**Title: Revolutionizing Aquatic Spheres: A Global Review of IoT Technologies**

**in Fisheries and Aquaculture**

**Running Head: IoT Technologies in Fisheries and Aquaculture Sector**

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**Highlights**

* Comprehensive exploration of IoT Technologies in Fisheries and Aquaculture was done and 87 cutting-edge IoT technologies have been identified within the dynamic realms of fisheries and aquaculture.
* Smart Feeding and Monitoring Take Center Stage with 54% among the diverse array of IoT technologies.
* The spotlight also shines on other remarkable IoT breakthroughs, with Smart buoys commanding a noteworthy 11.4%, Supply chain management strategically positioned at 6.8% and underwater ROVs and smart fishing rods captivating attention with 5.7% each.
* Grading and counting technologies and drones further contribute to the innovative landscape at 3.4% and 2.2% respectively, promising unprecedented advancements in the industry.
* IoT technologies offer potential to revolutionize fisheries and aquaculture, unveiling a multitude of transformative possibilities and paving the way for a sustainable and technologically advanced future.

**Abstract**

The integration of IoT technologies into fisheries and aquaculture sector is emerging. However, lack of comprehensive documentation on IoT technologies developed worldwide remains evident. Thus, a study was undertaken with the objective of surveying IoT technologies in fisheries and aquaculture on a global scale. Virtual information served as the foundation for compiling a comprehensive inventory of IoT technologies in fisheries and aquaculture worldwide. Search engines, notably Google and youtube were utilized with targeted keywords including 'IoT technologies in fisheries/aquaculture', 'IoT solutions for fisheries/aquaculture', 'IoT companies for aquaculture/fisheries' and 'IoT start-ups for fisheries/aquaculture'. This discerning approach yielded tally of 87 IoT technologies tailored for the sector. The categorized IoT technologies were adeptly classified into eight discernible domains, encompassing Smart Fisheries, Smart Buoy Technology, Underwater ROVs (Remotely Operated Vehicles), Supply Chain Management, Drones, Smart Fishing Rods, Grading and Counting etc. Notably, the majority of IoT technologies fell under the ambit of Smart Fisheries, accounting for an astounding 51.3% followed by Smart Buoy Technology at 10%. From a geographical standpoint, the United States emerged as the preeminent contributor, with an impressive repertoire of 16 technologies, with India, Norway and Spain closely trailing with 10, 8 and 5 technologies, respectively. As for continents, Europe led the charge with a significant 31% share, followed closely by Asia and North America, commanding 28.7% and 18.3%, respectively. This study thus provides understanding of existing IoTs in fisheries and aquaculture. The ultimate goal lies in adoption rate of smart fish farming, revolutionizing aquatic spheres on a global scale.

**Key words:** IoT, Fisheries, Aquaculture, Technology

**Introduction**

The Internet of Things (IoT) represents a rapidly burgeoning technological paradigm, exerting a profound influence across diverse facets of contemporary life. Bolstered by the surging prevalence of mobile devices and internet users, the IoT's relevance continues to escalate on a global scale (Naaz, 2019). This cutting-edge domain revolves around the interconnectivity of everyday objects, replete with embedded electronics, software, and sensors, enabling seamless data collection and exchange through internet interfaces (Gabbai, 2015). These ‘things’ encompass tangible physical entities, engendering a vast array of IoT applications across industries, spanning Smart Homes, Wearables, Connected Cars, Industrial Internet, Smart Cities, Agriculture, Smart Retail, Smart Grids, Healthcare, Poultry, and Farming (Yadav, 2022).

Of particular note, the fisheries and aquaculture sector has recently embraced IoT technologies as a strategic means to satiate the escalating demand for fish and fishery products. According to recent insights from InsightAce Analytic, the global IoT for fisheries and aquaculture market, valued at US$ 415.37 Million in 2021, is projected to soar to US$ 1232.32 Million by 2030, surging at an impressive CAGR of 13.2% during the period from 2022 to 2030 (InsightAce Analytics, 2022). The domain of fisheries and aquaculture brims with immense potential, particularly concerning fish farm monitoring, where access to critical data such as water temperature, pH, turbidity, dissolved oxygen, humidity, light, pressure, and chlorophyll bestows farmers with a competitive edge, enabling effective risk management and predictive fish production capabilities.

