Research of the Relations Among Cloud Computing, Internet of Things, Big Data, Artificial Intelligence, Block Chain and Their Application in Maritime Field

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Abstract. At the forefront of technological development, cloud computing, the Internet of Things (IoT), big data, artificial intelligence (AI), and blockchain (CTDAB) are not mutually exclusive, but complementary and integrated. The connotative characteristics and correlation of cloud computing, IoT, big data, AI, and blockchain are mainly introduced in this study, and their application in maritime field are summarized. Cloud computing, big data, and AI are the core technologies for realizing IoT technology. Blockchain technology supplements the functions of IoT. The cross-support and comprehensive application of these emerging technologies has started in the process of people's exploration of the maritime field, which has played a key role in promoting the intelligent development of the maritime field.

Keywords: Cloud computing; IoT; Big data; AI; Blockchain; Maritime field.

1. Introduction

The rapid development of information technology has brought us into the era of CTDAB. Cloud computing provides technical support for big data analysis. Big data provides assistance for data analysis of IoT. AI provides operational solutions for IoT. Cloud computing, big data, and AI are equivalent to the "brain of IoT", and the block chain technology fills the gaps of IoT. These five technologies support each other, fill in their shortcomings, and have played a huge role in various fields, which do save a lot of manpower and material resources, and improve efficiency [1].

Approximately 71% of the earth's area is occupied by the ocean, which plays an irreplaceable role in the earth's ecosystem. Navigation provides an important safety guarantee for the development and utilization of marine resources. At present, the shipping industry is developing rapidly and with high quality. Maritime transportation is undergoing profound changes, such as navigational weather forecasting, ship design and manufacturing, maritime shipping and transportation, maritime management are gradually becoming intelligent and digital. In addition, the "Outline for Building a Powerful Transportation Country" also pointed out that it is necessary to integrate various emerging technologies such as cloud computing, the Internet, big data, AI, and blockchain into the transportation industry to promote a more modern and intelligent transportation industry [2]. Therefore, it's very necessary for the intelligent development of the field of navigation to study the connotation and characteristics of CTDAB, sort out the interrelationship between them, and study the application of five emerging technologies in the field of navigation.

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This article first elaborates on the connotation and characteristics of CTDAB, and sorts out the correlation between them, and then studies their respective application research status and comprehensive applications in the navigation field. According to the research results, suggestions are put forward for the comprehensive application and development of them in the field of navigation.

2. The Connotation and Related Functions of CTDAB

2.1. The Connotation and Characteristics of Cloud Computing

IBM's technical white paper "Cloud Computing" [3] defines cloud computing: it describes a scalable application that can be accessed through the Internet. "Cloud applications" rely on powerful servers and large-scale data centers to run network applications and network services. Users only need a suitable Internet access device (computer, mobile phone, etc.) and a standard browser that can access a cloud computing application. The overview of cloud computing is shown in Figure 1.

Cloud computing is distributed computing that is the process of disassembling the required calculation processing program into multiple subroutines through the network, breaking them into parts, and processing them by multiple servers, and then merging the processing results. Compared with the traditional huge computing processing program, cloud computing is powerful and efficient. Cloud computing has the characteristics of supporting virtualization, high reliability, extensibility and availability, providing service quality assurance, and autonomy [4], providing users with a new experience. Cloud computing coordinates multiple computer resources together to make users only need to perform simple interaction and management through the network that can share network, server, application software, documents and other resources without being restricted by time and space.

![Figure 1. Overview diagram of cloud computing.](image-url)

2.2. The Connotation and Characteristics of IoT

As an important part of information science and technology in the new era, IoT collects various data information such as sound, light, heat, position, and mechanics through various devices and sensing technologies such as sensors, radio frequency identification devices (RFID), scanners, and global positioning systems, by wired, wireless, short-distance, long-distance and other communication methods. It is combined by the Internet to form a huge network system [5][6][7]. In short, IoT is the Internet that connects people to people, people to things, and things to things. The characteristics of IoT are intelligent processing, reliable transmission and comprehensive perception, which architecture is shown in Figure 2.
2.3. The Connotation and Characteristics of Big Data
As human beings explore the field of maritime all along, IoT consisting of a large number of sensors, satellites, ocean stations, buoys, aerial remote sensing, etc., continues to expand, and collect massive amounts of data which need to be stored, processed, inquired and analyzed before they are used by people and provide them with valuable information. The emergence of big data technology has provided help to solve this problem. Big data refers to the collection of data that traditional information technology and software and hardware cannot perceive, manage, process, and serve within a tolerable time. Different from the traditional data concept, big data has the characteristics of volume, high velocity, variety, and low value \[^8\][\(^9\)]. Volume means a large amount of data, which is due to the use of communication tools and various instruments, and makes the amount of perceived information increase exponentially. In addition, the low price of integrated circuits and the addition of intelligent components, so the amount of data acquired has exploded compared to traditional tools. With the development of science and technology, the types of smart devices, sensors that are used to obtain data have increased, and the types of data obtained have also increased. In addition to traditional relational data, it also includes semi-structured or unstructured, unprocessed data types in the form of videos, audios, documents, web pages, etc. Mass data information and data types require corresponding increases in data processing speed to enable data to flow quickly and continuously on the Internet. Big data uses PB level to replace the traditional TB level for data processing, ensuring that data changes rapidly and dynamically on the Internet in a fluid way.

