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IoT Frameworks for Digital Twin in Underwater Sensor Networks – A Review

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Abstract

A digital twin is a computerised representation of a planned or existing real-world physical framework or operation (a physical twin) that functions as a nearly identical digital equivalent system for practical reasons such as an imitation, amalgamation, evaluation, observation and administration. The digital twin was initially designed since its creation to be the basic concept for product life span management and lives throughout the whole lifespan of the physical thing it represents. This article will explain the concept of digital twin in underwater wireless sensors. The article examines various research works employing the digital twin in UWSN (Underwater Wireless Sensor Networks), and the research work explains the fundamentals of digital twins and their applications.

Keywords: Digital twin, UWSN, IoT, AI, cloud

1. Introduction

A digital twin is a virtual representation of a physical object that simulates and monitors processes throughout its lifespan, utilizing real-time data supplied by sensors embedded within the object. Many real-world products may be replicated using digital twins, ranging from individual pieces of manufacturing equipment to whole installations like turbines for electricity and even entire towns. Digital twin technology enables us to monitor an asset's performance, identify possible issues, and make more educated maintenance and lifecycle decisions [12]. Using a digital twin at the development process allows us to model as well as simulate the whole lifespan of the desired entity. A digital twin of an existing thing can be utilised in real-time and integrated with the actual system.

Mirror Worlds, written by David Gelernter in 1991, predicted the existence of digital twins. Michael Grieves made the first official introduction of the digital twin concept and model in 2002 at a Society of Manufacturing Engineers meeting in Troy, Michigan Grieves suggested the digital twin as a conceptual paradigm for product life cycle management (PLM) [13]. In 2010, NASA's John Vickers published the Roapmap Report, which was the first realistic analysis using a digital doppelganger to improve spacecraft real-world representation. Digital twins were the consequence of ongoing progress in the engineering and design of products efforts. Product drawings and requirements for engineering have evolved from hand-drawn to CAD or designing for model-based platforms design with a precise relationship to the physical equivalent.

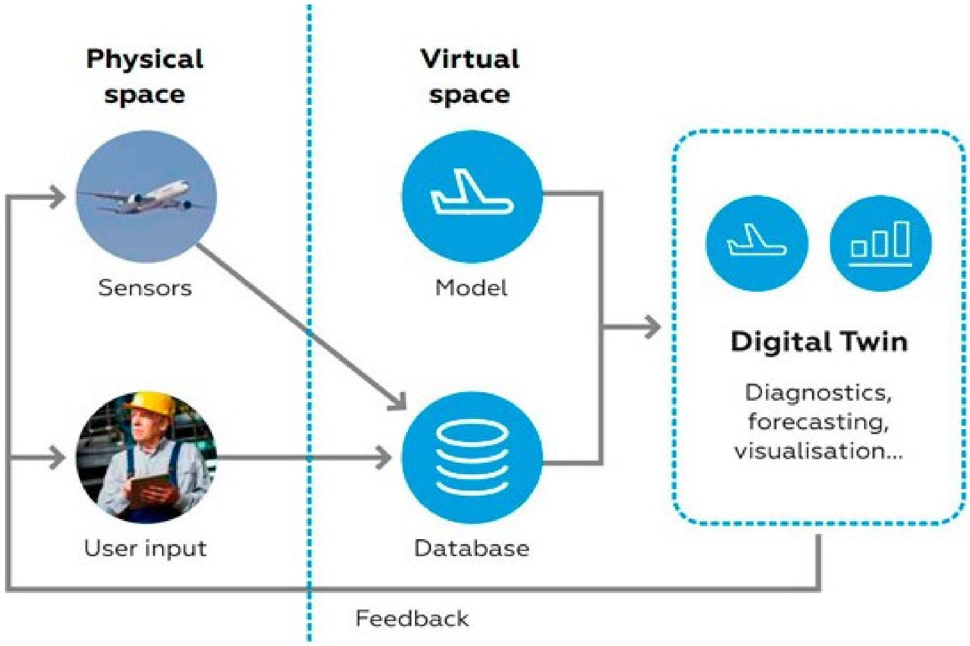

Figure 1. Digital Twin Process [14]

1.1 Benefits

- The utilisation of digital twins allows for more effective product research and design, as it generates a large amount of data concerning expected performance results. This data may lead towards insights which assist organisations make the necessary product modifications before commencing production.
- Once a new product has been put into manufacture, digital twins may assist reflect and monitor production processes in order to achieve and maintain optimal efficiency throughout the manufacturing process.