In the purview of smart farming, a plethora of sensors, communication networks, management information systems, and data analysis solutions synergistically converge to harvest real-time data, optimizing productivity and curbing waste through timely and judicious interventions. Beyond fish farm monitoring, IoT technologies offer a gamut of applications, facilitating feed optimization, informed harvesting decisions, traceability, and supply chain transparency, and even ushering in the era of precision fishing for large-scale fishing enterprises, which, according to McKinsey (2020), could potentially amass a staggering $11 billion in annual operating cost savings.

Numerous pioneering researchers have contributed to this domain, developing IoT-based systems for real-time aquaculture monitoring, integrating sensors to measure key water

quality parameters, integrating aerating and water supply pumps, and implementing automatic data acquisition and monitoring systems using fog computing technology (Chavan et al., 2018; Harun et al., 2018; Hussaini et al., 2018; Nandhini et al., 2018). Additionally, IoT-based aquaponics monitoring systems, combining temperature, humidity, pH, and water level sensors, have garnered considerable attention (Dutta et al., 2018; Varsha et al., 2019; Haryanto et al., 2019; Anand et al., 2021).

Despite these notable strides, a conspicuous gap in comprehensive information pertaining to IoT technologies developed by technology companies in the fisheries and aquaculture sector across different countries persists.

Addressing this vital research lacuna, the present study endeavours to review and document existing IoT technologies in fisheries and aquaculture on a global scale, laying the groundwork for pioneering research initiatives and fostering the development of cutting-edge technologies that will propel the sector.

**Methodology**

The present study adopted a virtual information compilation approach to ascertain a comprehensive array of Internet of Things (IoT) technologies pertinent to the domains of fisheries and aquaculture.

To this end, the search encompassed renowned search engines like Google and YouTube. In order to streamline the data collection process and efficiently collate relevant information, a keyword typology method was employed.

The designated search terms included 'IoT technologies in fisheries/aquaculture', 'IoT solutions for fisheries/aquaculture', 'IoT companies for aquaculture/fisheries', and 'IoT start-ups for fisheries/aquaculture'. These targeted and pertinent keywords were instrumental in acquiring relevant information within the study's scope. The search was conducted with a definitive time frame, up to January 2023, thereby ensuring the incorporation of all IoT technologies available until that date.

Upon gathering a comprehensive corpus of IoT technologies, categorization process ensued, yielding eight distinctive heads under which the information was systematically arranged.

Each head corresponded to a distinct category of IoT technologies, facilitating a coherent and organized representation of the data. Within each head, the information was further subdivided to include the name of the company responsible for the IoT technology's development, the country from which the company originates, and a concise description of the IoT technology in question.

In order to glean valuable insights from the compiled data, a percentage analysis was performed. This enabled the determination of the number of IoT technologies falling under each distinct category, thereby ascertaining the prominence of specific IoT applications in the domains of fisheries and aquaculture.

Additionally, the analysis shed light on the country exhibiting the highest concentration of IoT technologies, shedding light on the geographical distribution and prevalence of IoT initiatives in this field.

Through this methodology, the study offers a comprehensive overview of the IoT technologies harnessed in the fisheries and aquaculture sectors. The organized and structured presentation of the data allows for informed decision-making in future research and development. It is pertinent to note that any IoT technologies developed post-January 2023 lie beyond the purview of this study, emphasizing the importance of updating and re-evaluating the compilation at regular intervals to maintain relevancy.

So virtual information was used in the ambit of compiling different IoT technologies in fisheries and aquaculture.

**Results and discussions**

The comprehensive investigation into the domain of fisheries and aquaculture with regard to Internet of Things (IoT) technologies yielded 87 distinct IoT applications. These technologies were carefully scrutinized and categorized based on their specific functionalities and applications within the industry. The findings revealed that the majority of IoT technologies (54%) were dedicated to smart feeding and monitoring, exemplifying the significant role of technology in optimizing feeding practices and monitoring fish populations. Following closely, smart buoys accounted for 11.4% of the total IoT technologies, emphasizing their importance in buoyancy control and data collection at sea.

Furthermore, the study unveiled the prevalence of supply chain management IoT technologies, constituting 6.8% of the total, highlighting the industry's growing interest in enhancing logistical efficiency and traceability in the fisheries and aquaculture sector.

Additionally, underwater Remotely Operated Vehicles (ROVs) and smart fishing rods each accounted for 5.7% of the IoT technologies, exemplifying the increasing emphasis on advanced aquatic exploration and efficient fishing practices.

Grading and counting technologies, essential for accurate and precise fish quantification, constituted 3.4% of the total IoT technologies identified. Meanwhile, drones, serving diverse roles in fisheries and aquaculture, accounted for 2.2% of the corpus, contributing to tasks ranging from surveillance to aerial data collection.

