

Energy Conversion Efficiency of Wave Gliders

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Abstract:

Wave gliders are a new type of ocean observation platform that can gain forward power by receiving and converting wave energy. The ability of wave gliders to turn waves determines the speed, maneuverability, and precision of wave gliders' navigation control in various sea conditions. In order to examine their abilities to convert waves at different wave heights and periods, herein, a critical investigation is conducted on the energy efficiency of wave gliders. This article is aimed to introduce the structure, movement mechanism, as well as energy conversion, and transfer form of wave gliders. In addition, an appropriate mechanical model for wave gliders is developed and analyzed and the energy efficiency formula is derived using the numerical analysis approach. The "Blue Whale" wave glider is utilized to carry out energy efficiency experiments to assess the wave conversion ability of wave gliders, and to master the wave conversion efficiency of wave gliders in various sea conditions. Finally, based on the experimental data, the influences of wave height and wave period on the energy conversion efficiency of wave gliders are methodically analyzed. The achieved results reveal that the energy conversion efficiency of the wave glider is not directly correlated with the wave period or the wave period, but it exhibits a specific correlation with the ratio of wave period to wave height, but the correlation coefficient is only 0.78. This issue guides us to further examine the deep mechanism that affects the energy conversion efficiency of wave gliders in the near future.

Keywords: Wave glider; Conversion efficiency; Wave; Energy.

INTRODUCTION

Wave gliders are a new type of wave-powered and persistent ocean vehicles. The key innovation of wave gliders is their ability to harvest the abundant energy of ocean waves to afford limitless propulsion. By harvesting abundant natural energy from ocean waves, wave gliders provide a permanent ocean presence for accurate ocean observation (Willcox S et al., 2009; Manley J et al., 2010; Manley J et al., 2010). The wave glider is an interesting autonomous surface craft, it is a hybrid surface and underwater vehicle consisting of a "submersible glider" connected via an "umbilical cable" to a "surface float". The main function of the surface float is to absorb and convert solar energy, and it is also employed to absorb wave energy and transfer that to the submersible glider. There are two or three solar panels attached to the surface float, which can convert solar energy into electrical energy to provide communication, navigation, position and control system, as well as load sensors mounted on the wave glider. Six pairs of wings are symmetrically placed on the submerged glider, which can absorb the wave energy transmitted from the floating object and convert it into kinetic energy that can propel the wave glider system forward. With unlimited solar and wave power, the wave glider is capable of long-term deployment of up to one year. Its unique two-part architecture allows wave gliders to travel long distances over long periods while collecting and transmitting ocean data in real time.

Research on wave gliders started from Liquid Robotics in the United States (Carragher P et al., 2014; Hine R et al., 2009; Manley J et al., 2009). Currently, this company has completed the production of SV2 and SV3 wave gliders, which are utilized in diverse fields (Cervino NP et al., 2017; Morales Maqueda M et al., 2016; Mitarai S et al., 2016). Due to the abundant marine use of wave gliders, a large number of researchers have begun to study the technology associated with wave gliders. Some investigators studied dynamic and mechanical models of wave gliders and exploited these models for speed prediction, heading control, and navigation research. In addition, some researchers utilized wave gliders to observe waves and storms, including dynamic model research (Tian B et al., 2014; Zhou C et al., 2017; Zhang J et al., 2020; Chen J et al., 2018), heading and path control (Wang P et al., 2019; Wang D et al., 2020; Wang P et al., 2020), speed prediction (Ngo et al., 2014; Smith RN et al., 2011; Sanf H Q et al., 2018), wave, surface wind, and current observation (Qin Y et al., 2020; Penna NT et al., 2018; Maqueda MAM et al., 2017; Jha R 2018). Smith (Smith RN et al., 2011) exploited the wave glider provided by Liquid Robotics based on the kinematic model to examine the speed prediction model of the wave glider in the presence of significant wave height, ocean surface and subsurface currents, and wind speed and direction. Ngo (Ngo P et al., 2013) investigated the speed prediction of wave gliders based on an established wave model. To this end, the training data from an onboard sensor and forecasting with the WAVEWATCH III model were employed and the probabilistic regression models were utilized to develop an effective methodology for predicting glider wave speed. Song (Sanf H Q et al., 2018) performed a motion simulation based on the dynamic model of the wave glider

and established a quantitative relationship between the speed of the wave glider and the wave parameters. The above literature employs various research approaches to assess the movement speed of wave gliders, but no research has been devoted to motion efficiency. Tian (Tian B et al., 2014; Tian B Q et al., 2014) utilized an experimental model to evaluate the motion efficiency of the wave glider, but no sea trial verification and no analysis of the energy conversion efficiency driven by the waves were presented.

Up till now, as a new type of unmanned equipment for wave conversion and utilization, the energy conversion efficiency of wave gliders has been relatively less explored. Based on the analysis of the movement mechanism of the wave glider, this aims to examine the relationship between the wave's height and period and the efficiency of wave gliders, which provides a theoretical basis and a solid reference for enriching and optimizing their design.

SYSTEM DESCRIPTION

A wave glider represents a two-body structure consisting of a surface float and a submerged glider. The surface float has a lot of positive buoyancy such that floats on the surface of the water and oscillates with the up and down waves and simultaneously absorbs the wave energy. Generally, the submerged glider has a lot of negative buoyancy, the float in the water and pulls the float downward. Six pairs of underwater wings are distributed on the submerged glider, which are capable of converting the wave energy into the kinetic energy to propel the wave glider forward.

