource crisis, traditional energy (coal, oil, natural gas) is increasingly unable to meet the development and survival of human society. The ocean contains abundant natural resources, so people turn their attention to ocean energy. However, the marine environment is complex and changeable, and the natural conditions are very harsh, making long-term exploration of the ocean very difficult. With the rapid development of robotics, marine robots have been applied to the exploration and development of the ocean. Marine robots include unmanned surface vehicles (USV), autonomous underwater vehicles (AUV), Remotely Operated Vehicle (ROV)Human Occupied Vehicle (HOV) and hybrid-driven robots [1-3]. Marine robots mainly rely on batteries to provide energy for them, but the energy stored in batteries is limited and cannot provide the required energy for these vehicles for a long time. When the battery power is exhausted, it needs to be salvaged manually to recharge the device, and then replace the device after the battery is fully charged [4]. Moreover, if the battery suffers damage during use, it can cause pollution of the marine environment. Some marine robots rely on the surface mother ship to provide energy for them through cables. This method is usually limited by the length of the cable, so the operating range of marine robots is limited [5]. Researchers from various countries are seeking new ways to increase the operating range and time of marine robots [6].

One of the most important challenges facing marine robotics research over the past few decades has been the provision of underwater vehicles with long endurance. In order to reduce the consumption of vehicles, a lot of effort has been made to improve the power supply system, thereby extending the mission from hours to weeks or months, and extending the range to thousands of kilometers. There are a variety of energy that can be used in the working environment of marine robots, mainly including solar energy, wave energy, and temperature difference energy.

Wave energy is one of the most important sources of ocean energy, and it is a renewable and clean energy that is easy to use directly and has abundant reserves [7]. According to a survey by the World Energy Council, the world's available wave energy has reached 2 billion kilowatts, and the power generated by wave energy is equivalent to twice the current world's power generation energy. It can be seen that wave energy is rich in renewable energy reserves and has broad development prospects [8]. The use of ocean wave energy to provide power sources for aircraft has become a research hotspot in various countries. The use of ocean wave energy provides a new way for marine robots to develop and explore ocean resources in a large range, with long voyages and high efficiency.

2. WAVE ENERGY OVERVIEW

2.1 Mathematical Description of Wave Energy

Generally, in order to describe the ocean waves objectively and accurately, here a simple sine curve or cosine curve is used to describe mathematical model of the ocean waves [9].

The study of waves makes the following assumptions: the fluid is ideally incompressible, the motion is irrotational, there is a velocity $\Phi(x, y, z, t)$ and the following conditions are satisfied [10].

(1) Governing equation - Lagrangian equation

$\nabla^2 \varphi(x, y, z, t) = 0$ in the fluid domain

(2) On a horizontal seabed: $z = -H$ on

$$\frac{\partial \varphi}{\partial z} = 0 \tag{1}$$

(3) Conditions on the object plane, on the object plane S

$$\frac{\partial \varphi}{\partial n} = v_n \tag{2}$$

In order to mathematically describe waves, a wave motion coordinate system is established, and the origin of the coordinate system is selected on the water surface at rest, which coincides with xOy the still water surface, and Oz vertically upwards perpendicular to the still water surface. Since the water surface can fluctuate freely, it is called a free surface, the equation is set to $z = \mu(x, y, t)$, and the corresponding boundary conditions need to be supplemented on the free surface. The wave motion coordinate system is shown in Fig. 1.

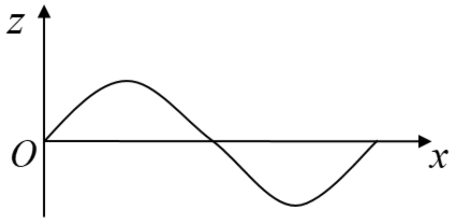

Fig. 1. Wave Motion Coordinate System

The kinematic conditions of the free surface: $z=\mu(x,y,t)$ the velocity of the fluid particle on the free surface rising and falling with the surface should be [11]:

$$v_x=\frac{\mathrm{d}z}{\mathrm{d}t}=\frac{\partial\mu}{\partial t}+v_x\frac{\partial\mu}{\partial x}+v_y\frac{\partial\mu}{\partial y} \tag{3}$$

