A Brief Review of Unmanned Underwater Vehicle Human-Machine Interaction

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***Abstract*—Unmanned Underwater Vehicle (UUV) research typically seeks to understand the physical performance and control aspects of the underwater vessel operated in a dynamic environment. Commonly, UUV operations involve highly orchestrated coordination to conduct surveys, maintenance, and repair missions. With the vast selection of UUV products in the market, the disparity in the standard user interface is evident. Despite the high-risk and critical operations faced by the UUV operators, very little focus has been dedicated to reviewing the human-UUV interface aspect of the operations of UUV. In this review, an area of Human Machine Interaction (HMI), within the perspective of UUV designs is discussed.**

***Index Terms*—human-computer interaction, HCI, human-machine interaction, HMI, unmanned underwater vehicle**

I. Introduction

The rapid adoption of the use of teleoperated, or remotely operated vehicles is evident recently in the field of ocean engineering. The application of remotely operated vehicles for underwater applications is attractive since it removes the requirement to expose humans to adverse environmental risks while completing their tasks, such as surveying, mapping, monitoring, object pick-ups, and maintenance. The use of the unmanned underwater vehicle (UUV) is seen to be the most valuable method since it possesses highly accurate sensors on board such as high-resolution cameras, side-scan sonars, current profiler, radio transmitter, GPS receiver, and environmental sensors. The extension of such technology remains an interesting field due to the advancement of virtualization technologies that offer safer and more accurate control of the UUV, therefore strengthening the value chain for exploration activities underwater such as mining, oil exploration, and marine resource studies.

Interest in the field of unmanned underwater vehicle development traditionally revolves around the development of control systems or the dynamical modelling of UUV. There is a vast body of literature that discussed the dynamics of UUV [15,16,19,21], which are not limited to traditional mathematical modelling, but also the use of the black box method that is validated in the laboratory [23]. The use of UUV is not only limited to the large area underwater but also involves a sensitive and tight area that requires highly accurate control via the use of tuning [24]. The requirement to control UUV accurately hence preventing collision underwater is a demanding task for the operator, especially when it involves dangerous underwater pipelines. This in effect brings out further discussion on the importance of Human Machine Interaction (HMI) which seeks to answer the relationship and find the balance between human capabilities (cognitive, psychomotor, and empathy) and the machine under which the human needs to operate, especially in a teleoperated setup [25].

The use of unmanned underwater vehicles is not only limited to ocean engineering tasks. The wide-ranging use of unmanned systems is also helpful in wildlife and nature missions such as resource mapping, marine disasters, and monitoring of wildlife [26]. While much of the works reported in the literature were focused on visual-based monitoring, the use of UUV is also evident to measure the water quality [29] not only in calm water operation but also in a high-disturbance environment. In this perspective, the research on UUV is not limited to only focusing on wireless UUV, but also on the tethered remotely operated vehicle in deep sea working-class applications [30]. Additionally, from the perspective of HMI, it can be observed that there is still a lack of work dedicated to studying the regulations for underwater operation [17].

This paper aims to present a brief review of the Human-Machine Interaction (HMI) discipline from the perspective of Unmanned Underwater Vehicle (UUV). With the recent rise of the application of mixed realities or Extended Reality or XR

(Augmented Reality, Virtual Reality, Digital Twin), there exists a significant opportunity for the research in HMI to contribute to the field of ocean engineering, particularly underwater vehicle applications. We seek to connect the concept by discussing several works of literature that have contributed to HMI-UUV in general, followed by extended reality, cloud applications, and other promising works that offer expansion to the field of remotely operated underwater vehicle development.