The propulsion system of wave gliders is completely mechanical. No electrical power is produced by the propulsion mechanism. When the surface float rises from the navel of the wave, it pulls the submerged glider up by the umbilical cable. The six pairs of wings are compressed downward as the submerged glider rises, converting the submerged glider's upward motion into an upward and forward motion that pulls the surface float forward. When the surface float moves down from the wave crest, the submerged glider descends, and the six pairs of wings are pushed tilt up as the submerged glider descends, turning the submerged glider's downward motion into a downward and forward motion, which again pulls the surface float forward.

In the motion of the wave glider that rises with the waves, the wave glider converts part of its vertical motion into forward, generating a portion of forward propulsion force. The surface float acquires parts of the potential energy and is then transferred to the submerged glider through the umbilical cable. Simultaneously, the wing converts portions of the potential energy into the kinetic energy, and then the submerged glider transfers parts of its kinetic energy to the surface float through the umbilical cable. When the surface float reaches the wave crest, the wave glider gains maximum potential energy as well as some kinetic energy. As the wave glider leaves the wave crest, the potential energy is gradually converted to the kinetic energy. When the wave glider reaches the wave trough, the potential energy arrives at a minimum value. In this cycle, the wave glider continuously absorbs the wave energy and converts it into the potential energy and kinetic energy, and continuously transfers the energy between the surface float and the submerged glider through the umbilical cable.

The movement of wave gliders is illustrated in Figure 1 and the energy transfer path of wave gliders is presented in Figure 2.

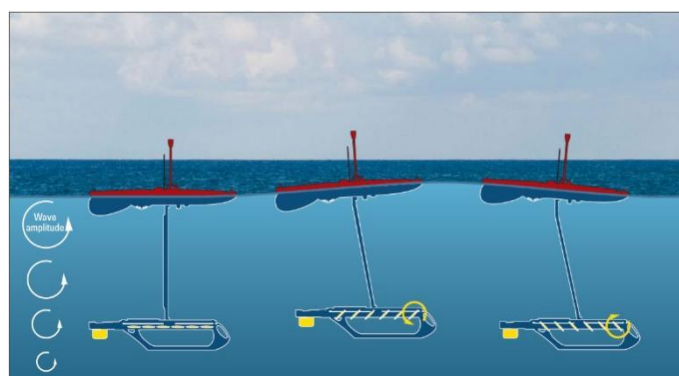


Figure 1: Schematic representation of the wave propulsion

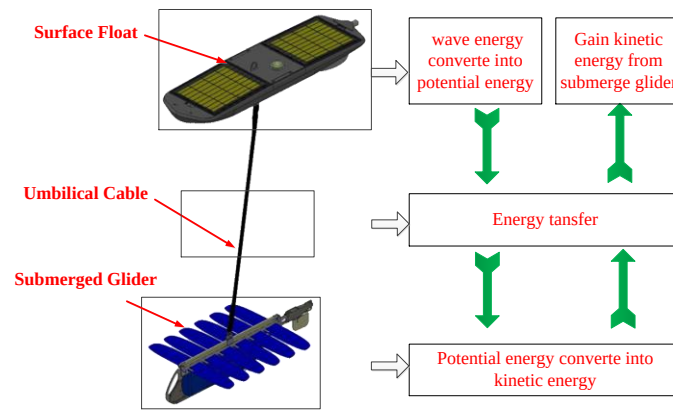


Figure 2: Chart of the energy transfer in wave gliders

ANALYSIS AND DEDUCTION

3.1 Model simplification and force analysis

The major forces of the wave glider consist of gravity, buoyancy, water resistance, wave force, and forward thrust transformed by the wings of the submerged glider. The main paths of energy conversion include the conversion between the wave energy and the potential energy and the conversion between the kinetic energy and the potential energy. In order to examine the relationship between the force on the wave glider and the efficiency of the wave energy conversion, the exerted forces on the surface float and the submerged glider should be rationally evaluated, and the mechanical model for the doubly rigid-body structure of the wave glider is then established. For the sake of simplifying the process of mechanical analysis, the water resistance of the umbilical cable is ignored, and only the weight in the water is included in the calculations, and the following main assumptions are made:

- (i) The surface float and the submerged glider are connected by the umbilical cable, the submerged glider has enough weight to keep the umbilical cable in a tight state, and both the surface float and the submerged glider can be regarded as a rigid connection separately.
- (ii) The upper end of the umbilical cable is connected to the mass center of the surface float, and the geometric surface center float is coincident with its mass center.
- (iii) The lower end of the umbilical cable is connected to the mass center of the submerged glider, and the geometric center of the submerged glider is coincident with its mass center.
- (iv) The wave surface is considered to be a monochromatic wave of infinite deep water, and the wave surface equation can be represented by a regular cosine wave.