2.4. The Connotation and Characteristics of AI
The concept of AI was first proposed by John McCavthy at the Dartmouth Summer Conference in 1956. AI is the studies of how to make computer systems perform tasks that can only be completed by human intelligence, such as making decisions, learning, speech recognition, and visual capture by comprehensively considering uncertain factors. In short, the purpose of AI is to allow machines to accomplish all tasks that human intelligence can accomplish. The main characteristics of AI are human design and service for humans, and the essence is calculation and data-based. Moreover, it can perceive the environment and produce reactions, interact with and complement people, evolve and iterate and be able to connection extension, and has adaptive characteristics and learning ability \[^{10}\].

2.5. The Connotation and Characteristics of Blockchain
The concept of blockchain was proposed by Satoshi Nakamoto in 2008. Blockchain originated from Bitcoin and is a technical solution to collectively maintain a reliable database based on concepts such
as distributed networks, consensus mechanisms, and encryption algorithms. Blockchain technology guarantees that data information cannot be tampered with during the transmission process, focusing on creating a trusted network environment, storing each transaction data record in a block, and each block records the ID of the previous block to form Chain structure. The structure of the blockchain system includes data layer, network layer, consensus layer, incentive layer, contract layer and application layer[11], and each layer is coordinated with each other to jointly complete the blockchain mechanism. Blockchain has the characteristics of decentralization, openness, autonomy, immutable information, and anonymity. Decentralization is due to the use of distributed accounting and storage in the blockchain, and the rights and obligations of all nodes are equal. Except that a small part of private information is encrypted, the public interface of the blockchain can provide anyone with data query and related applications developed, so the whole system has a high degree of openness. At the consensus level, the entire system adopts consensus-based specifications and agreements, and any human intervention does not work on the blockchain system. Once the information is verified and added to the blockchain, it will be jointly maintained by all nodes, and a single node cannot modify the information, so the data stability and reliability of the blockchain is extremely high. In the blockchain system, the trust system is constructed by the corresponding algorithm, and there is no need to open the identity to allow the other party to generate trust, thus achieving identity anonymity.

2.6. The Related Functions of CTDAB
These five emerging technologies are not independent of each other, but complement and support each other. Cloud computing, big data, and AI are all core technologies to realize IoT, and blockchain can supplement the deficiencies of IoT. For cloud computing, on one hand, IoT needs the powerful processing and storage capabilities of cloud computing as support, and use the cloud computing mode to manage various real-time dynamic nodes, which reduces the difficulty of managing complex terminals in IoT and meets people's growing demand. On the other hand, IoT provides ample application space for cloud computing. For big data, the massive nodes of IoT collect a lot of information, and some of this information cannot be used directly for us. Big data technology provides technical support for the data analysis of IoT while IoT is an important source of big data. For AI, scientific decision-making of IoT, intelligent management and control are closely related to it. What kind of plan is adopted by IoT to collect information requires the support of algorithms which are designed by technicians using AI technology, formulate corresponding plans through calculation processing, analysis and planning, deep learning, and finally implemented by IoT devices. And for blockchain, it can supplement the deficiencies of IoT[12]. In the process of long-term development and evolution, IoT has flourished in various fields, but it has also brought about problems such as information storage, information transmission, and privacy protection. In the blockchain, the complete equality between blockchain nodes can relieve storage pressure to a certain extent, and the application of the mutual trust mechanism to the IoT can prevent the collected data from passing through a third-party intermediary which can increase the transmission rate of data information and reduce the propagation delay. Moreover, the blockchain adopts a decentralized distributed storage method to distribute data in various network nodes, and uses asymmetric cryptography to encrypt the data, and the privacy-conscious blockchain connection gateway uses a blockchain privacy protection technology to manage and protect user information and prevent information leakage[13]. The blockchain gateway is used in IoT devices to provide a solution for user privacy protection. These five technologies are also closely related in the maritime field. Technicians use AI to formulate data acquisition plans, use IoT nodes to collect information, use blockchain technology to protect data and improve data credibility, and store data on cloud platforms to provide data sources for cloud computing, and finally use big data technology for analysis. The application diagrams of CTDAB are shown in Figure 3.
3. The Application of CTDAB in the Maritime Field

