Velocity Measurement by Doppler Sonar Using Coherent Method

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論文内容の要旨

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専　攻　海事科学専攻

論文題目（外国語の場合は，その和訳を併記すること。）

Velocity Measurement by Doppler Sonar Using Coherent Method

（コヒーレント方式を用いたドップラーソーナーによる速度計測に関する研究）

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（注）2,000 字～4,000 字でまとめること。

In this doctoral dissertation we present a combined method of conventional and coherent Doppler sonar systems (CMDS) to provide accurate and precise marine velocity information with a short time lag. The dissertation is divided into four chapters, background, sonar system, combined method of Doppler sonar and conclusion.

Chapter 1 introduces the background of velocity measurement systems in water. The purpose of the research is to provide accurate and precise velocity for surface and underwater vessels. After introducing several velocity measurement systems, such as electro-magnetic log, inertial navigation system, velocity information Global Positioning System and Doppler sonar system, we focus on the Doppler sonar system. Conventional Doppler sonar (CNDS) can provide velocity information without velocity ambiguity, but it needs some seconds to provide valuable reading velocity. Coherent Doppler sonar (CHDS) can measure the velocity with an accuracy of about 1 cm/s, but velocity ambiguity seriously limits its general application. Therefore, CMDS is proposed in order to take advantage of both CNDS and CHDS to provide accurate and precise velocity with a short time lag. A further brief description of the dissertation's structure can be found at the end of this chapter.

Chapter 2 introduces existing Doppler sonar systems, CNDS and CHDS, in detail. Firstly, types and usages of sonar systems are introduced briefly. Then with the basic knowledge of sonar systems, CNDS and CHDS are described in detail. The fundamentals of CNDS are explained and the equations used to calculate velocity using CNDS are shown. CNDS calculates velocity using measured frequency information by Fourier transform directly based on the Doppler effect. After introducing the measurement method of CNDS, error analysis of CNDS is also discussed. After explanation of CNDS, velocity measurement by CHDS is introduced. Phase change between two adjacent pulses is used to calculate moving velocity of measured object. But because the measured phase is limited from $-\pi$ to π, velocity ambiguity occurs. Several methods have been proposed to solve this problem. One method is to introduce dual time intervals. This method can extend the range of maximum measureable velocity several times, but it decreases the data rates. Because of introducing a new time interval, it also increases measurement error of CHDS. Although a data processing technique is used to make the measurement result of dual time interval method as precise as the single time interval method, maximum measureable velocity range is still limited. Multiple frequency method is also used to enlarge the maximum measureable velocity range without decreasing the data rates, but compared with dual time interval method, system device needed of multiple frequency method is expensive. The alternating dual time interval and dual frequency method, which has been proposed in weather radar systems, has also attempted to solve the problem of velocity ambiguity, but despite enlarging the range it was unable to solve the velocity ambiguity. Although, these previous methods could extend the measureable velocity several times larger, none of them could cancel it. At the end of this chapter error analysis using CHDS is explained.

In Chapter 3, CMDS is introduced as a solution to cancel the velocity ambiguity of CHDS. Firstly, basic CMDS is presented using the measurement results of CNDS and CHDS. The basic CMDS take advantages of both CNDS, the large measureable velocity range, and CHDS, the precise measurement result, to provide accurate and precise velocity information with short time lag. However, the result of this basic CMDS method is affected by the value of measured velocity. A velocity shift technique is introduced to solve this problem. With velocity shift, the measurement error of CMDS is independent of the measured velocity. CMDS using fixed ambiguity velocity only works well at the range of high SNRs, at the range of low SNRs it contains lots of impulsive noise due to a wrong estimation of integer factor, which makes the measurement error much larger than CHDS. Accordingly adaptive algorithm is employed to provide accurate and precise velocity information for CMDS at a wide range of SNRs. In adaptive algorithm, optimum ambiguity velocity is selected based on the minimum measurement error of CMDS under a provided range of ambiguity velocities at each SNR. With the optimum ambiguity velocity, CMDS can provide the accurate velocity information as precise as CHDS at low SNRs. After introducing the measurement method, the error analysis of CMDS is discussed. Measurement error of CMDS is deduced by the error of CNDS and CHDS. The effect of velocity shift technique is also discussed. Error reduction of adaptive algorithm is analyzed. Finally simulations and experiments of CMDS were carried out to evaluate its performance. Simulations were carried out with white Gaussian noise. Compared with the measurement errors of CNDS, CHDS and CMDS in the simulation, CMDS using adaptive algorithm can provide accurate and precise velocity information at a wide range of SNRs. And the results of CMDS fitted the theoretical analysis well, which means the equation used to calculate the measurement error of CMDS can be used to evaluate the performance of CMDS, when the noise is white Gaussian noise. With a constructed CMDS system in the laboratory, experiments were