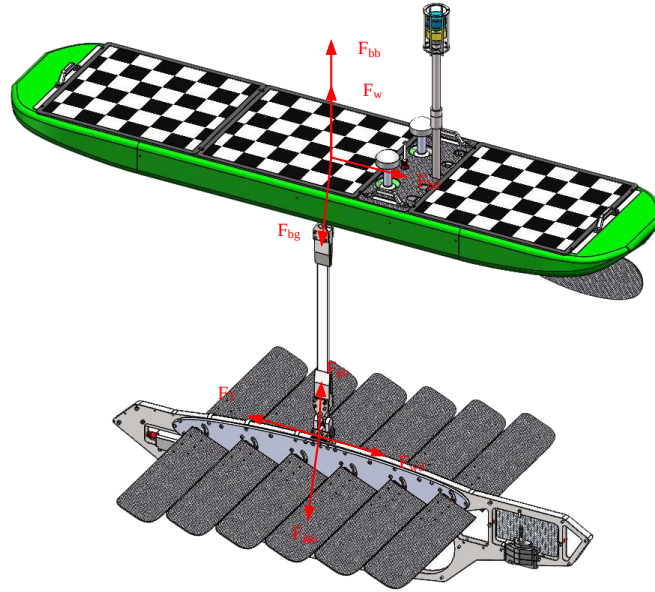


Figure 3: Force analysis of the wave glider

The applied forces on the surface float are consisting of the gravity force (F_{bg}), buoyancy force (F_{bb}), water resistance force (F_{bd}), and wave force (F_w). The forces on the submerged glider include the forward thrust force (F_T), gravity force (F_{gg}), buoyancy (F_{gb}), and water resistance (F_{gd}).

3.2 Analysis

3.2.1 Wave energy absorption

a. Ascending

The force analysis of the wave glider in this article is based on a complete wave motion. First, the force on the wave glider is analyzed when it begins to move from the wave trough. The wave glider is commonly acted upon by the upward force of the wave, moving off the wave trough and moving upward. In addition, the six pairs of wings of the submerged glider are pressed downward as the wave glider rises due to water resistance and generates forward thrust. As the wave glider rises, it gains parts of the potential energy and the kinetic energy.

Based on the calculation formula of the water resistance, the water resistance forces on both the surface float and the submerged glider can be stated by:

$$F_{bdu} = \frac{1}{2} C_{\rho bu} \rho A_{bu} v^2 \quad (1)$$

$$F_{gdu} = \frac{1}{2} C_{\rho gu} \rho A_{gu} v^2 \quad (2)$$

Therefore, the whole water resistance of the wave glider can be readily evaluated as follows:

$$F_{du} = F_{bdu} + F_{gdu} = \frac{1}{2} \rho (A_{bu} C_{\rho bu} + A_{gu} C_{\rho gu}) v^2 \quad (3)$$

where $C_{\rho bu}$ denotes the drag coefficient of the surface float during the ascending motion, A_{bu} is the windward area of the surface float, $C_{\rho gu}$ represents the drag coefficient of the submerged glider during the ascending motion, A_{gu} is the windward area of the submerged glider, and v signifies the velocity of the wave glider.

According to the Newton's second law, the acceleration of the wave glider in the horizontal direction during ascending can be evaluated as:

$$a_u = \frac{\Sigma F}{\Sigma M} = \frac{F_{Tu} - F_{bdu} - F_{gdu}}{M_b + M_g} \quad (4)$$

Assuming that the wave surface can be demonstrated by a regular cosine wave, the rise time can be reasonably set as half the wave period. Therefore, the velocity of the wave glider in the horizontal direction during the ascending stage takes the following form:

$$v_1 = \int a_u dt = \frac{F_{Tu} - F_{bdu} - F_{gdu}}{M_b + M_g} \frac{T}{2} \quad (5)$$

Using Eq. (5), the kinetic energy of the wave glider in the ascending phase can be stated by:

$$E_{ku} = \frac{1}{2} M v_1^2 = \frac{T^2}{8} \frac{(F_{Tu} - F_{bdu} - F_{gdu})^2}{M_b + M_g} \quad (6)$$

The forward movement distance of the wave glider during the ascending stage is calculated as:

$$S_1 = \frac{1}{2} a_u t^2 = \frac{1}{2} \frac{F_{Tu} - F_{bdu} - F_{gdu}}{M_b + M_g} T^2 \quad (7)$$

Where M_b and M_g , respectively, represent the masses of the surface float and the submerged glider, T is the wave period, F_{Tu} denotes the forward thrust produced by the wave gliders during the movement from wave trough to wave crest, and v_1 signifies the velocity of the wave glider.

b. Descending

When the wave glider moves from the wave crest to the wave trough, the wave glider is in the descending phase. The descent power comes from the potential energy gained during the ascending motion. During the descending, the six pairs of wings of the submerged glider are forced to tilt upward due to the water resistance. The energy of the wave glider changes and the potential energy obtained by the wave glider during the ascending stage is converted into the kinetic energy of the wave glider.

In the descending stage, the kinetic energy of the wave glider could be stated by:

$$E_{kd} = \frac{1}{2} M v_2^2 = \frac{T^2}{8} \frac{(F_{Td} - F_{bdd} - F_{gdd})^2}{M_b + M_g} \quad (8)$$

In which v_2 denotes the velocity of the wave glider during the movement from the wave crest to the wave trough. As a result, the forward movement distance of the wave glider during the descending phase is obtained as:

$$S_2 = \frac{1}{2} a_d t^2 = \frac{1}{2} \frac{F_{Td} - F_{bdd} - F_{gdd}}{M_b + M_g} T^2 \quad (9)$$

c. Calculations

As the wave glider returns in the longitudinal direction to its initial position within a wave period, the potential energy remains unchanged, and only a part of the kinetic energy is generated. Therefore, it is only necessary to evaluate the kinetic energy of the wave glider.