3.1. The Application of Cloud Computing in the Maritime Field
Cloud computing has been widely used in the maritime field due to its large scale, strong applicability, on-demand services, and strong scalability. The main field includes automatic marine meteorological detection, numerical forecasting, marine environmental information sharing, identity authentication, data processing, ship navigation and other aspects.

In terms of marine meteorology, Gao et al. [14] designed an intelligent nautical weather monitoring system by analysing the status quo and existing shortcomings of traditional marine meteorological monitoring systems, using the distributed computing, cloud storage and virtualization features of cloud computing. In terms of marine environmental information security, Wei [15] analysed the security risks of the login process of the marine environmental information sharing platform based on the Hadoop cloud computing platform, and proposed an identity authentication protocol based on public key encryption technology, enhanced the security of the identity authentication of marine environment information. In the visualization of nautical data information, Wu et al. [16] analysed the visualization of flow fields based on the line integral convolution (LIC) algorithm and built a cloud architecture platform for marine environment visualization, used Hadoop cloud computing with graphic processing unit (GPU) to process massive amounts of data, which greatly improves the calculation rate.

3.2. The Application of IoT in the Maritime Field
As an important part of the new generation of science and technology, the application and popularization of IoT has improved the automation and intelligence level of the maritime field, and has promoted human exploration and discovery in this field. The main application areas are as follows.

3.2.1. Marine environment monitoring. The accuracy and real-time nature of marine environmental information is a necessary condition to ensure safe navigation. In the monitoring of the marine environment, the integrated application of IoT technology such as embedded technology, geographic information system (GIS) spatial information processing technology, and wireless sensor network technology can realize intelligent monitoring of the marine environment. He et al. [17] realized dynamic monitoring of marine environment based on this data visualization processing of marine environmental information. Jiang [18] studied the ocean sensor network technology based on the real-time observation data and historical ocean observation data, designed and implemented the ocean sensor network prototype system according to the hierarchical design idea, which provided convenience for modern ocean environment observation. Yang et al. [19] designed a multi-functional surface unmanned boat based on the monitoring tool using controller area network (CAN), which can be used to monitor parts of the water that cannot be reached by technicians.

3.2.2. Maritime transportation. In May 2011, the China Automatic Identification System (AIS) shore-based network system constructed by the China Maritime Safety Administration of the Ministry of Transport was put into operation, meaning "Water IoT" in China was established. The system covers
the high-grade waterways of inland rivers and 99.97% of coastal waters, and all 264 base stations have successfully interconnected with the AIS National Data Centre \[20\]. The AIS shore-based network system establishes an information exchange platform between ship and ship, ship and shore station through the transceiver of the shore base station and ships, which realizes the exchange of information between ship and ship, ship and shore station such as identification code, position, heading, speed and so on, and plays an important role in ship monitoring, maritime search and rescue, maritime investigations, etc. \[21\].

On the basis of analysing the problems faced by China Association of Southeast Asian Nations (ASEAN) marine transportation, Wang \[22\] proposed that IoT should be added to the interconnection of marine transportation, and that the system architecture of marine transportation interconnection should be built as an important means, which provided new ideas for the construction of the Maritime Silk Road in the new era.

In addition, IoT is also applied to intelligent ship. The most representative results are the Internet of Ships. The emergence of the Internet of Ships has made shipping management more refined and industry services more comprehensive, forming the intelligent shipping information integrated network which integrates the core technology of IoT, focus on big data and make it possible for connecting people and ships, ships and ships, ships and shores, and ships and cargoes \[23\].

3.3. The Application of Big Data in the Maritime Field

With the continuous deepening of human exploration in the marine field, the amount of data collected is also expanding. Before it can be used by users, the amount of data needs to be stored, processed, queried, analysed and extracted to valuable information by using big data technology. The applications of big data in the maritime field mainly include geological information construction, navigation data management, marine buoy monitoring, navigation weather forecasting, and so on.