on the wave surface: $z=\mu(x,y,z,t)$

$$\frac{\partial\varphi}{\partial z}=\frac{\partial\mu}{\partial t}+v_x\frac{\partial\mu}{\partial x}+v_y\frac{\partial\mu}{\partial y} \tag{4}$$

on a free surface the boundary conditions need to be satisfied:

$$\frac{p_a(x,y,t)}{\rho}+g\mu(x,y,z,t)+\frac{\partial\varphi}{\partial t}+\frac{1}{2}\nabla\varphi\cdot\nabla\varphi=0 \tag{5}$$

where, p_a is the atmospheric pressure, g is the gravitational acceleration

2.2 Characteristics of Wave Energy

(1) Renewable and pollution-free

Wave energy is mainly used for power generation to provide clean energy for national defense and marine facilities in remote sea areas. Wave energy has the advantages of high energy density and wide distribution. The main reason for wave energy is the effect of wind, which is essentially formed by absorbing wind energy, so wave energy can be generated continuously.

(2) Large reserves, wide distribution

Wave energy appears in the form of mechanical energy, with the highest power density in Marine energy. It is ubiquitous in the ocean, which means that wave energy can be used all day long. The average density of wave energy can reach 2-4 kW/m^2 ,which is significantly higher than solar energy (100-200 W/m^2)and other new energy sources [12].

(3) Wave energy can be used as a source of driving force

Wave energy can be converted into power resources through certain devices. On the other hand, wave energy can also be used as a source of driving force for new marine robots. The wave-driven surface robot is a marine robot propelled by wave energy, which has the advantages of unmanned, high concealment, long endurance, zero pollution, and economy.

(4) Unstable wave energy

The distribution of wave energy has significant seasonal and regional differences, and the energy is difficult to be concentrated and used. In terms of energy current density, the wave energy current density in January and October in the South China Sea is generally higher than that in April and July. The wave energy current density in January is the highest in four representative months, and the energy current density in April is the lowest in four representative months. However, the energy current density in most of the sea areas is still within the available range [13].

(5) Low conversion efficiency of wave energy

Taking wave energy generation technology as an example, so far, wave energy generation devices have formed three mainstream types: oscillating water column type, wave-surpassing type, and oscillating body type. Through the statistics and evaluation of the existing devices, it is obtained that the energy-capturing efficiencies of the oscillating water column device and the surfing device are about 29% and 17% respectively. In the oscillating body device, 70.18% of the pendulous device efficiency was lower than 20%, and 70.9% of the pendulum device efficiency was lower than 40% [14,15].

3. APPLICATION OF WAVE ENERGY IN MARINE ROBOTS

3.1 Wave Propulsion for Marine Robots

The wave-driven surface robot is a marine robot propelled by wave energy, which has the advantages of unmanned, high concealment, long endurance, zero pollution, and economy. Foreign research on wave-driven surface robots began in 2005, and it is mainly used to monitor and study the sound of humpback whales. Wave-driven surface robots are identified as multifunctional platforms for scientific, commercial, and military applications. Liquid Robotics has developed two types of Wave Glider series, SV2 and SV3 [16,17]. So far, wave gliders have been tested in various harsh environments, and wave-driven surface robots have strong survivability in extreme environments. In 2011, a wave-driven surface robot set off from San Francisco on an aerial survey mission across the Pacific Ocean. In 2012, after a year of sailing, the wave-driven surface robot safely returned to the starting point and completed the task of crossing the Pacific Ocean, which set a new world record for autonomous robot navigation [18].

Another application of wave propulsion is wave-driven unmanned surface vessels [19]. Wave-driven unmanned surface vessels are small watercraft that are propelled by ocean waves. Due to the widespread and constant presence of waves in the ocean, these vessels utilize wave energy as their power source, providing them with strong endurance. Wave-driven unmanned surface vessels find extensive applications in military and agricultural sectors. In the military domain, they can be used for tasks such as mine sweeping, surveillance, and anti-submarine operations. In the field of agriculture, various fields such as marine environmental monitoring and maritime patrol can be carried out.