In a single wave cycle, the wave energy converted by the wave glider is written by:

$$E_{wgs} = E_{ku} + E_{kd} = \frac{(F_{Tu} - F_{bdu} - F_{gdu})^2 + (F_{Td} - F_{bdd} - F_{gdd})^2}{8(M_b + M_g)} T^2 \quad (10)$$

Further, the forward movement distance of the wave glider in a single wave is obtained as follows:

$$S = S_1 + S_2 = \frac{(F_{Tu} - F_{bdu} - F_{gdu}) + (F_{Td} - F_{bdd} - F_{gdd})}{2(M_b + M_g)} T^2 \quad (11)$$

As a result, the energy absorbed and converted by the wave glider per unit length is expressed by:

$$E_{wg} = E_{wgs} / S = \frac{1}{4} \frac{(F_{Tu} - F_{bdu} - F_{gdu})^2 + (F_{Td} - F_{bdd} - F_{gdd})^2}{(F_{Tu} - F_{bdu} - F_{gdu}) + (F_{Td} - F_{bdd} - F_{gdd})} \quad (12)$$

3.2.2 Wave energy for a single wave

Wave energy is essentially generated due to the vertical motions of water points, resulting from the surface friction and uneven hook pressure by the wind blowing; hence, the water points experience periodic fluctuations (i.e., upward and downward motion). When the sea surface fluctuates under the influence of the wind, the water points leave the equilibrium position, vibrate up and down, and spread the energy in a certain direction; this part of the wave energy is converted into the energy that can be utilized by human beings through special energy conversion devices.

Before arriving at the major calculations, the following assumptions are made:

- (i) Sea water is a non-viscous and incompressible fluid;
- (ii) During the movement of the water quality point, gravity is the only external force;
- (iii) The free surface pressure is set equal to the atmospheric pressure;
- (iv) The water depth is infinite.

a. Kinetic energy

Let us assume that the sea surface wave is a regular cosine wave such that it can be stated by the following function:

$$z = \zeta(x, t) = a \cos \theta = a \cos(\alpha x - \omega t) \quad (13)$$

Where ζ denotes the sea surface height, a is the amplitude, $\theta = \alpha x - \omega t$ represents the wave phase, α is the wave number, and ω is the circular frequency.

The kinetic energy of a single wave can be expressed as:

$$E_k = \frac{\rho}{2} \int \Phi \frac{\partial \Phi}{\partial n} ds = \frac{\rho}{2} \int_0^\lambda \left(\Phi \frac{\partial \Phi}{\partial z} \right)_{z=0} dx \quad (14)$$

Where the velocity potential in infinite deep water is considered in the following form:

$$\Phi = \frac{ag}{\omega} \exp(\alpha z) \sin(\alpha x - \omega t) \quad (15)$$

Hence, we can calculate the velocity potential and its first derivative at the water surface as follows: $\Phi|_{z=0} = \frac{ag}{\omega} \sin(\alpha x - \omega t)$

, $\left(\frac{\partial \Phi}{\partial z} \right)_{z=0} = \frac{a\alpha g}{\omega} \sin(\alpha x - \omega t)$. Therefore, the kinetic energy Eq. (14) is stated by:

$$E_k = \frac{\rho}{2} \frac{a^2 g^2 \alpha}{\omega^2} \int_0^\lambda \sin^2(\alpha x - \omega t) dx \quad (16)$$

Additionally, the dispersion relation of infinite deep waters reads, $\omega^2 = g\alpha$, $\int_0^\lambda \sin^2(\alpha x - \omega t) dx = \lambda/2$; Therefore, the kinetic energy of a single wave can be evaluated as:

$$E_k = \frac{\rho}{2} \frac{a^2 g^2 \alpha}{\omega^2} \int_0^\lambda \sin^2(\alpha x - \omega t) dx = \frac{\rho}{4} a^2 g \lambda \quad (17)$$

Where λ represents the wavelength, and g specifies the gravitational acceleration.

b. Potential energy

For the water surface height ζ and the width dx , the corresponding mass is evaluated as:

$$dm = \rho g \zeta dx \quad (18)$$

The position of the gravity center of the water column would be $\zeta/2$, thereby, the corresponding potential energy can be evaluated by:

$$dE_p = \frac{1}{2} \rho g \zeta^2 dx \quad (19)$$

Therefore, the potential energy of a single wave is calculated as follows:

$$E_p = \int_0^\lambda \frac{1}{2} \rho g \zeta^2 dx \quad (20)$$

By introducing the following sea surface relation to Eq. (20),

$$\zeta = a \cos(\alpha x - \omega t) \quad (21)$$

The potential energy of a single wave is obtained as:

$$E_p = \frac{1}{4} \rho g a^2 \lambda \quad (22)$$

c. Calculations

The total wave energy is composed of the kinetic energy and the potential energy, which can be obtained from the above analysis process. By this virtue, the whole energy of a single wave is calculated as:

$$E = E_k + E_p = \frac{1}{2} \rho g a^2 \lambda \quad (23)$$

For a unit length, the wave energy is defined as the ratio of the single wave energy to its wavelength:

$$E_w = \frac{E_k + E_p}{\lambda} = \frac{1}{2} \rho g a^2 \quad (24)$$

Furthermore, based on the multiple relationships of the wave height and wave amplitude (i.e., $H = 2a$), the wave energy per unit length can be evaluated by:

$$E_w = \frac{E_k + E_p}{\lambda} = \frac{1}{2} \rho g a^2 = \frac{1}{8} \rho g H^2 \quad (25)$$