- Digital twins can also assist producers determine what to do with items that have reached the end of their lifespan and require final processing, such as recycling or other steps. They can use digital twins to assess which product materials are harvestable.
- A virtual depiction of a real thing might include financial information, such as material and labour costs. Availability of a significant quantity of real-time data as well as sophisticated analytics allows firms to take better and faster choices on whether or not changes to their manufacturing process are financially viable.

1.2 Types

There are numerous sorts of digital twins, which can commonly coexist in a single system. While certain digital twins basically copy specific portions of an item, each of them play an important role in generating a virtual depiction. The most common kind of digital twins include the following [15]:

- **Component Twins:** Component twins are digital representations of certain parts of a system or a product that is a gear or screw like engine in a wind turbine. Rather to just modelling all of the separate pieces of a product, component twins are commonly employed to describe integral elements, such as those subjected to high stress or heat. Engineers and designers can understand ways to enhance the components' integrity in anticipated circumstances by digitally modelling them and running dynamic simulations on them.
- **Asset Twins:** It is also known as product twins, were computerised representations of a physical thing rather than distinct components. While asset twins can be made up of many component twins, their goal is to figure out how the various pieces work together in a specific real-world product. In this case, a wind turbine may have a related asset twin that can be utilised to track its performance and indicate potential components failure due to normal wear and use.
- **System Twins:** System twins, also known as unit twins, is virtual representations of items that function together. Asset twins mimic real-world goods made up of numerous elements, whereas system twins represent such individual products as elements of a broader system. Understanding how resources communicate with one another provides

the chance to optimise their relationships, resulting in increased production and efficiency.

- **Process Twins:** Process twins will be digital models of systems that function together. For example, a system twin may mimic a production line, but a process twin may represent the whole factory, includes the employees who use the machinery on the manufacturing floor.