II. Human-Machine Interaction (HMI)

In the study of UUV design, Human-Machine Interaction (Fig. 1) is a concept that serves as a bridge between the UUV operator and the vehicle of concern. HMI in UUV applications is not limited to traditional peripherals such as keyboard, mouse, and joysticks, but it expanded to several other interfaces such as virtual touch interface, wearable devices, speech recognition (non-visual interface) and eye-controlled system [7]. Although the consensus concerning the typical peripheral among the UUV practitioners leaned towards the use of a joystick, [9] expanded the usability of a joystick with a more intuitive interface design, where three interface scheme was proposed which are: (a) joystick with gesture control, (b) steering wheel with trackball, and (c) steering wheel with gesture controls.

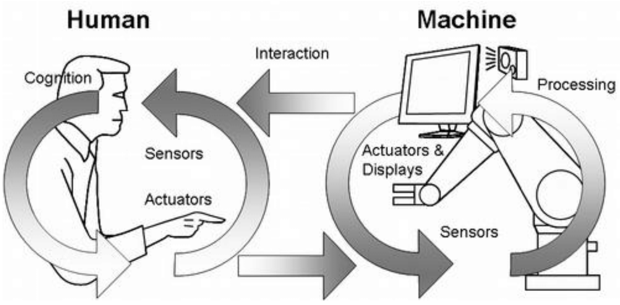

Fig. 1. An example of Human-Machine Interaction [31]

The use of HMI ultimately is to assist UUV operators to complete the mission efficiently. Manual UUV operations are typical among commercial UUVs, which require highly trained UUV operators to be able to perform several missions such as underwater surveying, maintenance, and repair. This in effect exposed the mission to chances of failure, therefore [11] highlighted that certain automation systems should be in place to ensure that a trained ROV operator can perform in a highly efficient manner and to reduce fatigue. To achieve certain competencies and efficiencies, the availability of facility and time are paramount. A typical operation requires long hours of planning and setup, including divers, boats and its operator, loading and unloading system, and other costs. In the work of [13], the importance of graphical simulators is very important. Virtual simulators are capable to assist in UUV training without the tedious and costly physical preparation. The advantages of virtual simulators are many, which include mission playback, hardware in the loop system, and training analytics for continuous improvements.

An efficient human-computer interface is capable to increase the yield of a mission. In the work of [27], via the use of an efficient setup of a mini UUV, compared with the traditional snorkelling method to monitor fish behaviour, it has been shown that the mini UUV is capable to achieve 39% higher fish abundance and 24% more diverse than a snorkeler. Faster and more efficient coordination between teams of integrated operators has been shown in the work of [22] where in an offshore drilling platform virtual simulator, two simultaneous systems were integrated which are the Dynamic Position System (DPS) and remotely operated vehicle (ROV). This in effect provides for better underwater mission management, better walk-through of the possible situations and strategizing for a heave compensation system during the drilling mission. With disaster risk management and pollution control in place, tragic system failures can be avoided via the use of virtual simulator systems [20]. This may come in the form of virtualization of layout systems [14] or the strategic intervention that may be put in place during the simulator, via the use of situational-based missions [18].

III. Extended Reality (XR)

The emergence of faster computing power and miniaturized screens resulted in the rise of two popular meta-universe which are Virtual Reality and Augmented Reality. These two concepts, which are grouped as Extended Reality (XR) aim to bridge the physical world and digital world together to create a richer experience and offer limitless possibilities in the field of work and entertainment. Although the term VR has been a popular jargon since the 90s, especially in the age of early internet via VRML (VR Markup Language), the integration of VR in the field of underwater vehicle studies has remained lacking.

The integration of web interfaces and sensors in early 2010 offered a possibility to integrate VR and underwater vehicle technologies. In 2012, [10] presented a human-robot interface using a web interface and VR to provide an interactive environment of a sea floor, which is editable concerning the user's demand. In the world of XR, environment manipulation is a very important feature to offer limitless mission configuration. This is demonstrated by [8], where such setup is used to construct underwater manipulation tasks (underwater archaeology, oil & gas facility building) with sensorized robotic arms, and stereoscopic 3D perception. As a result, an a-priori understanding of the manipulators and their environment [12] can be achieved by the UUV operator before embarking on the real UUV in the physical world.