3.2.3. Energy conversion efficiency

Wave gliders absorb wave energy and convert it into the appropriate kinetic energy. In this regard, the energy conversion efficiency of wave gliders can be defined as the ratio of the kinetic energy of wave gliders to the wave energy. As a result, the energy conversion efficiency of wave gliders is therefore given by:

$$\eta = E_{wg} / E_w = 2 \frac{(F_{Tu} - F_{bdu} - F_{gdu})^2 + (F_{Td} - F_{bdd} - F_{gdd})^2}{(F_{Tu} - F_{bdu} - F_{gdu}) + (F_{Td} - F_{bdd} - F_{gdd})} / (\rho g H^2) \quad (26)$$

In addition, if the velocity of the wave glider would be available to us at any time, the conversion efficiency can be also defined as the ratio of the kinetic energy of wave gliders to the wave energy. Therefore,

$$\eta = E_{wg} / E = \frac{1}{2} MV^2 / \left(\frac{1}{8} \rho g H^2 \right) = 4MV^2 / (\rho g H^2) \quad (27)$$

EXPERIMENTS AND DATA

4.1 Experiment setup

In order to master the wave energy conversion efficiency of wave gliders, this paper exploits a wave glider to conduct sea trials. For this purpose, the energy conversion efficiency of wave gliders is suitably tested in the presence of different wave heights and periods. The corresponding experiment was carried out in the South China Sea, and the equipment used in the experiment was a wave glider named “Blue Whale”. The wave glider “Blue Whale” is a mobile ocean observation platform designed by National Ocean Technology Center. The structural parameters of this specific wave glider are presented in Figure 4. The sensors equipped on the wave glider include a temperature and salt depth sensor (CTD), a weather station, and a wave sensor. The physical parameters and geometric distribution of “Blue Whale” are demonstrated in Figure 5.

The experiment began on August 20, 2020, and ended on September 5, 2020. In order to more accurately analyze the energy conversion efficiency of the wave glider, the experimental data at the initial and final stages are removed, and the experimental data of seven cases from August 24 to August 31 were intercepted.

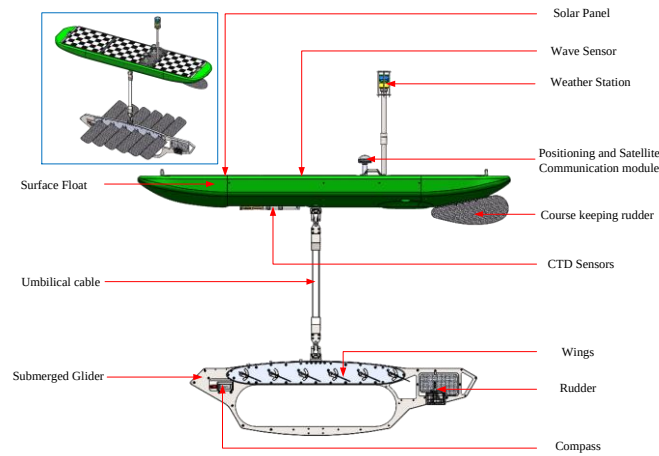


Figure 4: The structure of the “Blue Whale” wave glider

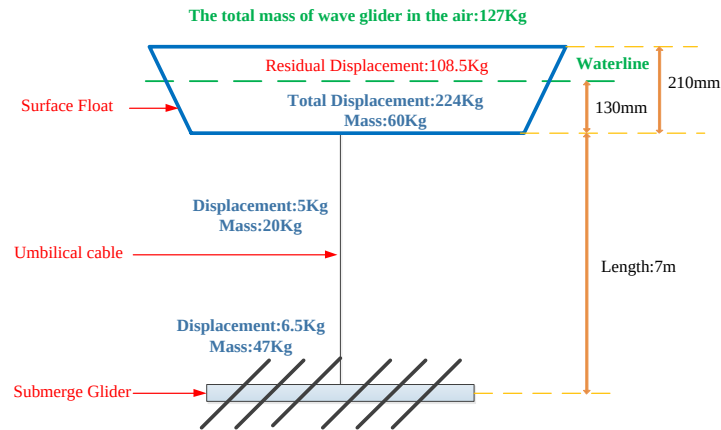


Figure 5: The physical parameters of the “Blue Whale” wave glider

4.2 Analysis

The wave height includes the maximum wave height (MWH), one-tenth wave height (OTWH), significant wave height (SWH), and average wave height (AWH). The wave period consists of the maximum wave period (MWP), one-tenth wave height (OTWP), significant wave period (SWP), and average wave period (AWP). There exist n waves in a wave surface record and all the observed wave heights are sorted in order of magnitude $H_1, H_2, H_3, \dots, H_n$, and the corresponding wave periods are sorted as: $T_1, T_2, T_3, \dots, T_n$. The maximum wave height is the maximum value of the wave height magnitude in the continuous wave record, and the maximum wave period is the wave period associated with the maximum wave height. The OTWH represents the average value of the first 1/10 in the recorded wave height magnitude, and OTWP is the wave period pertinent to the one-tenth wave height. Further, the significant wave height is also called 1/3 wave height, which represents the average value of the first 1/3 in the recorded wave height magnitude. The significant wave period is the wave period associated with the significant wave height. Besides, the average wave height is the average of all wave heights in the wave height magnitude, and the average wave period is the wave period pertinent to the average wave height.