(1) Structure and components of wave-driven surface robots

The structure of the wave-driven surface robot is mainly composed of three parts, which are the surface floating body, the middle mooring cable and the underwater driving carrier, as shown in the Fig. 2. The cabin of the floating body on the water surface is divided into three parts, consisting of the front cabin, the rear cabin and the control cabin in the middle [20-22]. The front compartment and the rear compartment are mainly load compartments, and communication systems, sensor systems and energy systems are installed in these two compartments. Wireless communication equipment, a weather station, a wave height meter and a camera are installed on the deck of the floating body on the water surface. The fixed tail rudder at the tail of the floating body adopts a sickle shape, and the tail rudder makes the hull have good stability, which can make the hull avoid obstacles and sail normally according to the predetermined track. Solar panels are installed on the surface of the floating body, which can provide energy for the electronic communication equipment and sensor equipment in the cabin. Solar panel power generation is greatly affected by seasons and geographical locations, and sometimes cannot provide the maximum output power.

The underwater drive carrier is mainly composed of a main frame, a hook, a gliding hydrofoil and a steering tail rudder. The underwater drive carrier is shown in the Fig. 3 [23]. The main frame is the frame of the carrier, the hook is used to lift the carrier and connect the middle tether cable, and the steering rudder is used to control the direction of the robot's movement. The gliding hydrofoil is the key to the entire underwater drive carrier, and the hydrofoil provides a steady stream of power for the wave-driven surface robot.

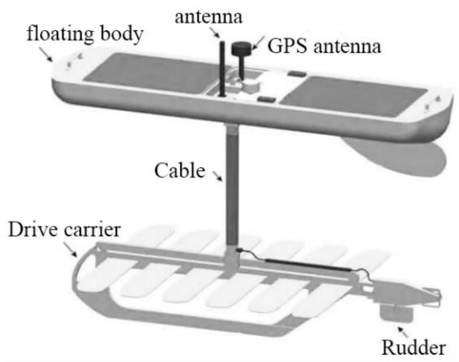

Fig. 2. Structure of a wave-driven surface robot

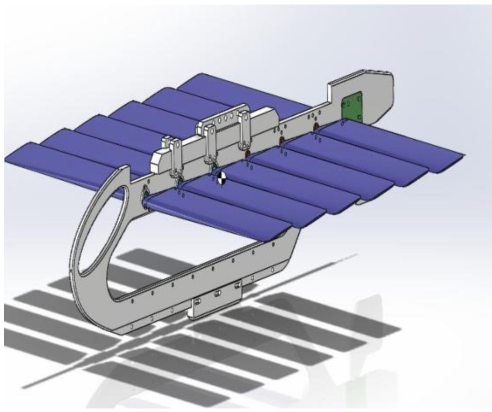

Fig. 3. Structure of the underwater drive carrier

The length of the middle mooring cable should not be too long, otherwise it will cause asynchronous movement and increase the overall resistance of the wave glider. According to the working environment of the wave-driven surface robot, the length of the middle mooring cable can refer to the working water depth. The material selection of the intermediate tether needs to have good tensile resistance and toughness. Since it works in a seawater environment, it should also have good waterproof and corrosion resistance. There are cables inside the middle tether, which transmit signals for the floating body on the water surface and the underwater drive carrier. When the surface floating body receives the shore-based signal, the middle tether cable transmits the signal to the tail rudder of the underwater drive carrier to control the robot to turn according to the predetermined route.

(2) Propulsion mechanism of wave-driven surface robot

The movement of the wave-driven surface robot in the waves is shown in the Fig. 4. The wave-driven surface robot moves in the waves, among which the underwater drive carrier plays a decisive role, which provides power for the entire robot. Wave undulations cause the heave motion of the floating body on the water surface. The heave motion causes the lifting motion of the underwater drive carrier through the middle tether cable. The 12 hydrofoils of the underwater drive carrier generate forward driving force, and then pass through the middle will pull the entire robot forward.