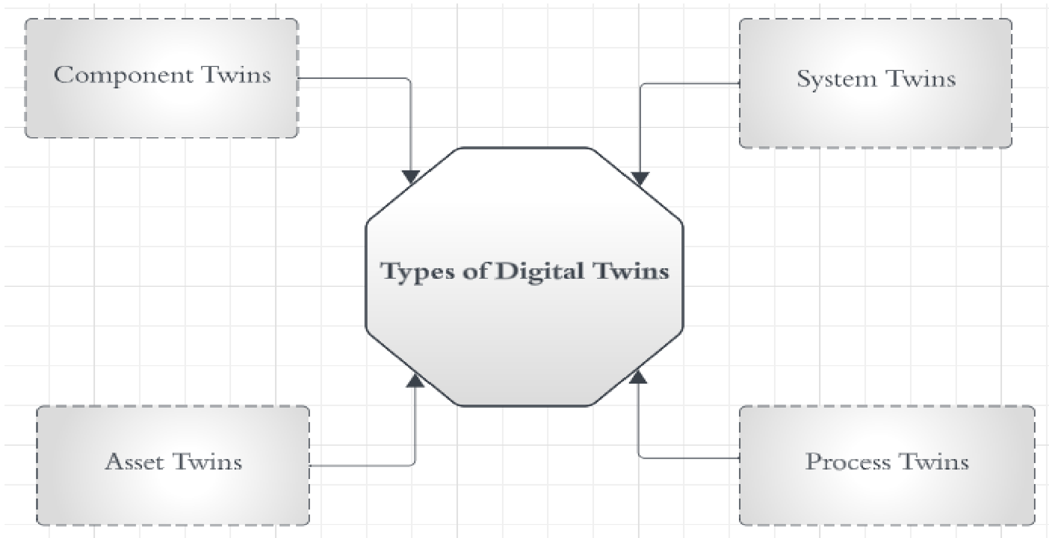

Figure 2. Different Types of Digital Twins

2. Literature Survey

This study [1] focuses on developing a Digital Twin architecture to enable a flexible Artificial Intelligence Internet of Things (AIoT) framework for smart cultivation of fish in aquatic farming. Our actual thing is outfitted with smart components, such as actuators and sensors incorporated in intelligent equipment, which gather and communicate big data through the cloud over wireless networks of communication for actual time and distant monitoring. We provide four primary digital twin services, they are feeding the fish for automating the feeding procedure, metric estimate, monitoring the environment, and healthcare monitoring. Every digital twin service contains numerous AI services that are capable of executing complicated and other operations such as optimisations, forecasts, and analysis for smart decision-making to maximise farm revenues and productivity.

The purpose of this article [2] investigates the use of digital twin technology (DTT) as well as artificial intelligence (AI) to advance underwater wireless sensor networks (UWSNs). The problem statement highlights UWSN's difficulties with the accuracy of data, decision-making in real time, and conservation of energy. Typical UWSN technologies have lack of their capacity to respond quickly to evolving underwater circumstances and assure consistent data transfer. This work tackles these issues by offering a unique technique that combines DTT and AI to improve UWSN function. Its technique entails the development and deployment of a DTT-AI based UWSN system. DTT mimics the physical undersea world, creating a virtual image that changes in the moment. AI algorithms interpret data gathered by UWSN sensor into this digital twin, allowing for smart decision-making with statistical analysis.

In the following article [3], the research work provides an idea for using digital twin as a way of improving the functionality of smart environments. Researchers create a general model architecture with four different levels: the physical environment, the sensor detecting infrastructure, network connections, and the fundamental computing infrastructure. subsequently, defines and solve essential needs for the implementation of digital twins in innovative areas, as well as analyse their advantages, utilising the business analytics ascendancy model. In conclusion, to show the feasibility of digital twinning, provide an experimental results digital twin that represents the TELUS innovative environment at the University of Oulu in Finland, that utilise to bring out possible advantages of various ascendancy stages.

This article [4] presents a unique analysis of the current implementation progress of Digital Twins Technology (DTT) in several maritime industry sectors, such as shipbuilding (SBI), offshore oil and gas, marine fisheries, and marine energy. The findings show that DTT provides strong support for complete life cycle management (LCM) in SBI, which includes digital layout, intelligent processing, execution, and error control. Furthermore, the present article dives into the obstacles and opportunities of DTT use in the maritime sector, with the goal of providing references and framework for intelligent systems throughout the industry, as well as guiding the rational growth and utilisation of marine resources into the future.

This study [5] demonstrates that Distributed Simulation (DS) may facilitate DTs using a network of distributed computer resources. DS can accelerate the execution of simulation programmes in DTs (and hence reduce the time required to analyse system behaviour) and link simulations to enhance composability in addition to reusability during DT development. In the instance of an Underwater Unmanned Vehicle (UUV) DT, a networked real-time simulation system based on the IEEE 1516 High Level Architecture Standard (HLA) was built to increase the ship's capabilities. In this study, primary Italian customers who work in the shipping industry are creating a number of resources and technologies that are required for the real-world execution of an expanded ship via a fleet of underwater along with surface drones, and they discovered that the HLA-based DS is the ideal replacement for a simulation-based DT.

Using thorough literature surveys, this article [6] examines the prerequisites of a five-layered digital twin foundation for the digital revolution. Thus, the findings contribute to our objective of offering efficient administration and remote surveillance of aquaculture activities. The system monitors fish eating behaviour, illness, and growth utilising based on the cloud digital twins powered by machine learning as well as computer vision, in addition to sensor and artificial intelligence-based Internet of Things (AIoT) technology. As a result, this study employs an altered analytic hierarchical approach to determine user needs and deployment methods for digital twins in order to realise the aim of smart fish farming operations. In accordance with the requirement evaluation, the cloud-based digital twin technology was built to significantly increase the productivity of standard fish farm administration.