Let us sort out the experimental data of the wave glider “Blue Whale” and then demonstrate the plots associated with the wave height and period, as illustrated in Figure 6 and Figure 7.

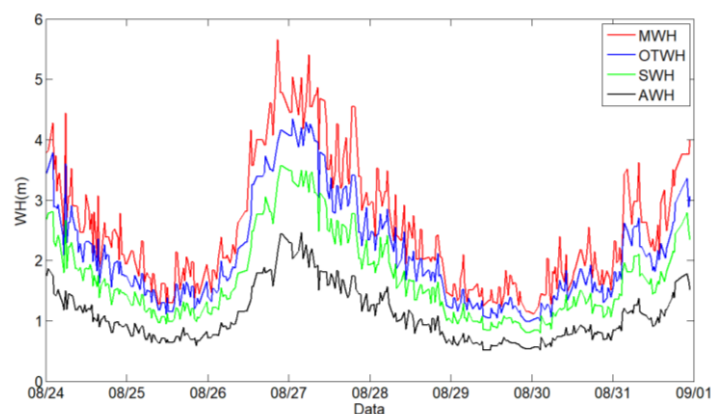


Figure 6: The wave height based on the MWH, OTWH, SWH, and AWH

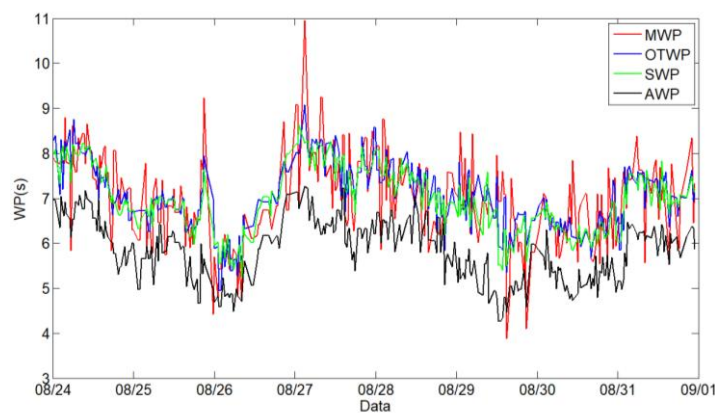


Figure 7: The wave period based on the MWP, OTWP, SWP, and AWP

According to Eq. (25), the wave energy can be separately calculated based on the MWH, OTWH, SWH, and AWH. In Figure 8, the evolution curves of the wave energy calculated based on various wave heights are presented.

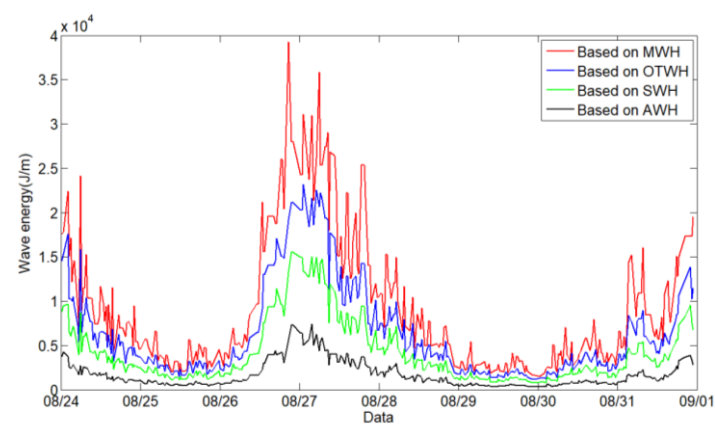


Figure 8: The wave energy based on the MWH, OTWH, SWH, and AWH

Based on the GPS position of the wave glider at various times, the velocity of the wave glider is calculated at different times and the corresponding velocity curve is demonstrated in Figure 9. Additionally, the kinetic energy of the wave glider based on the velocity of the wave glider, and then the kinetic energy curve of the wave glider, as illustrated in Figure 10.

