Proceedings of the 33rd European Safety and Reliability Conference (ESREL 2023)
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doi: 10.3850/978-981-18-8071-1_P159-cd

Preliminary reliability analysis of autonomous underwater vehicle in the polar environment based on failure mode and effects analysis and fault tree analysis

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Autonomous underwater vehicles (AUVs) are often used in extreme environments, making reliability assessment important. To evaluate the preliminary reliability of AUVs operating in polar environments, this study utilized failure mode and effects analysis (FMEA) and fault tree analysis (FTA). FMEA was conducted based on the functional analysis of the AUV, identifying nineteen potential failure modes and thirty failure causes. The results suggest correlations between major failures, accidents, and their causes. Using the FMEA results, a fault tree diagram was constructed by defining the loss of the AUV as the top event (TE) causing the greatest loss. The study categorized basic events (BEs) into two categories: BEs related to equipment reliability, such as equipment aging, equipment failure, and manufacturing defects, and BEs caused by polar environmental factors, such as collision with ice, low-temperature environment, and thermocline. By conducting a literature review, it was obtained failure probabilities of BEs. Using the obtained information, preliminary reliability analysis was conducted. This research can be useful for designing and testing AUVs that can perform reliably in extreme environments.

Keywords: Autonomous Underwater Vehicles (AUVs), Reliability, Risk, Polar Environments, Failure Mode and Effects Analysis (FMEA), Fault Tree Analysis (FTA)

1. Introduction

Autonomous underwater vehicles (AUVs) are becoming increasingly important for performing missions in difficult underwater environments. Brito et al. (2010). Due to the high cost of developing or purchasing AUVs, ensuring their reliability is of paramount importance. Thieme and Utne (2017). Unfortunately, the harsh conditions in which AUVs are often used can result in failures or even the loss of the device, which can cause significant losses in terms of time, resources, and data. Loh et al. (2019). To improve the reliability of AUVs, this study aims to analyze the preliminary reliability of AUVs in polar environments using failure mode and effects analysis (FMEA) and fault tree analysis (FTA).

2. Results

First, we conducted a functional analysis of the AUV to define the essential functions required for its operation. And six functions are defined as follows:

- Power supply/distribution function
- AUV movement function
- Acquisition/distribution of necessary information for autonomous navigation
- Navigation and mission control function
- Exploration and measurement function
- AUV normal state maintenance function

2.1. *Failure Mode and Effects Analysis (FMEA)*

Based on the functional analysis results, we performed Failure Mode and Effects Analysis

(FMEA) to identify potential failure modes such as functional failure, performance degradation, intermittent operation, and unintended operation, and analyzed their effects and potential causes. The severity (S), occurrence (O), and detection (D) of failure mode were evaluated. Then, the Risk Priority Number (RPN) was calculated to prioritize the failure modes. Nineteen potential failure modes and thirty failure causes were suggested. And the following failure modes were identified as high-risk with a high RPN:

- Main thruster motor controller wiring harness short/opens
- Stuck of linear actuator
- Network errors between equipment responsible for internal network communication
- Loss of USBL wit ATM signal
- Loss of iUSBL signal and incorrect signal transmission
- Failure of ADCP/DVL to measure velocity and altitude. ,

The results of FMEA were used to make design changes to the AUV and prepare operation and maintenance manuals.

2.2. *Fault Tree Analysis (FTA)*

Based on the FMEA results, a fault tree diagram was constructed to determine the loss of AUV as the top event (TE) causing the greatest loss. By conducting a literature review, it was obtained failure probabilities of basic events (BEs). Using the obtained information, preliminary reliability analysis was conducted. The analysis of critical systems for mission failure revealed that navigation and communication equipment, battery systems, propulsion systems, and sensors, in that order, have the greatest impact. In addition, BEs were classified into two categories: (1) Equipment failure such as equipment aging, equipment failure, and manufacturing defects, and (2) Failure caused by polar environmental such as collision with ice, low-temperature environment, and thermocline.

In particular, we utilized Dynamic FTA to analyze the causal relationships over time and sequence of sensor failures, which are difficult to analyze using traditional FTA.

3. Conclusion

In conclusion, this study aimed to analyze the preliminary reliability of AUVs in polar environments using FMEA and FTA. By FMEA, potential failure modes were identified, and evaluated their severity and occurrence. Then, by conducting FTA, the probability of AUV loss was calculated. The results of this study will be useful for designing and testing AUVs that can perform reliably in extreme environments. While precise failure rates are difficult to obtain for AUVs, the results of this study are expected to contribute to the development of more reliable AUVs in the future.

Acknowledgement
This research was supported by Korea Research Institute of Ships and Ocean engineering a grant from Endowment Project of “Development of core technologies of underwater robot ICT for polar under-ice-shelf exploration and remote monitoring” funded by Ministry of Oceans and Fisheries (PES4820).

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