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Analysis of Submarine-Civilian Vessel Collision Cases and Investigation of Collision Avoidance Technology

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Abstract Submarines are considered crucial assets, providing a military balance and ensuring national security, while elevating a country's standing and influence in the international community. The increasing deployment of submarines has led to a rise in incidents involving contact and collisions with civilian vessels, posing military tensions and national security concerns. To address these issues, the development of collision prevention technologies for submarines is imperative. This paper presents cases of collisions between submarines and civilian vessels, outlining the associated causes. The identified causes are categorized into two main perspectives: equipment-oriented factors such as sonar systems and periscopes, and human-related factors, including errors in judgment. Based on these perspectives, technologies employed or potentially applicable for collision prevention on submarines, both domestically and internationally, are discussed. It is anticipated that the implementation of the proposed technological developments will contribute to maritime safety and international stability.

요 약 잠수함은 국가 간의 군사적 균형과 안전을 제공하며, 국제 사회에서의 입지와 영향력을 높이는 역할을 수행하는 중요한 수단으로 여겨지고 있다. 잠수함과 민간선의 운용 증가로 인하여 민간 선박과의 접촉 및 충돌사고가 빈번해지고 있기 때문에 군사적 긴장과 국가적 안보 문제로 귀결될 수 있다. 이러한 문제를 방지하기 위해 잠수함에 탑재되는 충돌 방지 기술 개발은 필수적이다. 본 논문에서는 잠수함과 민간선의 충돌 사례와 사고 원인을 함께 제시하였고, 사고 원인으로 크게 소나체계와 잠망경과 같은 기기 관점과 인적 오류 관점으로 나뉘었다. 이러한 관점을 중심으로 하여 국내외 잠수함에 탑재된 충돌방지 기술 또는 탑재 가능성이 있는 기술을 서술하였다. 제시된 기술 개발의 적용을 통해서 해양 안전과 국제적인 안정에 기여할 수 있을 것으로 기대된다.

Keywords : Submarine, Collision Avoidance, SONAR, Periscope, Autonomous Navigation

1. Introduction

Submarines can serve to establish and maintain military equilibrium and stability among nations, elevating their standing and influence within the international community. Through this, they are capable of exercising strategic deterrence, playing a pivotal role in maritime strategy, and fostering cooperation and alliances between nations.

As the number of operational submarines increases, so does the frequency of incidents involving contact and collisions with civilian

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vessels. A notable example is the collision incident between the USS Greenville and a Japanese training vessel in 2001[1]. At the time, the USS Greenville, a Los Angeles-class submarine of the U.S. Navy, was rapidly surfacing to demonstrate emergency surfacing procedures when it collided with the Ehime Maru, a Japanese training vessel conducting language training exercises. As a result of the accident, as depicted in Fig. 1, the Greenville suffered damage to its hull exterior, with four out of nine crew members aboard the Ehime Maru losing their lives. The causes of the accident are attributed to two main factors: the inability of the Greenville's sonar system to detect the training vessel due to underwater noise and the failure to visually detect the vessel due to maritime fog. This incident led to a deterioration of public opinion toward the U.S. military in Japan; however, the United States conducted a thorough investigation and engaged in compensation negotiations, ultimately leading to an agreement between the U.S. and Japan to strengthen maritime safety regulations between the two countries. Such collisions between submarines and civilian vessels not only pose risks to maritime safety and international norms but can also escalate into military tensions and security issues. Therefore, the development of technology to prevent such incidents is imperative. Research on submarine and tanker collisions has been underway, focusing on analyzing the external dynamics of submarine collisions[2]. However, there is a lack of analysis on the causes of actual incidents involving submarines and civilian vessels, as well as related technological aspects. This paper analyzes the causes of collisions between submarines and civilian vessels based on currently available data. Additionally, it describes collision prevention technologies already installed or potentially deployable on submarines both domestically and internationally.

Fig. 1. The Greenville undergoing repairs after the accident

2. Point

2.1 Analysis of Collision Incidents

Table 1 summarizes the collision incidents described in this paper. The table provides details such as the date of the accident, the name of the vessel, the location of the incident, and the extent of the damage. In Section 2.1, incidents from case 2 to case 5 are analyzed.