Table 1 encapsulates the complete breakdown of the identified IoT technologies in the fisheries and aquaculture sector, offering a comprehensive overview of the respective percentages associated with each category.

Furthermore, figure 1 complements the tabulated data by providing a visually engaging graphical representation of the distribution, facilitating a more intuitive understanding of the prominence of each IoT technology category.

This comprehensive and scientific approach to categorizing and presenting the plethora of IoT technologies in fisheries and aquaculture not only contributes valuable insights to the industry but also serves as a foundational resource for researchers, policymakers, and stakeholders alike.

The precise classification and graphical representation enhance the clarity and accessibility of the data, empowering decision-makers to make informed choices in adopting and implementing these cutting-edge technologies.

The dynamic nature of the field warrants the periodic updating and reassessment of this study to account for any advancements and novel IoT technologies that may emerge beyond the current scope of the investigation.

Table 1. IoT technologies in fisheries and aquaculture

|  |  |  |
| --- | --- | --- |
| System | Number | Percentage |
| Smart Fisheries (Smart feeding, Monitoring and control systems) | 47 | 54.0 |
| Smart buoy technology | 10 | 11.4 |
| Under water Remotely Operated Vehicles | 5 | 5.7 |
| Supply chain | 6 | 6.8 |
| Drones | 2 | 2.2 |
| Smart fishing rods | 5 | 5.7 |
| Grading and counting | 3 | 3.4 |
| Others | 9 | 10.3 |
| Total | 87 |  |

Figure 1. IoT Technologies in fisheries and aquaculture

Table 2, provides a comprehensive overview of the distribution of Internet of Things (IoT) technologies developed across different countries and continents in the domain of fisheries and aquaculture. The data encapsulated in the table offers valuable insights into the global landscape of IoT technology adoption and innovation within the industry.

An analysis of the information in the table reveals that North America and Asia emerge as the leading regions in terms of IoT technology development, with North America contributing 18.39% of the total IoT technologies identified, and Asia contributing 30.29%. Within North America, the United States (USA) stands as the prominent frontrunner, accounting for 18.39% of the total IoT technologies. Notably, Canada also showcases a noteworthy presence with 4.59% of the IoT technologies.

In Asia, India and China hold substantial significance, with each contributing 11.49% and 9.19% of the IoT technologies, respectively. In addition, Singapore, Japan, Indonesia, Vietnam, South Korea, Taiwan, and Thailand collectively add to the Asian IoT technology landscape, underscoring the widespread interest and advancements in the region.

Europe demonstrates a commitment to IoT technology development, with a total contribution of 27.58%. Norway emerges as a prominent European player, contributing 9.19% of the IoT technologies. Spain and the United Kingdom (UK) follow suit with 5.74% and 4.49%, respectively. Germany, Iceland, Slovenia, Switzerland, Finland, Portugal, Lithuania, France, and Italy each contribute to the European IoT technology spectrum.

Australia, accounting for 3.44% of the IoT technologies, showcases a presence in the Australasian region. Meanwhile, the Middle East and Africa exhibit limited IoT technology developments, with Tehran and Kenya contributing 1.14% each.

In summary, the data presented in table 2 indicates a geographically diverse and widespread interest in IoT technology adoption and innovation within the fisheries and aquaculture industry. The prominence of countries like the USA, India, China, and Norway, coupled with contributions from various other nations across different continents, underscores the global significance of IoT technologies in transforming and optimizing the practices and operations within the fisheries and aquaculture domain.

This scientific inference enhances our understanding of the global IoT technology landscape and may facilitate collaborative efforts and knowledge-sharing among countries to further advance and harness the potential of IoT in the sustainable development of fisheries and aquaculture.

According to Research and Markets (2020) Leading IoT markets include the USA, China, and the mature markets of Western Europe and the Asia Pacific Region. The USA was an early adopter and leads the list of countries with IoT deployment. A strong start up culture with focus on providing IoT solutions and funding from venture capital firms made the country a global leader in IoT projects. Strong government support and legislation have pushed 2019 IoT connectivity spending to $194 billion in the USA (U.S. Senate, 2019).

In terms of region, the global IoT for fisheries and aquaculture market can be divided into North America, Europe, Asia Pacific, Middle East & Africa, and South America. (Adroit Market Research, 2022).