carried out in a large shallow water tank. Under the situation of fixed projector and hydrophone, the noise in the received signals could be considered as white Gaussian noise, and the measurement results of CNDS, CHDS and CMDS fitted the theoretical results well. When the projector moves forward and backward, the measurement results became noisy. The large measurement error is directed by two types of noise. One is the electro-magnetic noise generated by three dimension moving device. The other one is that the movement of projector caused a vibration to be generated from the bar and frame of the experimental platform. The electro-magnetic noise and vibration caused the results of CNDS to be much noisier than in the stable situation, especially at the range of high SNRs. With a worse measurement result of CNDS, the CMDS using adaptive algorithm did not work well as in the stable situation. This shows that the deduced equations for adaptive algorithm only work well in white Gaussian noise. We can also figure out that measurement error of CMDS is seriously affected by measurement error of CNDS which directs a wrong estimation of integer factor. To handle this situation, ambiguity velocities several times the standard deviation of CNDS at different SNRs, were used to decrease the impulsive noise generated by CMDS. When ambiguity velocity is four times of measurement error of CNDS, CMDS can provide accurate velocity information as precise as CHDS at a wide range of SNRs, although the noise in the received signal is not white Gaussian noise. According to the simulation and experiment results CMDS can provide accurate and precise velocity at a wide range of SNRs.

In Chapter 4, conclusions based on the theoretical and experimental results of the proposed CMDS are explained. Future considerations and proposals are also discussed to improve the performance of CMDS. One of the considerations is to add some other sensors to provide more comprehensive information to cancel the impulsive noise generated by the wrong estimation of integer factor. Another one is to improve the robustness of CMDS by using some data processing techniques, such as fuzzy algorithm and neural networks.

（別紙１）　　　　　　　　　　　論文審査の結果の要旨

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論文題目	Velocity Measurement by Doppler Sonar Using Coherent Method (コヒーレント方式を用いたドップラーソーナーによる速度計測に関する研究)		
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要　　旨

審査概要

現在，洋上や水中移動体の移動速度の計測はドップラー方式，電磁誘導方式などのログあるいはソーナーによってなされている．電磁誘導方式は測定可能範囲が設置されたセンサー位置近辺に制限され，ドップラー方式では計測範囲は電磁誘導方式と比較して広範囲であるが，計測の対象が周波数変移量であることから瞬時の計測が困難で，さらに雑音に対する計測特性が良好とは言えず，特に高雑音領域では平滑化のために比較的長い計測時間を要することから時間遅れが生じている．

近年，ドップラー方式によるソーナーの欠点を補うべく，コヒーレント方式のソーナーが開発された．本コヒーレント方式のソーナーは雑音に対する計測特性に優れおり，高雑音領域においても比較的短時間で高精度の速度計測が期待されている．しかしながら，本コヒーレント方式は計測対象が位相であることから速度を求めるためには波数の曖昧さが残り，これにより計測可能な速度範囲が制限されている．

本研究は周波数計測の従来方式のドップラーソーナーと位相計測によるコヒーレント方式ドップラーソーナーの両速度情報を用いて，両方式の融合をはかることにより波数の曖昧さを除去し，計測速度に制限が無くかつ高精度なドップラーソーナーを提案（融合方式）し，さらにその計測性能を解析的，数値的かつ実験的に評価している．

論文は５章から構成され，第１章では本研究を行うに至った動機および本研究に関連した事項を述べ，第２章では従来方式およびコヒーレント方式のソーナーシステムについて概説している．第３章では本研究で提案する従来方式とコヒーレント方式を融合した融合方式ソーナーシステムにおける速度計測原理について説明した後に，本方式の中核である適応アルゴリズムについて詳細に述べている．第４章では従来方式，コヒーレント方式および提案する融合方式の各々で得られる計測誤差について，解析的な誤差を導出し，その計測誤差について数値的なシミュレーションおよび実験的に比較・検証を行っている．その結果，本提案方式が計測誤差の点で特に優れており最小の計測誤差を実現できることを示している．最後に第５章では本研究をまとめ，さらに今後進めるべき研究課題を明らかにしている．

本研究は，洋上・水中移動体における移動速度を計測するために用いられているソーナー技術に関して十分な成果を上げており，海洋計測学に関する分野の進展に大いに役立つと考えられ，学位申請者の刘鹏は博士（工学）の学位を得る資格があると認める．