In the construction of the XR world, the emphasis is not limited to the environmental settings (sea floor, underwater living, water shaders and so on). A complete XR UUV technology would also focus on the HMI aspects such as the navigational Graphical User Interface (GUI) to give enough information to the operator [3]. Such oversight and intervention [5] are helpful to the operator to reduce cognitive fatigue which is likely to cause underwater incidents by giving enough information about the UUV surroundings while maintaining its workload at a low level (Fig. 2).

Fig. 2. VR interface within a simulated environment [5]

IV. Cloud-Based UUV and Other Advancements

UUV operations are expanding, in which for any desired mission definition, a single operator is no longer limited to controlling one UUV at a moment. As the commercial observatory UUV business expands, fleets of UUV are deployed to conduct measurements at one time and different locations throughout the world. With the advent of high-speed internet and better satellite connectivity, a cloud-based remote-control framework for the unmanned surface vehicle has been proposed [28]. Though [28] does not strictly discuss such capability to be applied to UUV, [2] has brought forward the idea for such implementation for the underwater vehicle via the development of a communication interface for multilayer cloud computing architecture. One of the characteristics of cloud-based service is its capability to perform real-time reporting. While such capability is challenging due to network latency, the use of swarms is beneficial to communicate with other batches of UUV for communication continuity to the satellite or the closest dedicated measurement station.

While ocean traffic is not as busy as inland routes, UUV operations are exposed to high-risk incidents which may cause a larger magnitude of threats. Despite the serene underwater nature, subsea traffic is busy with various natural living such as fish and corals, offshore pipelines, submarine cables and unmanned underwater vehicles. The work reported by [17] presented a very niche area of UUV studies, in which it attempted to develop safety envelopes and subsea traffic rules for autonomous ROVs, to prevent loss of subsea assets and the ROV in question.

Perception, in the UUV design discipline typically refers to the capability of the vehicle to perceive its environment. However, in the field of HMI, UUV perception may refer to how the operator perceives the surroundings underwater. While visual perception is very popular in the UUV design literature, the work by [4] and [6] stands uniquely in presenting the use of spatial auditory interface (Fig. 3), in which a UUV operator offloaded their visual channel by including hearing modality for trajectory tracking to reduce fatigue, therefore decreasing the risk of accidents [1] and increasing the efficiency of the mission.

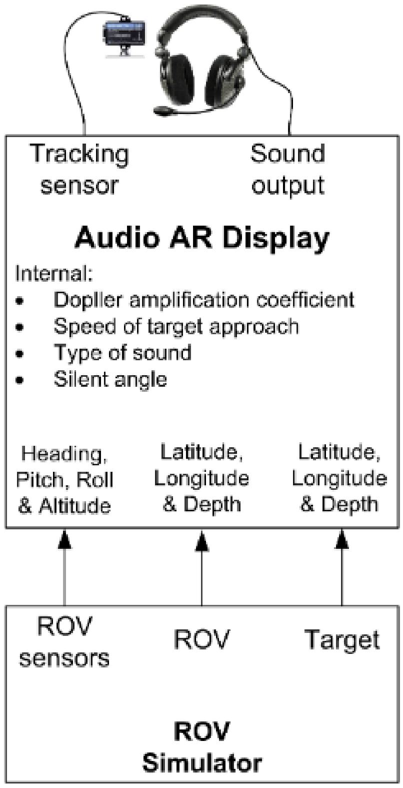

Fig. 3. Spatial-Auditory Interface setup for ROV operator [4,6]

V. Conclusions

This review discussed in brief the design of UUV within the perspective of human-machine interaction. This review aimed to expand the frontiers of UUV design by showing gaps in UUV design literature, which typically focused on physical modelling, communication, and missions, by introducing the element of human needs to perform safer and more efficient UUV operations. In this review, three core discussions were presented; the underlying HMI concept is UUV development, the usage of XR in mission familiarization, cloud based UUV control and other interesting potential areas of research. It is envisaged that via the expansion of the field and larger collaborative multidisciplinary research, safer and efficient UUV operations can be achieved which contribute to a larger economic value throughout the world.