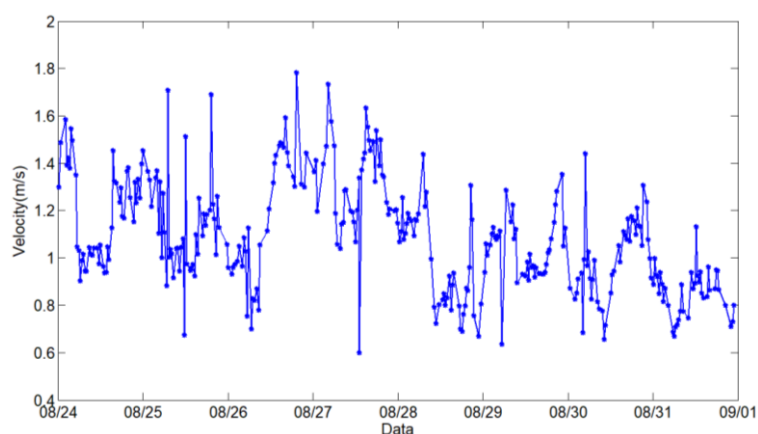


Figure 9: Velocity curve

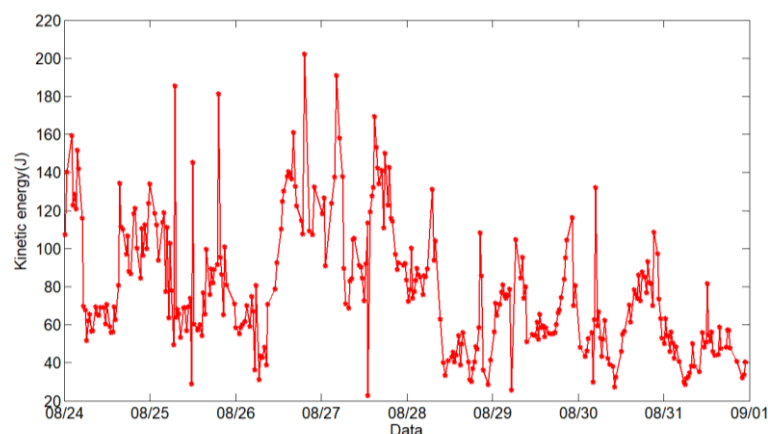


Figure 10: Kinetic energy curve

In continuing, the ratio of the kinetic energy of the wave glider to the wave energy at the same time is calculated to obtain the energy conversion efficiency of the wave glider. Next, the energy conversion efficiency curve separately is plotted based on the MWH, OTWH, SWH, and AWH, as demonstrated in Figure 11.

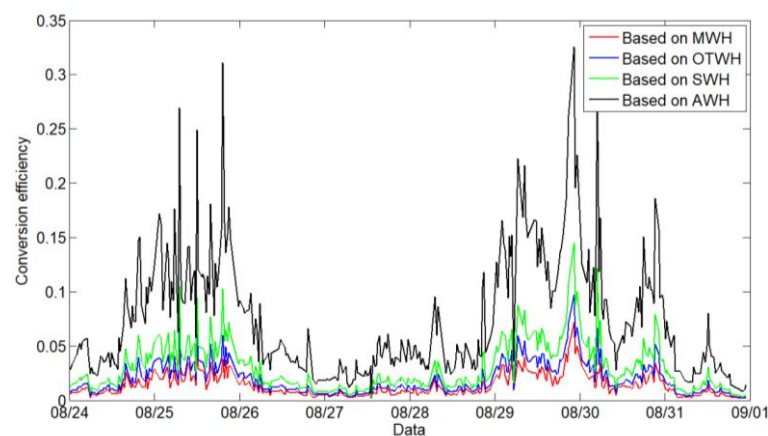


Figure 11: The energy conversion efficiency based on the MWH, OTWH, SWH, and AWH

DISCUSSION AND CONCLUSION

The values of MWH, MWP, ASWH, and ASWP observed by the wave glider during the experiment were 5.66 m, 10.96 s, 1.68 m, and 6.97 s, respectively. The maximum wave energy based on the MWH is predicted to be $3.92 \times 10^4 \text{ J/m}$, whereas the average value is evaluated as $8.89 \times 10^3 \text{ J/m}$. Further, the maximum wave energy based on the SWH is estimated as $1.55 \times 10^4 \text{ J/m}$, while the corresponding average value is obtained as $4.00 \times 10^3 \text{ J/m}$. It can be seen that the wave energy is very sufficient, which can supply enough energy for the wave glider to appropriately convert that. Some of the characteristic parameters of the wave achieved from the experimental data analysis are presented in Table 1.

Table 1: Wave characteristics parameters

Wave height (s)	Maximum (m)	Average (m)
MWH	5.66	2.51
OTWH	4.35	2.08
SWH	3.56	1.68
AWH	2.46	1.07
Wave period (s)	Maximum(s)	Average (s)
MWP	10.96	6.97
OTWP	9.08	7.04
SWP	8.63	6.97
AWP	7.26	5.84

Wave energy (J/m)	Maximum (J/m)	Average (J/m)
Based on the MWH	3.92×10^4	8.89×10^3
Based on the OTWH	2.32×10^4	6.14×10^3
Based on the SWH	1.55×10^4	4.00×10^3
Based on the AWH	7.41×10^3	1.64×10^3

The analysis results of the velocity and kinetic energy of the wave glider reveal that the wave glider is capable of absorbing and converting part of the wave energy and utilizing it to drive its motion. The maximum velocity and maximum kinetic energy of the wave glider in order are 1.78 m/s and 202.02 J. The conversion efficiency based on the various wave heights have been presented in Table 2.

Table 2: The conversion efficiency of the wave glider based on various wave heights.

