WORK DOMAIN ANALYSIS FOR ECOLOGICAL INTERFACE DESIGN TO PREVENT SHIP COLLISION

SEUNG-KWEON HONG

Department of Industrial & Management Engineering, Korea National University of Transportation
E-mail: skhong@ut.ac.kr

Abstract—Anti-collision at sea is technically difficult to realize as it involves the complex interaction between human navigators, ships and surrounding topographical environment. Collision avoidance should be conducted by human navigators. This paper proposes a way to graphically present relevant information for collision avoidance to help the human navigators' decision making. The display can provide accurate situation awareness and reduce cognitive workload. This paper provided an abstraction hierarchy model for collision avoidance and several design tips for ecological interface design to support navigator who are confronted with ship collision situation.

Index Terms—Collision Avoidance, Ecological Interface Design, Maritime, Work Domain Analysis.

I. INTRODUCTION

Collision at sea is one of the major operational risks. Ship collisions can cause fatal marine accidents with human and economic losses as well as environmental pollution. Many digital technologies, such as Automatic Radar Plotting Aid (ARPA), Electronic Charting Display and Information System (ECDIS), and Global Positioning System (GPS), have been introduced for safe navigation. The introduction of these technologies improved the level of safety, providing the navigators with necessary tools during the whole context of operations. However, the level of safety was not increased as expected [1].

Decision support systems were also developed to support navigators' decisions for collision avoidance [2-3]. However, such systems could not take carefully consideration of navigators' cognitive aspects. Some researchers [1] pointed out disadvantages of technological improvements on bridges systems.

Anti-collision at sea is technically difficult to realize as it involves the complex interaction between human navigators, ships and surrounding topographical environment [4]. It may be more efficient and safe that final decision for collision avoidance is made by the human navigators. Some researchers proposed how to visualize relevant information for collision avoidance [5- 7]. However, these displays did not fully take into account the cognitive aspects of the navigator.The final purpose of current research is to propose a way to graphically present relevant information for collision avoidance to the human navigators. The display has to support human navigators' rapid and exact decision and should not impose mental workload. A methodology to develop this display is to use the principles of Ecological Interface Design (EID).

This paper focused work domain analysis as an initial step for ecological interface design. Section II presents a general method for work domain analysis. In Section III,the principles of Ecological Interface design is described. Section IV describesWork Domain Analysis and Ecological Interface Design for collision avoidance.

II. WORK DOMAIN ANALYSIS

Work domain analysis (WDA) is to describe work domain as a space of possible activities, finding the constraints on action given the work domain itself. This looks like a city map representing the possible routes between different locations [8]. An actor may choose a route among many routes between locations. Generally, an abstraction hierarchy (AH) proposed by Rasmussen [9] has been utilized for the work domain analysis. The AH consists of five layers, from functional purpose to physical form. The relationship between layers presents mean-end ("how-why") relationship. The AH also represents constraints imposed by the environment.
The AH has been successfully applied to the complex systems such as nuclear power plant control [10], health care systems [11] and aviation domain [12]. However, the AH on the maritime domain was rarely researched [13]. In particular, the AH for ship collision avoidance system was not researched.

III. ECOLOGICAL INTERFACE DESIGN

Ecological Interface Design (EID) is an approach to interface design that was introduced specifically for complex sociotechnical, real-time, and dynamic systems.The goal of EID is to make constraints and complex relationships in the work environment perceptually evident to the user.EID aims to improve user performance and overall system reliability for both anticipated and unanticipated events in a complex system, by reducing mental workload and supporting knowledge-based reasoning

According to Rasmussen [14] and Vicente [15], developing an ecological interface system requires a two stage process. At the first stage, the work domain is analyzed by AH. The second stage is related to Rasmussen's SRK taxonomy [14].The Skills, Rules, Knowledge (SRK) framework defines three types of behavior or psychological processes present in operator information processing. The SRK framework is used to determine how information should be displayed to take advantage of human perception and psychomotor abilities

IV. ABSTRACTION HIERARCHY AND EID FOR COLLISION AVOIDANCE

Ecological interface design that proposed in this paper was designed focusing the following three points. At first, EID should be able to provide information related to the collision avoidance even in situations involving many ships.The risk of ship collision is high in the congested area where many ships exist. Avoidance of collision in the context of encountering only one target vessel is fully resolved by current Automatic Radar Plotting Aid (ARPA).