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References

[1] M. Lager and E. A. Topp, “Remote Supervision of an Autonomous Surface Vehicle using Virtual Reality,” IFAC-PapersOnLine, vol. 52, pp. 387-392, 2019.

[2] M. Cruz, G. A. Casañ, P. J. Sanz and R. Marín, “A New Virtual Reality Interface for Underwater Intervention Missions,” IFAC-PapersOnLine, vol. 53, pp. 14600-14607, 2020.

[3] F. Bruno, A. Lagudi, L. Barbieri, D. Rizzo, M. Muzzupappa and L. D. Napoli, “Augmented reality visualization of scene depth for aiding ROV pilots in underwater manipulation,” Ocean Engineering, vol. 168, pp. 140-154, 2018.

[4] C. Domingues, M. Essabbah, N. Cheaib, S. Otmane and A. Dinis, “Human-Robot-Interfaces based on Mixed Reality for Underwater Robot Teleoperation,” IFAC Proceedings Volumes, vol. 45, pp. 212-215, 2012.

[5] J. Zhang, W. Li, J. Yu, X. Feng, Q. Zhang, G. Chen, “Study of manipulator operations maneuvered by a ROV in virtual environments,” Ocean Engineering, vol. 142, pp. 292-302, 2017."

[6] A. Cardaillac and M. Ludvigsen, “A Communication Interface for Multilayer Cloud Computing Architecture for Low Cost Underwater Vehicles,” IFAC-PapersOnLine, vol. 55, pp. 77-82, 2022.

[7] Z. Wang, S. Yang, X. Xiang, A. Vasilijević, N. Mišković and Đ. Nađ, “Cloud-based remote control framework for unmanned surface vehicles,” IFAC-PapersOnLine, vol. 53, pp. 14564-14569, 2020.

[8] O. Eidsvik and I. Schjølberg, “Finite element cable-model for Remotely Operated Vehicles (ROVs) by application of beam theory,” Ocean Engineering, vol. 163, pp. 322-336, 2018.

[9] O. Landstad, H. S. Halvorsen, H. Øveraas, V. Smines and T. A. Johansen, “Dynamic positioning of ROV in the wave zone during launch and recovery from a small surface vessel,” Ocean Engineering, vol. 235, 2021.

[10] A. Bagheri and J. J. Moghaddam, “Simulation and tracking control based on neural-network strategy and sliding-mode control for underwater remotely operated vehicle,” Neurocomputing, vol. 72, pp. 1934-1950, 2009.

[11] J. Avila and J. Adamowski, “Experimental evaluation of the hydrodynamic coefficients of a ROV through Morison’s equation,” Ocean Engineering, vol. 38, pp. 2162-2170, 2011.

[12] S.M. Ahmad and R. Sutton, “Dynamic Modelling of a Remotely Operated Vehicle,” IFAC Proceedings Volumes, vol. 36, pp. 43-48, 2003.

[13] G. Conte, S. M. Zanoli, P. Buchi and A. Serrani, “Interactive Design of Control Schemes and Obstacle Avoidance Strategies for UUVS,” IFAC Proceedings Volumes, vol. 33, pp. 519-524, 2000.

[14] H. Shim, B. Jun, P. Lee, H. Baek and J. Lee, “Workspace control system of underwater tele-operated manipulators on an ROV,” Ocean Engineering, vol. 37, pp. 1036-1047, 2010.

[15] Z. Yang, X. Yu, S. Dedman, M. Rosso, J. Zhu, J. Yang, Y. Xia, Y. Tian, G. Zhang and J. Wang, “UAV remote sensing applications in marine monitoring: Knowledge visualization and review,” Science of The Total Environment, vol. 838, 2022.