This study [7] proposes a structure of DT-driven RID and FLM for the UGS based upon past conceptual research and method development. The suggested structure of DT-driven approach is then thoroughly examined in terms of digital modelling, design optimisation, digital confirmation, and implementation in practice. At last, Petrel, created by China, is described, and a specific initial implementation of DT-driven technique is given using Petrel to test its usability. The design suggested in this review is also applicable to different forms of self-driving submarines.

The research problems which are constantly appearing on this field have a significant connection to the interactions, compatibility, as well as secure operation of the trusted UUVs, and also to its volume, velocity, variety, followed by veracity of the information transferred with low bandwidth due to the medium that is, the water. This study [8] focuses on similar difficulties in the UUV arena, with a particular emphasis on compatibility and cybersecurity in swarms of trusted UUVs in a military/search-and-rescue (SAR) environment. The purpose of this article is to offer initial research on a conceptual simulation and modelling approach with the goal to enable officers of military/search-and-rescue activities in efficiently assisting essential and lifesaving decision-making processes, while managing interoperability along with cybersecurity concerns on the Internet of Underwater Things (IoUT).

Acoustic transmission technique is used to interact with growing ad-hoc UWSNs, which are established technologies with broad coverage regions and constant connection however consume a lot of energy and poor operating bandwidth. Considering that it’s not possible to improve sound speed with lack of physically changing the underwater channel, increasing complete time of delivery in every case is heavily reliant on the design of the hardware involved, the communication protocol chosen for the data and network layers, and the network's physical topology. This simulation-driven study [9] seeks to determine how the routing strategy and topological selection affect entire delivery intervals in densely inhabited, busy deep sea oil drilling locations. The model was performed in NS-3/Aquasim-NG and determined which a constructed topology of fixed-location nodes in a Depth Based Routing (DBR) would prove to be ideal for crucial moment situations, attaining the shortest time among sink along with source which makes it the most effective strategy for an immediate reaction to a hazards when it is compared with Hop-to-Hop Vector Based Forward (HH-VBF).

In this study [10], three separate sets of trials are carried out over a 200-meter region. The results of the simulation demonstrate that the FSOA method may completely encompass the events, completely eliminate node blind movements, and maintain node and event distribution density consistency. The proposed NC-HARQ protocol retransmits using relay nodes, which have a substantially greater success rate than the originating node. The data packets can be successfully delivered up to 99.6% of the time at distances beyond 2,000 metres. Depending on the MICN framework, a smart ship built using the digital twins’ architecture may deliver accurate ship functioning state forecast data. This work contributes significantly to increasing UWSN efficiency as well as tracking maritime data.

3. Digital Twin in UWSN

The Internet of Things relates to a network of connected things and technologies that enables them to communicate with the cloud and with one another. Everyone now has billions of internet-connected gadgets as a result of developing inexpensive processors for computers and large bandwidth telecoms. Digital twins use data from IoT sensors to transfer information from a real-world object to a digital-world entity. The data is sent onto a software platform or dashboard, which displays data updates in real time.

Underwater Wireless Sensor Networks (UWSNs) are made up of numerous components, including vehicles and sensors, which are placed in a defined auditory region for collaborative tracking and data collecting. These networks enable interactive communication between nodes as well as ground-based stations [11].