In the construction of maritime geological informatization, people began to attach importance to the information service value of data. Dai et al. \[24\] used big data thinking and explored marine geological visualization technology and big data mining to maximize the value of data. In nautical data management and information detection, big data technology can efficiently store and manage the diversity and mass of data. Huang et al. \[25\] expounded the basic structure of navigation data management and put forward the challenges in data security and data quality. Ren et al. \[26\] studied a big data visualization experiment platform for marine buoy monitoring based on the Shiny webpage framework. The platform obtained public marine buoy monitoring data in real time through crawler technology, used Oracle database to efficiently store and manage the acquired data, and used R language for data mining and visualization, which facilitates users to understand the real-time information of marine buoys.

In addition, marine remote sensing satellites are developing in the direction of multiple payloads, high resolution, and full coverage. With the increase in payload types and transmission rate, the generated satellite data also shows multi-source heterogeneity, and the amount of data has increased sharply \[27\]. Therefore, in order to provide better services for intelligent navigation, it is necessary to build a large-scale satellite data centre to analyse and process the amount of data.

3.4. The Application of AI in The maritime Field

AI technology can be used to simulate human actions and behaviour. In the field of maritime, AI can realize automatic operation by the pre-set procedures to substitute some manual operations, which can improve efficiency and ensure the safety of working in dangerous deep-sea areas. Furthermore, the intervention of AI can reduce the manual inspection of marine meteorology, save manpower, and predict and analyse marine meteorology scientifically. In the current development process, AI continues to innovate, creating more and more value for the development of marine technology.

3.4.1. Unmanned application. In some deep-sea fields, if technicians go to detect and collect information, it will not only cause a lot of waste of manpower and material resources, but also bring unpredictable danger to the technicians due to various reasons such as weather and temperature. Based
on this status quo, intelligent and unmanned applications such as unmanned cargo ships, unmanned underwater vehicles, and unmanned surface craft are also emerging in the field of maritime\textsuperscript{[28]}. In 2014, the British Rolls-Royce Company planned to develop an unmanned cargo ship with the intention to replace the existing fleet with unmanned remote-controlled cargo ships, so that the captain can remotely control ships sailing around the world in the master control room\textsuperscript{[29]}. The inspection of intelligent ships and the unmanned work in the era of intelligent navigation have also been carried out in China. Intelligent robots based on AI technology have begun to be introduced into the field of navigation at present. For example, logistic service robots are used to ensure the post-service of personnel on ships, and access control robots are used to ensure the safety of relevant information.

3.4.2. Marine meteorology observation and forecast. The application of AI in the field of marine meteorology is mainly divided into meteorological observation and meteorological forecast. In meteorological observation, AI can improve the observation density and the quality of observation data with image processing and computer vision technology such as converting video data into meteorological data, identifying the video through AI technology, distinguishing special weather phenomena like thunderstorms, strong winds, and fog, which improve the efficiency and observation density of obtaining meteorological data\textsuperscript{[30]}. In terms of meteorological forecast, AI can quickly organize all kinds of weather data to facilitate the use of forecasters. For instance, Ni et al. and his team used convolutional neural networks (CNN) and recurrent neural network (RNN) deep neural networks for short-term precipitation forecasts in 2018\textsuperscript{[31]}.

3.5. The Application of Blockchain in the Maritime Field
Blockchain technology is still in the early stage of research without unified technical standard at present. Various technical solutions are still being developed and tried. Due to the characteristics of traceability and non-tampering of information, blockchain has been widely used in maritime supervision and shipping.
In maritime supervision, blockchain technology is used in ship registration, information authentication of maritime-related certificates, verification of container weight, collection of maritime regulations, and credit evaluation of maritime-related entities\textsuperscript{[32]}. At present, many national maritime institutions including the Danish Maritime Administration, the Singapore Shipping Association and the British Maritime Association have initiated project research on the application of blockchain technology to ship registration.
In terms of shipping, Maersk Line cooperated with IBM to develop a ship transportation solution based on blockchain technology while Dubai Global Ports and a number of shipping companies reached a consensus on building a shipping blockchain alliance in 2018\textsuperscript{[33]}. In May 2020, China Merchants Group reached a cooperation agreement with Alibaba and Ant Group to jointly prepared the application of digital technology to the port industry. And the entire port business chain will be connected to create a blockchain-based digital Port open collaboration network through Ant blockchain technology, which will promote the development of port trade\textsuperscript{[34]}. In addition, marine informatization in China is facing problems such as imperfect privacy and security and poor sharing of marine information. In order to realize the rational use of marine information resources, it is recognized that blockchain technology can be used to build a marine information sharing system where information collectors can use public keys to upload all marine information to chain, and scientific research institutions can use relevant data after obtaining authorization.

3.6. The Comprehensive Application of CTDAB in the Maritime Field
Emerging technologies have played an important role in the development and evolution of the great navigation era. Among them, the comprehensive role of CTDAB is particularly critical.