Fig. 4. The wave-driven surface robot in the waves

When the wave crest comes, the floating body moves upwards driven by the waves, and the underwater drive carrier is pulled through the middle mooring cable, and the whole robot moves upwards. At this time, under the action of hydrodynamic force, the wing plates on both sides of the underwater drive carrier rotate counterclockwise at a certain angle, causing the water to generate a horizontal forward component force on the underwater drive carrier, which is transmitted through the middle tether Give the floating body on the water surface and pull the whole robot to move forward. When the trough comes, the water surface floating body will move downward due to its own gravity, and the middle mooring cable will become slack without tension for a period of time. The underwater driving carrier will also move downward due to its own gravity. At this time, under the action of hydrodynamic force, the wing plates on both sides of the underwater driving carrier will rotate clockwise at a certain angle. The rotation of the wing plate will cause the water to generate a horizontal forward component force on the underwater drive carrier, which is also transmitted to the water surface floating body through the middle tether cable, and then pulls the entire robot to move forward. In short, when the waves come, no matter the crest or the trough, the floating body on the water surface does heave motion in the vertical direction, and the hydrodynamic component of the underwater wing plate is always forward, so it can always provide direction for the wave-driven surface robot. previous driving force. Wave-driven surface robots use mechanical means to directly convert wave energy into propulsion, without consuming other energy sources, and can achieve long-term battery life and large-scale work The propulsion mechanism of the wave-driven surface robot is shown in the Fig. 5 [24].

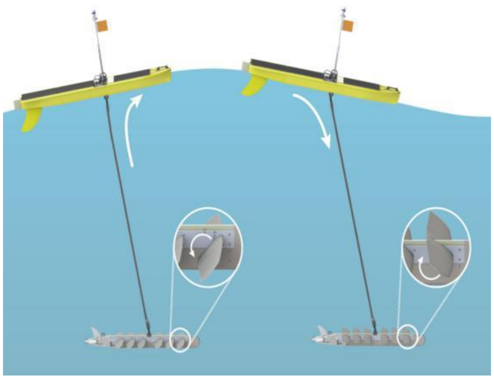

Fig. 5. Propulsion mechanism of wave-driven surface robot

(3) Application of wave-driven surface robots

The characteristics of low cost, long-lasting endurance, and wide application range of wave-driven surface robots make them widely used in the monitoring of marine environments. The wave-driven surface robot relies on the conversion of wave energy by the underwater drive carrier to provide driving force for the robot without the consumption of other energy sources, which greatly improves the range and time of its navigation.

Wave-driven surface robot applied to fishery acoustic survey [25]. The fisheries research community has been working to reduce the noise of vessels used in acoustic stock assessment surveys, and while significant noise reductions have been achieved, no vessel powered by a diesel engine can match the quiet operation of a wave-driven surface robot. Acoustic data obtained from wave-driven surface robots will have significant advantages over data obtained from traditional low-noise shipboard surveys for population assessment. Most importantly, the survey of fish stock distribution by wave-driven surface robots takes less time than traditional low-noise shipboard surveys.

Wave-driven surface robots are used in military aspects such as sea area surveillance. Wave-driven surface robotic ocean observation platforms can be controlled remotely, with some capability for autonomous operation. They are powered by wave energy and are designed for constant surveillance. The wave-driven surface robot applied in sea area surveillance is shown in the Fig. 6 [26].

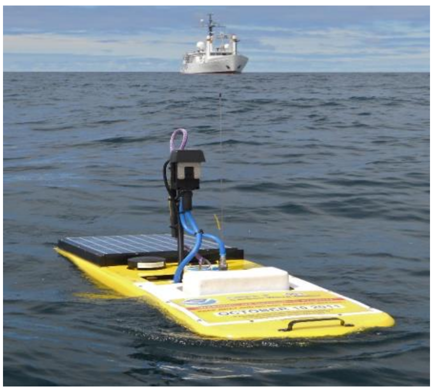

Fig. 6. The wave-driven surface robot applied in sea area surveillance

Wave-driven surface robots are used in ocean exploration. The wave-driven surface robot attaches the two equipment with side-scanning sonar to the tail end of the underwater tractor of the wave- driven surface robot to realize terrain mapping, and the experimental results are good. Wave-driven surface robots applied to marine hurricane forecasting and research. Wave-driven surface robotic ocean observation platforms have become a major component of many U.S. and international ocean hurricane warning systems.