Table 1. The case of submarine and civilian ship collisions

Case No.	Date of Incident	Vessel Involved in the Incident	Incident Location	Extent of Damage
1	Feb. 2001	USS Greenville(USA) - Ehime Maru(Japan)	Japanese maritime zone	4 crew members of Ehime Maru died
2	Feb. 2021	Soryu-class submarine(Japan) - Civilian vessel(Hong Kong)	Japanese maritime zone	3 individuals injured and equipment damaged
3	Sep. 2005	USS Philadelphia(USA) - Yaso Aysen(Turkey)	Mediterranean Sea area	Minor damage to the vessel's hull
4	Aug. 2018	Warship YooGwansoon(Korea) - Shinhangho(Korea)	Sea area near Busan port	External damage to YooGwansoon and damage to the Shinhangho
5	Jul. 2020	Warship Nadaeyong(Korea) - Hoegh London cargo ship(Norway)	Sea area near Busan port	Damage to the propeller blades of the Nadaeyong, the foreship of the Hoegh London

2.1.1 The collision incident between a Japanese Soryu-class submarine and a civilian vessel from Hong Kong

The incident occurred in February 2021 in the waters near Ashizurimisaki, Kochi Prefecture, Japan, involving a collision between a Japanese Soryu-class submarine and a civilian ship from Hong Kong. According to the investigation conducted by the Maritime Security Agency, the collision damaged part of the Soryu-class submarine's hull due to impact with the civilian ship's sonar system, resulting in injuries to three crew members. As depicted in Fig. 2, the collision appears to have caused damage to the upper wings. Subsequent to this event, officials from the Maritime Self-Defense Force emphasized the necessity not only of passive sonar systems currently equipped on patrol vessels but also the consideration of active sonar systems for enhanced safety measures[3].

Fig. 2. The collision resulted in damage to the upper wings of the Soryu-class submarine

2.1.2 The collision incident between USS Philadelphia and a Turkish ship

The incident occurred in September 2005 in the Gulf of Oman, involving the US vessel USS Philadelphia and the Turkish ship Yaso Aysen. According to the US Navy's statement, the USS Philadelphia was conducting maritime operations en route to Bahrain for a port visit when it collided with the Turkish vessel[4]. There were no casualties reported from the collision, and while the propulsion system of USS Philadelphia remained intact, it sustained superficial damage. The Turkish ship incurred minor damage to its hull just above the waterline. The cause of the collision was attributed to the inexperienced maneuvering by the submarine's duty officer.

2.1.3 The collision incident between warship YooGwansoon and Shinhangho

The incident occurred in August 2018 within the waters of Gadeok Harbor, Busan, involving the South Korean naval vessel YooGwansoon and the cargo ship ShinHangho. The movement paths of the vessels involved in the collision can be discerned through Fig. 3. According to data from the Busan Regional Maritime Safety Tribunal, as a result of this collision, the YooGwansoon sustained damage to its hull, while the ShinHangho experienced damage to its bow[5]. Furthermore, it was determined that the collision was caused by insufficient vigilance on the part of the ShinHangho, which was crossing the main shipping lane within Gadeok Harbor at an excessive speed and failed to adequately heed the approaching YooGwansoon. However, the YooGwansoon was also found to have failed to respond appropriately due to its own negligence.

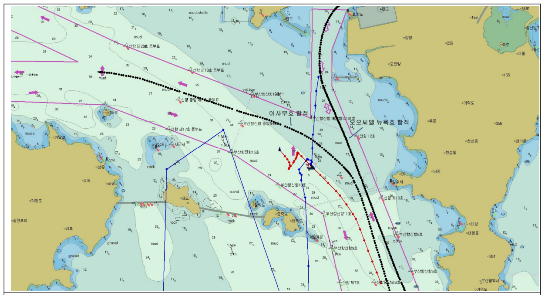

Fig. 3. The track records of surrounding vessels at the time of the incident related 2.1.3

2.1.4 The collision incident between warship Nadaeyong and cargo ship from Norway

The incident occurred in July 2020 in the waters south of Gadeok Island, Busan, involving the South Korean naval vessel Nadaeyong and the Norwegian car carrier Hoegh London. As depicted in Fig. 4, the paths of the vessels involved in the collision can be observed. According to the Central Maritime Safety Tribunal data, as a result of this collision, the Na daeyong experienced damage to its propeller and damage to its horizontal sonar and sound-absorbing tiles. The Hoegh London suffered a breach in its hull above the waterline, allowing seawater ingress[6]. Additionally, considering that neither vessel made significant alterations in course early nor decelerated or stopped, both the Nadaeyong and the Hoegh London were deemed to have contributed to the incident.