3.6.1. Ocean condition monitoring. Japan is currently developing an ocean condition monitoring system to collect comprehensive information about air, sea, and islands through satellites, radars, aircraft, ships and other means, integrate and share the information to form a comprehensive system serving maritime safety, maritime environment, disaster prevention and mitigation, etc\textsuperscript{[35]}. In this
IoT is the basic framework for macro-control of information collection, information integration and interconnection. AI plays an important role in intelligent R&D and intelligent information collection. Cloud computing realizes information storage and sharing applications while big data processes and analyses the collected information. Under the combined effect of the four emerging technologies, it finally forms valuable information that can serve the fields of maritime safety, maritime environment, disaster prevention and mitigation.

3.6.2. Marine traffic flow monitoring. At present, the Vessel Traffic Management System (VTS), which is widely used in maritime traffic, is a system that provides information to ships, supports ship navigation, and implements navigation control services for the purpose of improving the navigation safety and efficiency of ships, and protecting the marine environment [36]. VTS monitors sailing ships through communication facilities such as CCTV, AIS base stations, wireless phones, radars, and shipborne terminals, which jointly build a ship traffic management system with IoT as the core technology, big data and cloud computing technology as the support. A large amount of information monitoring by the VTS infrastructure such as whether the ship’s route is separated, the speed and direction of the ship, and the ship’s mutual traffic, can be stored in the cloud to realize data sharing. Big data technology is used to analyse and process this information to extract valuable information, and then send it to the ship to provide safe navigation information.

3.6.3. Smart ship research and development. With the continuous development of various emerging technologies, smart ship technology is becoming more and more mature [37]. The proportion of AI in the shipbuilding process of smart ships has gradually increased. New sensing technologies, network interconnection technologies, fault diagnosis and maintenance technologies based on virtual reality, and identification technologies based on RFID chips have also become the key technology of smart manufacturing [38]. The intelligent ship system is an integrated intelligent information service system for ships and shore-based, which uses the sensing, positioning, tracking and other means of IoT, combined with big data technology, connects ships and ships, ships and shore-based through the network to achieve refined management of shipping, and toward the development trend of globalization, networking, greening, and intelligence [39]. The system can build information service centres for ship design, general assembly and construction, shipowner operations, ship protection and so on by relying on a cloud platform, and using the sharing, analysis and application of big data to realize an intelligent system for the entire industrial chain of the shipbuilding industry [40]. In general, these technologies complement each other and merge with each other, and jointly promote the development of intelligent ship systems.

3.6.4. Marine anti-pollution assistance. In the new era, China advocates green and sustainable development while the navigation technology continues to develop towards intelligence, which requires to pay more attention to marine pollution prevention [41] and the construction of green ships [1] while rationally developing and using marine resources. Taizhou, Zhejiang, has developed a hazardous waste recycling device named "Ocean Cloud Warehouse" based on IoT and blockchain technology, which can automatically record the type, quantity and time of pollutants, and filter and concentrate them before planning transportation route, and finally send the treated pollutants to the corresponding treatment company [43]. This device uses blockchain technology to visualize the entire information of the hazardous waste treatment process, and uses IoT technology to connect all aspects of the treatment to ensure the normal operation of the treatment process, which provides assistance for marine pollution prevention.

4. Conclusion
This study introduces the connotation and characteristics of CTDAB, sorts out the correlation between them, and elaborates the application of five emerging technologies in the maritime field, including maritime supervision, maritime traffic flow monitoring, smart ship research and development, ocean condition detection, marine information management, marine anti-pollution assistance, etc. At present, various emerging technologies continue to develop, the technology gradually matures, and the scope
of application will continue to expand. Compared with the earlier development of other technologies, blockchain technology will quickly rise to catch up. It is recognized that blockchain will play an important role in maritime freight to record cargo logistics information on the chain, while combining big data and AI technology to analyse and process a large amount of past cargo transportation information. Thus, it can complete the adjustment and optimization of shipping routes under different conditions, and select the best route to improve cargo transportation efficiency and save shipping transportation costs.

As emerging technologies at the forefront of scientific and technological development, CTDAB complement each other and integrate with each other. The realization of IoT technology requires the support of cloud computing, big data and the core technology of AI, while the blockchain technology is insufficient for it. Based on the analysis and summary of the connotation and characteristics of CTDAB, the application of five emerging technologies in the maritime field is expounded in detail in this study, which provides a reference basis for the in-depth exploration of the ocean field, and promotes the cross support and comprehensive application of CTDAB.

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