3.2 Marine Robot Wave Power Generation

One of the most important challenges in marine robotics research over the past few decades is to provide long endurance for underwater vehicles. A great deal of effort has focused on power system improvements to reduce the consumption of the aircraft, thereby extending missions from hours to weeks or months, and to ranges of several thousand kilometers. Recharging the internal batteries of marine robots during missions is another unique approach to long-term autonomy. A more flexible, almost unexplored idea is to equip marine robots with a portable device capable of harvesting energy directly from surrounding waves to power the marine robot's internal electrical equipment. Waves in the ocean are not limited by time and place, so it is of great research significance to directly convert wave energy into usable energy.

(1) Introduction of marine robot wave power generation device

Townsend team at the University of Southampton in the UK have considered a new rotary, wave-based energy harvesting system for charging underwater vehicles. The schematic diagram of the wave-based energy harvesting system is shown in the Fig. 7 [27]. A control moment gyro is installed inside the underwater vehicle. The control moment gyroscope is composed of a universal flywheel, and the swing of the underwater vehicle caused by waves will cause the movement of the universal flywheel, thereby generating relative motion and torque. The flywheel rotates to store energy in the form of kinetic energy. The flywheel has a diameter of 0.1 m, a mass of 3.5 kg, a moment of inertia of 0.00482 $kg \cdot m^2$, a rotation speed of 5000 r/min, and can collect an average of 0.05 W～0.6 W of energy per hour, the peak can reach 8 W per hour [28,29].

Researchers from Northwestern Polytechnical University have developed a shaking power generation device based on wave kinetic energy.

The power generating device is mainly composed of a rare earth permanent magnet generator and a swinging pendulum. The rare earth permanent magnet generator is fixedly installed on the unmanned underwater vehicle, and the swing pendulum is installed on the rotor of the generator. Its structure and installation position are shown in the Fig. 8 [30].

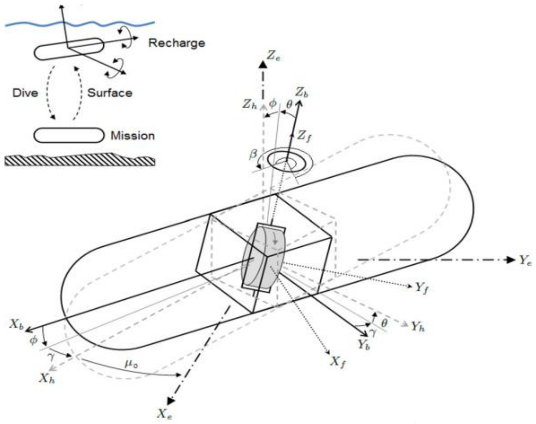

Fig. 7. Schematic diagram of a wave-based energy harvesting system

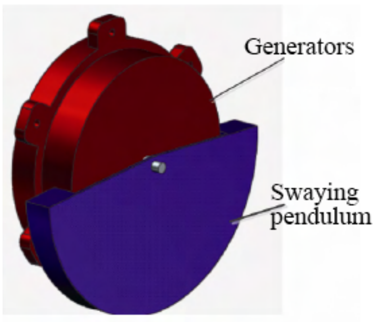

Fig. 8. Principle structure of power generation device

(2) Application of marine robot wave power generation

Townsend team at the University of Southampton in the United Kingdom conducted two experiments on the south coast of England. The first test was carried out at low tide after high tide, in order to avoid the influence of tide on the waves. The second trial took place in Southampton waters at around high tide. This experiment found that the angular velocity of the underwater vehicle was greatest in roll, which exhibited different amplitudes and a larger frequency range compared to the measured pitch and yaw angular velocities. When the underwater vehicle oscillates and rotates under the interference of waves, the voltage is generated at the frequency of the angular velocity of the wave excitation of the vehicle. Experiments performed at low tide after high tide yielded a maximum instantaneous power of 3.58 W, and experiments performed at high tide yielded a maximum instantaneous power of 2.86 W.