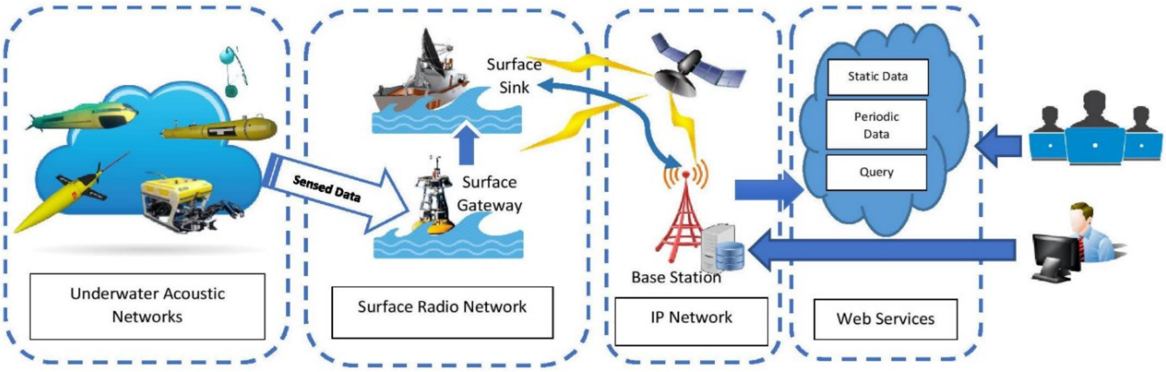

Figure 3. Overview of Underwater Wireless Sensor Network [16]

Underwater wireless sensor networks consist of modules that may be installed on both the ground and beneath the water. Every node in the network should share and exchange data with each other along with the main station. A sensor network's communication technologies employ acoustic, electromagnetic, and or optical wavelength carriers to send data. Acoustic communications are the most common and extensively utilised form of medium owing to its reduction properties in water. The poor transmission factor results from the absorption along with conversion of power into temperature in water. Meanwhile, acoustic signals use low frequencies, allowing them to be broadcast and received across large distances.

3.1 Requirements

- **Longevity:** The network longevity forms one of the most important consideration for UWSNs. It has an important effect on the price, time, requirements for maintenance, and efficiency of underwater nodes of sensors. It is crucial for increasing the network's lifetime, particularly for portable sensor node functions.

- **Accessibility:** Every sensor node interacts with one another over the communication distance defined by the area. Another significant criterion for UWSN is the communication range, which influences node density, implementation feasibility, and network expense in the desired monitoring region. Underwater sensor networks include two communication modes: acoustic and optical. Underwater acoustic wireless communications have become one of the most widely utilised technologies since it has become easily accessible and needs interaction over extended distances.

- **Complexity:** The definition of the sensor node positioning at the location is also critical for UWSN. Thus, an issue of complexity must be addressed when establishing the connectivity system, which includes the physical components, firmware, and network setup of node placements. Furthermore, the protocol for routing choices and computational demands help to find paths constantly with no additional data or previous understanding regarding other nodes.
- **Security and Privacy:** UWSNs are associated with privacy and security issues pertaining to sensor node connection, synchronisation, and data transmission responsibilities. The constantly changing characteristics of the underwater environment and its surroundings exposes the network to a variety of challenges and attackers. Before all nodes may safely connect with the network and communicate for exchange of data, the networks must first establish trust. It is critical to investigate the extent of security owing to the increasing computational demands and volume of transferred data while consuming additional resources inside the network.
- **Sustainability of the Environment:** The introduction of technology for communication in UWSN has to consider the influence on the environment and fauna. Wildlife is impacted by surrounding and boat disturbances, which can cause stress and increase the danger of species. Furthermore, an increased noise level in the maritime environment might cause modifications to marine habits, populations variation, and impairment of hearing.

4. Discussion

From the current methods mentioned above, the digital twin approach will be used in the aquatic area as an innovative technique that protects aquatic life and living organisms. They will use various sensors to monitor or track something. The various studies and research forecast numerous methods to employ the digital twin to extensively investigate aquatic life, aquatic organisms, sea depth, military search and rescue operations, massive ship construction for receiving and transmitting products, and so on using the sensor networks. From the aforementioned techniques, a few obstacles will emerge, which may be solved by developing an enhanced way of digital twin using underwater sensors.

5. Conclusion

Based on the study presented above, the article concluded that the digital twin can be utilised in underwater by employing various IoT sensors for different research on aquatic life and living organisms. The essay discusses the digital twin and how it has grown across the technological world. Additionally, there will be further a discussion on Underwater Wireless Sensor Networks (UWSN) with the merging technology of digital twin, which highlights the progress of these technologies in the aquatic field. The future of digital twins will see the incorporation of edge computing capabilities, allowing for instantaneous data analysis and decision-making at network edges. By analysing information close to the source, digital twins may adjust quickly to changing conditions and deliver timely insights.

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