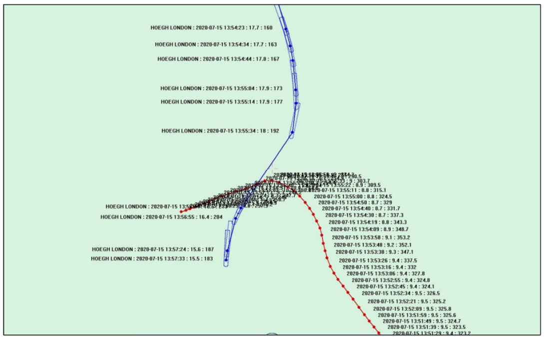

Fig. 4. The collision situation between the two vessels related 2.1.4

2.2 Collision Prevention Technology

The commonality among the previously occurring collision incidents is that they could have been prevented if improvements were made either from a device perspective or a human error perspective. In this paper, we describe the current and potential technologies applied or applicable from both device and human error perspectives to prevent collisions.

2.2.1 SONAR

The SONAR(SOund Navigation And Ranging) system of submarines is utilized to detect and analyze sounds originating from the surrounding maritime environment, thereby identifying the position of adversaries and assessing the underwater terrain and conditions near the submarine. The sonar system can be broadly categorized into passive sonar and active sonar. Passive sonar operates based on the principle of detecting sounds generated in the surrounding environment, thus posing a lower risk of detection as it does not emit noise from the submarine itself. It allows for discreet monitoring of enemy activities. Active sonar, on the other hand, operates by emitting noise with controlled amplitude or frequency to generate echoes and detect reflected sounds, enabling more accurate identification of the target's location. However, there are drawbacks associated with the sole installation of either active or passive sonar systems, and there exist limitations in resolution depending on the frequency and wavelength of the sonar.

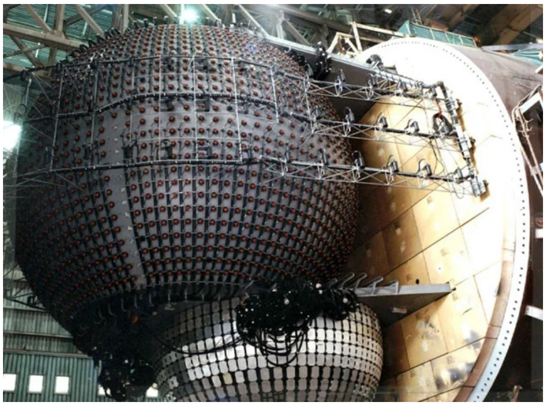

Fig. 5. Spherical sonar System

According to reports issued by the DOT&E, sonar systems installed on submarines developed in the United States are designed to incorporate both passive and active sonar systems, starting from the Los Angeles-class submarines. This approach aims to establish a system with complementary functions, leading to comprehensive performance enhancement and tactical flexibility, thereby gaining an advantage from a tactical diversity perspective. The latest sonar system deployed on the Virginia-class submarines in the United States is the spherical bow-mounted sonar (Fig. 5), equipped with AN/BQQ-10(V)4, which operates as a combined passive and active sonar system mounted below. This sonar system replaces the previous BQQ-6 sonar system and offers improved detection range and identification capabilities compared to the sonar system on the Los Angeles-class submarines. Additionally, utilizing fiber optics technology for transmitting and detecting acoustic signals, the flank array sonar is equipped with the LWWAA mid/low-frequency detection sonar.

Furthermore, the development of the curved array sonar system, which enhances sonar performance through the rearrangement of sensors, has been completed as part of the 'Submarine Curved Array SONAR Technology Development Program,' a core technology project led by the Agency for Defense Development(ADD)[7]. This program concluded its technological development in 2023. By improving directionality, signal processing, and performance optimization compared to existing sonar systems, it is reported to have secured technology and capabilities that enhance the survivability of friendly submarines.

2.2.2 Periscope

The periscope of a submarine is a device used when the submarine surfaces from underwater to observe the surrounding situation or to engage targets on the surface. It primarily serves reconnaissance and detection functions, often combined with search and surveillance capabilities. However, there are instances where the periscope's field of view is limited by the surrounding environment, or its performance may prevent it from fulfilling these functions.

To overcome these limitations, recent periscope technologies have been equipped with high-performance cameras for rapid and clear image acquisition. In the case of domestic developments, in 2017, the Navy Logistics Command succeeded in producing high-resolution digital camera periscopes to replace the traditional ones, enabling them to be installed on currently operational submarines[8]. These cameras boast a resolution of 15 million pixels and can store up to 100,000 images, with additional features such as continuous shooting at one-second intervals and automatic focusing. Overseas, periscopes installed on Virginia-class submarines are equipped with Photonics Masts instead of traditional ones. Photonics Masts are sensor systems that perform periscope functions without the need for a periscope tube, offering improved performance over conventional systems and having fewer positional constraints.