4. THE PROSPECT OF WAVE ENERGY APPLICATION IN MARINE ROBOTS

Wave energy is widely distributed, abundant in reserves, and relatively convenient to develop and utilize, which provides a new way for the energy supply of marine robots. At present, there are two main ways of applying wave energy to marine robots. First, the wave energy is directly converted into mechanical energy for the movement of marine robots, such as wave-driven surface robots and wave-driven ships; second, the wave energy is converted into electrical energy through the device and stored, and then the electrical energy is used. The two methods have different advantages and disadvantages, and a reasonable choice needs to be made according to the task requirements.

Wave energy still needs to be improved in several aspects in the application of marine robots. First, improve the conversion efficiency of wave energy directly into mechanical energy. Through the optimization of the motion mechanism and parts, the marine robot can make full use of wave energy. Second, efficient energy storage technology. After passing through the wave energy capture device on the marine robot, the obtained electric energy needs to be stored. The pros and cons of energy storage technology have a great impact on the working ability of the marine robot. In addition, the energy storage method must also meet the characteristics of safety, reliability and stability. Third, the wave energy conversion device and the robot body structure should be integrated. The integration of various devices can reduce the loss in the energy conversion process, reduce the weight of the marine robot.

More new technologies are coming soon. With people's attention to the development of wave energy technology, it is certain that in the near future, more and more new technologies will be cited and carried on marine robots, such as new materials, new methods, new devices, etc. For example, efficient energy storage technology. After energy is obtained, energy must be stored, and the advantages and disadvantages of energy storage technology have a direct impact on the endurance and sustainable operation ability of marine robots.

The comprehensive utilization of new energy is an important development trend. In the future, the comprehensive utilization of various marine new energy sources will expand the operating time and scope of marine robots. With the development of new energy technology, more forms of energy will be used in the design and development of marine robots in the future.

5. CONCLUSION

The utilization of ocean wave energy is a way of utilizing new ocean energy. With the rapid development of ocean wave energy utilization technology, the conversion method and utilization efficiency of wave energy will continue to improve. Regarding the research on the use of wave energy by marine robots, this paper draws the following conclusions.

(1) At the same time, more and more marine new energy sources such as solar energy, wind energy, and temperature difference energy will be widely used in marine robots.
(2) With the advancement of material technology and engineering technology, energy harvesting devices will become safe and reliable, providing a stable and efficient energy supply for marine robots.
(3) It is foreseeable that more and more marine new energy will be utilized by marine robots in the future.
(4) The comprehensive utilization of multiple energy sources has expanded the scope of application of marine robots. To a large extent, this solves the problem of insufficient energy supply of a single energy source under specific sea conditions.

ACKNOWLEDGEMENTS

Author wishes to express his sincere thanks to reviewers for their valuable comments in the preparation of revised version.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. RPM, SY W, RM J. Marine robots for coastal ocean research in the western Indian Ocean. Ocean & Coastal Management. 2021;212.
2. Stöcker C, Bennett R, NEX F, Gerke M, Zevenbergen J. Review of the current state of UAV regulations. Remote Sens. 2017; 9(5):459.
3. peng y, yanG Y, Cui J, Li X, Pu H, Gu J et al. Development of the USV 'JingHai-I' and sea trials in the southern Yellow Sea. Ocean Eng. 2017;131:186-96.
4. Wernli RL. AUVs-the maturity of the technology. In: Proceedings of the oceans'. Vol. 99. MTS. IEEE Publications. 1999; 189-95.
5. Aguirre-Castro OA, Inzunza-González E, GARCÍA-Guerrero EE, Tlelo-Cuautle E, López-Bonilla OR, Olguín-Tiznado JE et al. Design and construction of an ROV for underwater exploration. Sensors (Basel). 2019;19(24):5387.
6. JIN S, Greaves D. Wave energy in the UK: Status review and future perspectives. Renew Sustain Energy Rev. 2021;143: 110932.
7. Zhao L-C, Zou H-X, XIE X, Guo D, Gao Q, Wu Z et al. Mechanical intelligent wave energy harvesting and self-powered marine environment monitoring. Nano Energy. 2023;108:108222.
8. Khaligh A, ONAR OC. Energy harvesting: solar, wind, and ocean energy conversion systems. CRC Press; 2017.
9. Guled CN, Tawade JV, Kumam P, Noeiaghdam S, Maharudrappa I, Chithra SM et al. The heat transfer effects of MHD slip flow with suction and injection and radiation over a shrinking sheet by optimal homotopy analysis method. Results Eng. 2023;18:101173.
10. Guled C, Singh B. MHD flow over a stretching permeable surface using homotopy analysis method. Vol. F2016(12). Atlantis Press; 2017.
11. Guled CN, Singh BB. Homotopy analysis of the radiation effect on MHD flow with heat and mass transfer due to a point sink. Adv Math Phys. 2016;2016:1-14.
12. Zheng C, Shao L, SHI W, Su Q, Lin G, Li X, et al. An assessment of global ocean wave energy resources over the last 45 years. Acta Oceanol Sin. 2014;33(1):92-101.
13. Chongwei Z, Gang L. Simulation research on wave energy resources in South China Sea in recent 22 years. J Trop Oceanogr. 2012;31(06):13-9.
14. Zhang Y, Zhao Y, Sun W, Li J. Ocean wave energy converters: technical principle, device realization, and