The Asia-Pacific market is expected to dominate during the forecast period of 2022-2030, due to presence of large number of aquaculture farms, the fast adoption of advanced technologies and the growing aquaculture industry.

India, China, Indonesia, and Japan are the leading countries in this Region (InsightAce Analytics, 2022). Europe’s IoT market for fisheries and aquaculture is driven by rise in demand for food, advancement in digital technologies, prevalent mobile devices, and government initiatives (Market Research Report, 2021).

The USA holds the major share of North America’s aquaculture IoT market. The increasing awareness about the quality of crops and the growing need to enhance the farm yield due to high food quality requirements have increased the adoption of aquaculture IoT solutions in the country.

The presence of prominent vendors of aquaculture equipment in the USA and Canada increases the rate of adoption of precision aquaculture in North America. (Transparency Market Research, 2022)

Table 2. Countries, continents and number of IoT technologies developed

|  |  |  |  |
| --- | --- | --- | --- |
| Continent | Country | Number of IoT Technologies | Percentage |
| North America | USA | 16 | 18.39 |
| Canada | 4 | 4.59 |
| Asia | India | 10 | 11.49 |
| China | 8 | 9.19 |
| Singapore | 4 | 4.59 |
| Japan | 3 | 3.44 |
| Indonesia | 3 | 3.44 |
| Vietnam | 2 | 2.29 |
| South Korea | 1 | 1.14 |
| Taiwan | 1 | 1.14 |
| Thailand | 1 | 1.14 |
| Europe | Norway | 8 | 9.19 |
| Spain | 5 | 5.74 |
| UK | 4 | 4.49 |
| Germany | 3 | 3.44 |
| Ice land | 1 | 1.14 |
| Slovenia | 1 | 1.14 |
| Switzerland | 1 | 1.14 |
| Finland | 1 | 1.14 |
| Portugal | 1 | 1.14 |
| Lithuania | 1 | 1.14 |
| France | 1 | 1.14 |
| Italy | 1 | 1.14 |
| Australia | Australia | 3 | 3.44 |
| Middle East | Tehran | 1 | 1.14 |
| Africa | Kenya | 1 | 1.14 |



Figure 2. World map showing number of IoT technologies developed continent wise

Figure 2. Continents and number of IoT technologies

IoT technologies are used to monitor numerous water conditions using IoT sensors to improve the fish habitat. These devices include sensors that detection of pH, dissolved oxygen, water temperature, ammonia, TDS, salinity, TAN, turbidity etc. Some devices capture feeding patterns, fish behaviour, and fish health, calculates fish lice count, estimate biomass. There are devices which automatically dispense feed based on the captured fish behaviour and planned fish feeding schedules. The IoT technologies which are developed for smart feeding and monitoring and control of fish farms are given in table 3.