Conversion efficiency	Maximum	Average
Based on the MWH	0.072	0.014
Based on the OTWH	0.097	0.020
Based on the SWH	0.145	0.031
Based on the AWH	0.326	0.077

It can be seen from Tables 1 and 2 that when different wave heights are employed to evaluate the wave energy, the achieved results would be very distinct, which results in a large discrepancy in the calculation of the energy conversion efficiency of the wave glider. Therefore, in evaluating the long-term energy conversion efficiency of wave gliders, instead of considering the conversion efficiency at a specific moment, the significant wave height can be employed to analyze and calculate the wave energy and wave conversion efficiency of wave gliders. From the analysis results, it can be seen that during the motion of the wave glider, the maximum conversion efficiency of the wave energy based on the significant wave height is calculated to be 0.145, and the average value is estimated to be 0.031.

Further analysis of coupling relationships among the wave height, wave period, wave glider speed, and energy conversion efficiency reveals that the velocity of wave gliders and the wave conversion efficiency are not directly related to the wave height or the wave period. However, there seem to be special coupling relationships among the conversion efficiency of the wave, the wave height, and the wave period. Through exploring the curve characteristics of the wave height (WH), wave period (WP), and energy conversion efficiency, it is obtainable that there would exist a high correlation between the ratio of wave period to wave height (WP/WH) and the conversion efficiency. Let us depict the wave conversion efficiency curve and the ratio curve of the wave period to the wave height, and reduce the ratio of wave period to wave height by one hundred times (i.e., $0.01 \cdot \text{WP/WH}$) to draw the corresponding curve, as presented in Figure 12. Further analysis of the correlation between the conversion efficiency and the ratio of wave period to wave height reveals that the corresponding correlation coefficient could reach 0.7827. According to the presented correlation curve in Figure 13, there exists a fairly high correlation between the above two factors.

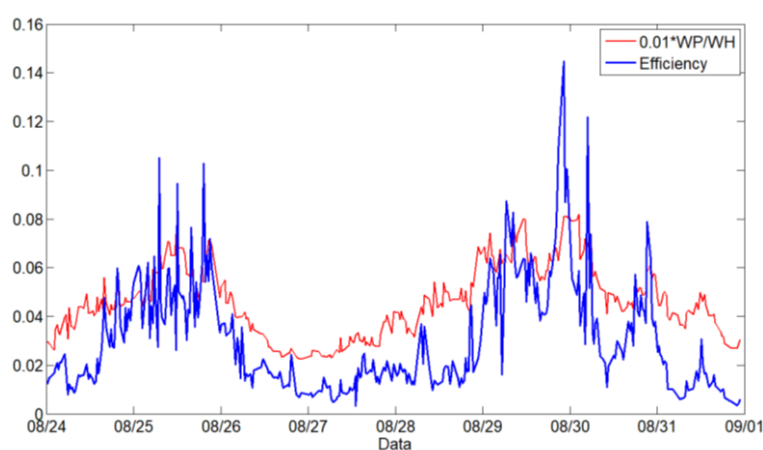


Figure 12: Evolution plots of the efficiency and the wave condition

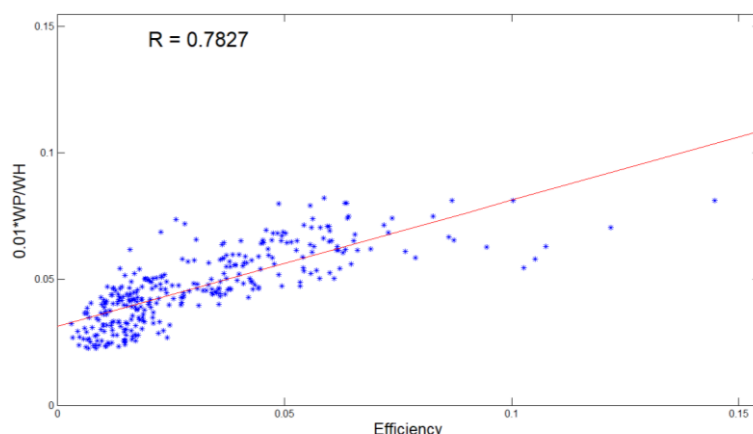


Figure 13: Correlation distribution between the efficiency and the wave condition

This investigation provided above shows that the conversion efficiency of the wave energy does not directly depend on the wave height or the wave period. Based on the current research, the energy conversion efficiency of wave gliders is mostly correlated with the ratio of wave period to wave height; however, the correlation is not particularly high since the correlation coefficient is only 0.7827. Therefore, there must be some other laws that could affect the conversion efficiency of wave gliders.

CONCLUSIONS

The research work is conducted on the energy conversion efficiency of wave gliders. The mechanical characteristics of wave gliders during the motion are appropriately analyzed via a mechanical approach. The calculation methodologies and formulas of the energy conversion efficiency of wave gliders are deduced. In addition, a validation experiment is designed to examine the conversion efficiency of the wave energy glider under different sea conditions. The analysis of the observation data reveals that wave gliders have a strong capability of the wave energy conversion, and their conversion efficiency mostly relies on the wave height and wave period. Further performed calculations indicate that the conversion efficiency of the wave energy exhibits a certain correlation with the ratio of wave period to wave height, but the correlation is not particularly high.

For future investigations, the author will comprehensively examine how wave height and wave period affect the conversion efficiency of the wave energy when the wave glider performs energy conversion, and explore the influence of the wave height and wave period on the conversion efficiency of the wave energy.

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CONFLICTS OF INTEREST

“The authors declare that they have no conflicts of interest to report regarding the present study.”

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