performance evaluation. Renew Sustain Energy Rev. 2021;141:110764.

15. Rodrigues C, Ramos M, Esteves R, Correia J, Clemente D, Gonçalves F et al. Integrated study of triboelectric nanogenerator for ocean wave energy harvesting: Performance assessment in realistic sea conditions. Nano Energy. 2021; 84:105890.
16. Brown P, Hardisty D, Molteno TCA. Wave-powered small-scale generation systems for ocean exploration. In: Proceedings of the oceans. IEEE Publications; 2006-: 1-6.
17. Beach JN. Integration of an acoustic modem onto a wave glider unmanned surface vehicle: Naval Postgraduate School Monterey CA; 2012.
18. Villareal TA, Wilson C. A comparison of the pac-X transpacific wave glider data and satellite data. Plos One. 2014;9(3): e92280.
19. SAKAGAMI N, TERAO Y. Development of a measurement and autonomous control system for wave-powered boats; proceedings of the 2012. Oceans-Yeosu. IEEE Publications; 2012.
20. Yu JC, Liu SJ, Jin WM, Huang Y. The present state of deep-sea underwater glider technologies and applications. J Eng Stud. 2016;08(2):208-16.
21. Manley J, Willcox S. The wave glider: A new concept for deploying ocean instrumentation. IEEE Instrum Meas Mag. 2010;13(6):8-13.
22. Hine R, Willcox S, Hine G. The Wave Glider: A Wave-Powered autonomous marine vehicle. In: Proceedings of the oceans. 2009;F26-29.
23. Andersen A, Bohr T, Schnipper T, Walther JH. Wake structure and thrust generation of a flapping foil in two-dimensional flow. J Fluid Mech. 2017;812.
24. Zhou C-L, Wang B-X, Zhou H-X, Li J, Xiong R. Dynamic modeling of a wave glider. Frontiers Inf Technol Electronic Eng. 2017;18(9):1295-304.
25. Greene CH, Meyer-Gutbrod EL, Mcgarry LP, et al. A wave glider approach to fisheries acoustics: Transforming how we monitor the nation's commercial fisheries in the 21st century. Oceanography. 2014;27(4):168-74.
26. Schmitt MN, Goddard DS. International law and the military use of unmanned maritime systems. Int Rev Red Cross. 2016;98 (902):567-92.
27. Townsend NC, Shenoi RA. Feasibility study of a new energy scavenging system for an autonomous underwater vehicle. Auton Robots. 2016;40(6):973-85.
28. Bracco G, Giorcelli E, Iswec MG. A gyroscopic mechanism for wave power exploitation. Mech Mach Theor. 2011; 45(10):1411-24.
29. Townsend NC, Shenoi A. Recharging autonomous underwater vehicles from ambient wave induced motions. Piscataway: IEEE Publications. 2013;1-10.
30. Ding WJ, Song BW, Zhaoyong M. Design of wave energy generation system for unmanned underwater vehicles for shallow water exploration. J Mech Eng. 2015;51 (2):7.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/102919