Furthermore, the research team led by ViVek Goyal at Boston University has incorporated 'computational periscopy' into digital cameras using advanced devices. This enables the creation of devices capable of reproducing hidden entities through shadow analysis[9]. Professor Goyal stated, 'We have succeeded in creating devices that can observe a wide range of areas by combining new computer programs with cameras.' This innovation holds the potential to overcome the localized observation limitations of conventional periscopes.

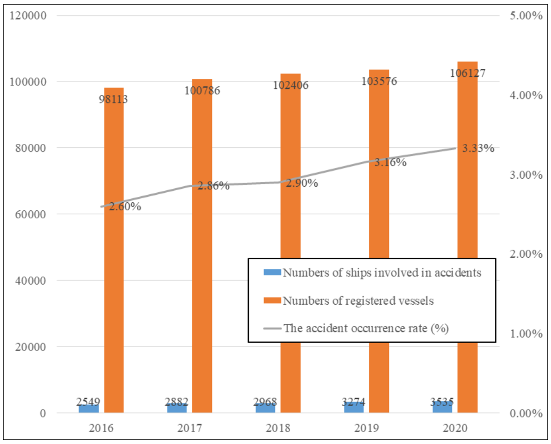

Fig. 6. Trend comparison of accident vessels relative to registered vessels from 2016 to 2020

2.2.3 Autonomous Navigation System

As depicted in Fig. 6, there has been a consistent increase in the number of accident vessels alongside registered vessels from 2016 to 2020, indicating a rising trend in accident rates over the five-year period. According to data released by the Central Ocean Safety Tribunal under the Ministry of Land, Infrastructure and Maritime Affairs in 2009, more than half of maritime accidents were attributed to navigational errors, with over 90% of collision incidents resulting from negligence in observing boundaries and violations of navigation regulations. Furthermore, research has been conducted to analyze the underlying causes of maritime accidents, categorizing them into four factors: external factors, personal factors, vessel factors, and operational factors, with ongoing efforts to reduce human errors[10]. In the civilian shipping sector, research is also actively underway, with a focus on intelligent navigation systems as a means to reduce ship collision accidents[11]. Particularly, the collision risk assessment method utilizing fuzzy inference, pioneered in Japan, is widely applied not only in ship navigation collision avoidance systems but also in collision avoidance models for underwater vehicles[12]. Thus, minimizing human error, one of the leading causes of maritime accidents, appears to be a significant approach in significantly reducing such incidents[13]. Consequently, recent research in autonomous navigation has been actively pursued.

In the domestic sphere, in collaboration with the Agency for Defense Development, Hanwha Systems has successfully developed the unmanned surface vessel AURA (Open Architecture Based Unmanned Surface Vehicle), achieving the implementation of a common architecture for unmanned systems and key autonomous mission modules[14]. Furthermore, under the auspices of the Agency for Defense Development, a consortium including Hanwha Systems and academia-industry partners is slated to develop 'Clustered Unmanned Surface Vessel Operational Technology' by 2024. Hanwha Systems plans to advance defense technology development in conjunction with cutting-edge technologies of the Fourth Industrial Revolution, such as establishing a clustered communication network and AI algorithm demonstration platform.

In the international arena, the Defense Advanced Research Projects Agency (DARPA) and the Naval Research Laboratory (NRL) of the United States completed the development of the autonomous surface vessel prototype 'Sea Hunter' in 2016. Developed as part of the Anti-Submarine Warfare Continuous Trail Unmanned Vessel (ACTUV) project, Sea Hunter is capable of autonomously planning routes, navigating, and performing various missions upon reaching its destination. It underwent two years of unmanned navigation tests prior to the prototype unveiling. Building upon this development, the U.S. Navy is advancing the concept of a sophisticated unmanned surface vessel fleet known as the Ghost Fleet[15].

Fig. 7. The operational demonstration of AURA developed by Hanwha Systems

Fig. 8. The operational demonstration of Sea Hunter developed by DARPA

3. Conclusion

In this paper, an analysis of the damages and causes of collisions between submarines and civilian vessels was conducted. Through various domestic and international cases, it is evident that the damages resulting from collisions not only involve direct harm to civilians and vessels but also pose serious implications for international security. To prevent such collisions, technologies currently applied or potentially applicable to submarines were presented from both equipment and human error perspectives, based on domestic and international development statuses. Building upon the lessons learned from technological development and accidents, strengthening education and training for relevant personnel, and making efforts to prevent collisions, it is anticipated that similar collision accidents that may occur in other vessels due to similar causes can be prevented. Ultimately, this is expected to contribute to maritime safety and international stability.

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〈Research Interests〉
Defense Industry, Maritime Technology