Secondly, the display to support collision avoidance should reflect the COLREGS rules.Some researchers indicated that most of the ship collision accidents are due to violation of the COLREGS rules [16-17].Thirdly, the information display should be designed to clarify the encounter situation between own ship, target ships and environments. It should be provide a direct perception to the navigators so as to facilitate the avoidance operation of the ship.

Work domain analysis and Ecological interface design was conducted considering these three points. An abstraction hierarchy (AH) was utilized for the work domain analysis. The five levels of AH are mapping to navigators' activities needed to achieve related goals such as collision avoidance. These five levels include functional purpose, abstract function, general function, physical function and physical form.

The uppermost level of the abstraction hierarchy is the functional purpose of the system. The purpose of collision avoidance is to provide the safe and economical passage to a destination. Safe manoeuvring should have higher priority than economical manoeuvring, because safety is the most important in the collision avoidance system. However, navigators do not want to deviate too far from their desired navigation path.

Abstract function defines the principles or laws that govern how the system should work to achieve the functional purposes. This level indicated the variables that navigators need to control to achieve the functional purposes. Three variables should be considered for achieving the functional purposes. The own ship should be controlled by minimum separation standards. Typically own ship maintained the required minimum safety distance of 2 ~ 5 miles from the target ships, depending on traffic density at the navigation area. For the safe manoeuvring, ships have to observe the International Regulations for Preventing Collisions [18] at the encounter situation. Finally, navigators want to minimize economic loss that may occur by ship manoeuvre for collision avoidance.

General function above the physical functional levelis the physical processes that enable navigators to perform tasks at the abstract function level. Navigators should control their ship, satisfying three variables depicted at the abstract function level. Navigators first try to control their ship direction for collision avoidance. If they cannot turn their own ship by the desired angle, they will try to control the ship speed. This priority is due to economic problem. The control of ship speed requires more energy than the control of the ship direction.

The physical function specifies the individual parts from which a composite system is made. These individual parts include target ships'conditions, own ship's condition and environmental conditions. This level provides navigators with necessary information about these parts that is sufficient to perform maneuvering activity.

At the lower level of the hierarchy is detailed information about the physical system. This level specifies theindicators on the target ships, own ship and environments. This information is sensed by the bridge equipment such as Global Positioning System (GPS),Automatic Radar Plotting Aid (ARPA), and Auto Identification System (AIS). Figure 1 shows five layers of AH for collision avoidance.

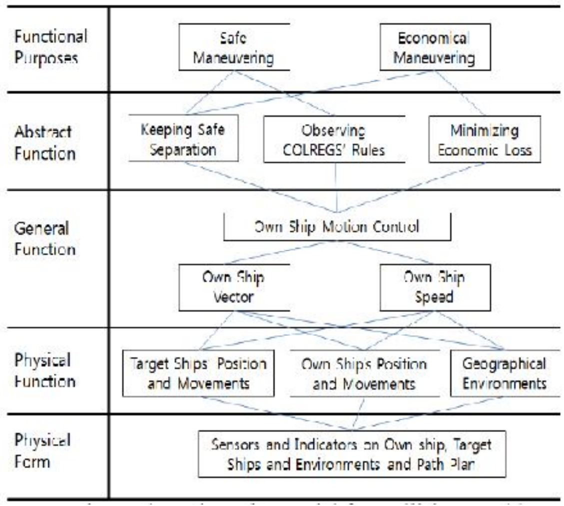

Figure 1. Abstraction Hierarchy Model for Collision Avoidance

Obtained from AH model and SRK taxonomy, several tips of ecological interface design are the followings. The final action of the navigators for collision avoidance is to control the direction or speed of the own ship. The display should provide a direct perception interface on the possible directions and speeds of the own ship, inducing navigators' skill-based behavior. This part is corresponds to the general function of AH model.

On the other hand, it should be indicated on the display how the space of possible direction and speed is derived. It will be information related to the abstract function of AH model. Navigators can check if their control action complies with minimum safety separation standard, observes COLREGS rules and minimizes economic loss. This display can also provide information that can cope with appropriately to unexpected actions of target ships.

CONCLUSION

This paper has provided an AH model for collision avoidance and several design tips for interface design to support navigator who are confronted with ship collision situation. In the ship collision situation, navigators have to have accurate situation awareness and have low cognitive workload in order to efficiently avoid the collision situation. Collision avoidance Interface that is based on the principles of EID approach will improve navigators' situation awareness and reduce cognitive workload. This paper only provided a research direction of collision avoidance interface design. In the future study, graphical interface for collision avoidance will be designed in the more details and an experimental study will be conducted in order to validate the effects of the interface.

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