[16] D. Wu, K. Yuan, Y. Huang, Z. Yuan and L. Hua, “Design and test of an improved active disturbance rejection control system for water sampling unmanned surface vehicle,” Ocean Engineering, vol. 245, 2022.

[17] T. Z. Htun, H. Suzuki and D. García-Vallejo, “On the theory and application of absolute coordinates-based multibody modelling of the rigid–flexible coupled dynamics of a deep-sea ROV-TMS (tether management system) integrated model,” Ocean Engineering, vol. 258, 2022.

[18] J. Soares, A. Vale, and R. Ventura, “A Multi-purpose Rescue Vehicle and a human–robot interface architecture for remote assistance in ITER,” Fusion Engineering and Design, vol. 98-99, pp. 1656-1659, 2015.

[19] G. Prabhakar and P. Biswas, “A Brief Survey on Interactive Automotive UI,” Transportation Engineering, vol. 6, 2021.

[20] A. Chia and C. Balash, “Towards an improved intuitive interface for Remotely Operated Vehicles,” Journal of Ocean Engineering and Science, vol. 5, pp. 346-357, 2020.

[21] E. H. Henriksen, I. Schjølberg and T. B. Gjersvik, “Adaptable Joystick Control System for Underwater Remotely Operated Vehicles,” IFAC-PapersOnLine, vol. 49, pp. 167-172, 2016.

[22] O. Matsebe, C.M. Kumile and N.S. Tlale, “A Review of Virtual Simulators for Autonomous Underwater Vehicles (AUVs),” IFAC Proceedings Volumes, vol. 41, pp. 31-37, 2008.

[23] B. Zhou and M. Zhao, “Numerical simulation of thruster-thruster interaction for ROV with vector layout propulsion system,” Ocean Engineering, vol. 210, 2020.

[24] G. Marani, S. K. Choi and J. Yuh, “Underwater autonomous manipulation for intervention missions AUVs,” Ocean Engineering, vol. 36, pp. 15-23, 2009.

[25] A. Mairaj, A. I. Baba and A. Y. Javaid, “Application specific drone simulators: Recent advances and challenges,” Simulation Modelling Practice and Theory, vol. 94, pp. 100-117, 2019."

[26] K.Park, S. Ham, N. Ku, A. Jo and H. Suh, “Development of offshore drilling platform simulation for virtual onboard experience,” International Journal of Naval Architecture and Ocean Engineering, vol. 14, pp. 2092-6782, 2022."

[27] V. Raoult, L. Tosetto, C. Harvey, T. M. Nelson, J. Reed, A. Parikh, A. J. Chan, T. M. Smith and J. E. Williamson, “Remotely operated vehicles as alternatives to snorkellers for video-based marine research,” Journal of Experimental Marine Biology and Ecology, vol. 522, 2020.

[28] J. Hegde, E. H. Henriksen, I. B. Utne and I. Schjølberg, “RDevelopment of safety envelopes and subsea traffic rules for autonomous remotely operated vehicles,” Journal of Loss Prevention in the Process Industries, vol. 60, pp. 145-158, 2019.

[29] A. Vasilijevic, E. Omerdic, B. Borovic and Z. Vukic, “Acoustically aided HMI for ROV navigation,” IFAC-PapersOnLine, vol. 45, pp. 49-55, 2012.

[30] A. Vasilijevic, Z. Vukic and N. Miskovic, “Teleoperated trajectory tracking of remotely operated vehicles using spatial auditory interface,” IFAC-PapersOnLine, vol. 49, pp. 97-102, 2016.

[31] M. A. Razzaq, M. A. Qureshi, K. H. Memon and S. Ullah, “A Survey on User Interfaces for Interaction with Human and Machines” International Journal of Advanced Computer Science and Applications (IJACSA), vol. 8, 2017.