Table 3. IoT technologies developed for smart fisheries and aquaculture

|  |  |  |  |
| --- | --- | --- | --- |
| S. No | Company | Country | Technology |
| 1 | Aquabyte | Norway | Provides a fish-farm monitoring solution that uses underwater smart cameras to gauge temperature and oxygen, calculate lice count, estimate biomass, detect appetite, and plan feeding schedules. |
| 2 | Afarinesh Samaneh Mehr Engineering Co. (ASM) | Tehran | Developed a Smart Water sensor network to measure the water quality parameters of the fish farms like Dissolved Oxygen, ph, Ammonium, Nitrite, Water temperature |
| 3 | aquaTracker | UK | Cloud based fish farm management software that capture feedings, mortalities, water quality parameters and other useful information in real time directly from the field. |
| 4 | Akvasmart | Norway | Monitors water temperature, oxygen, salinity, ph, current speed and direction which are important for making correct farming decisions. The systems advanced video camera and sensor systems monitor both the fish and the feeding process |
| 5 | Aquanetix | UK | Cloud-based software application that allows farm workers to record production data and get real-time reports of operations and stocks in order to make management decisions. It provides real time alerts related to farming activities such as feeding. |
| 6 | AquaEasy | Vietnam | Smart IoT solution made for shrimp farmers, to help them automate daily tasks and gives farmers and aquaculture technicians a comprehensive view of the farm’s important parameters, biomass estimation, access to farming protocol and direct connection to recognized shrimp experts. |
| 7 | Ambrotechs | India | IOT enabled water quality measurement system that measures the critical water quality parameters at the pond site for a fraction of the current cost- pH, ammonia, DO, temperature, TDS, salinity, TAN, turbidity. |
| 8 | Bluegrove company | Norway | Developed Cage Eye which enables us to follow the fish’s natural behaviour, routines and feed according to their appetite resulting in more efficient feeding |
| 9 | Boqu | China | Developed multi-parameter analyser which can test pH, DO, salinity, ORP, ammonia. The user can check the data remotely with the help of alerts sent to the phone. |
| 10 | cFog | India | Developed a solar-powered system that can automate aerators and feeders across multiple ponds, monitors with parameters of dissolved oxygen, ph, ammonia and temperature |
| 11 | Cargill | USA | Developed iQShrimp, a predictive software platform that uses machine learning to help farmers with data such as shrimp size, health, quality of water, feeding patterns and weather conditions which can be collected by using mobile devices, sensors and, automated feeders |
| 12 | Delfers Smart Aqua | Singapore | Monitors pH and dissolved oxygen levels which in turn activates the mechanical equipment to increase or decrease the speed of the air pump. The system also dispenses the anti-bacterial medicine by sensing the ph levels. |
| 13 | eFishery | Indonesia | Developed an Automatic fish feeder that can be controlled using a smart phone app. |
| 14 | Eruvaka Technologies | India | Developed a technology for real time monitoring of DO, ph. There is a voice call alert in case of low DO levels helps farmers to avoid shrimp mortalities. |
| 15 | HydroNeo | Thailand | Gathers data regarding feeding and water quality to improve the efficiency of shrimp farming. The smart aeration solution optimizes energy costs to improve fishery profitability |
| 16 | Innovasea’s system | USA | Uses underwater sensors using sound waves to report data such as dissolved oxygen and water temperature, as well as surface monitoring tools tracking tidal and weather conditions, and physical sensors to report any stress on the structure of the pens and mooring lines. |
| 17 | Jala | Indonesia | Developed IoT sensors and software for monitoring dissolved oxygen, temperature, humidity, ph, salinity and total dissolved solids at shrimp farms. |
| 18 | Jiafeng365 | China | Offers an IoT enabled platform to monitor water quality, aquatic environment, fish feeding etc. The platform comes with integrated sensors and software to remotely monitor aquaculture farm. |
| 19 | Kamahu | France | It offers SaaS solutions that enable users to track and monitor the activities and performances of aquaculture farms. It also provides performance analysis, production forecast, feedstock monitoring, and traceability solutions. Reports are also generated on production and performance by consolidating data collected from integrated farm sensors. |
| 20 | Monitorfish | Germany | Enable fish farmers to keep a close watch on their stocks from their smartphones The system detects abnormal water quality (ph, temperature, ammonia), fish behaviour, or appearance and also provides an action plan alongside the diagnosis, to help farmers to resolve the issue promptly. |
| 21 | Marine Instruments | Spain | Developed smart feeding system called Marine Acoustic System. The implantation of this system in shrimp ponds highly increases growth rate and shortens its production cycle. |
| 22 | Milesight IoT | China | Provides visualised aquaculture management. It monitors pH, dissolved oxygen, water level in the pond and present the data on Milesight cloud that can be viewed at any time, providing the users with real-time and highly accurate data. |
| 23 | Safar | China | It uses advanced IoT technology, AI-based data analysis and industrial automation for water quality monitoring. Sensors such as temperature, DO, pH, salinity and NH4 are used to collect real-time water quality parameters. It allows users to monitor and control their fish farms via mobile phones, desktops, laptops, and tablets. |
| 24 | Smart water planet | Spain | Developed Medusa which is a multifunctional, autonomous and rechargeable IoT device that continuously measures water quality and physico-chemical parameters like ph, temperature, dissolved oxygen, electro conductivity in real time. |
| 25 | Suzhou Lushan Sensing Technology | China | Developer of water quality monitoring sensors, that monitors multiple parameters including dissolved oxygen, fiber turbidity, the concentration of blue-green algae, ammonia, nitrogen, digital pH and digital ORP. |
| 26 | Minushri Madhumita and Amrita Jagatdeo | India | Developed three solar powered devices that are Internet of Things (IoT) enabled. Dhivara Mitra help in uniform distribution of feed, aeration and maintain uniformity of dissolved oxygen level. Krishi Dhanu is a solid fertiliser dispenser and matsyabandhu is a fish/prawn feed dispenser. |
| 27 | Osmo systems | USA | Developed a device which measures different parameters like pH, dissolved oxygen, water temperature, water level, air temperature, relative humidity etc. for  hydroponic, aquaculture, aquaponic or aquaculture system. |
| 28 | Ocean vision | Spain | Developed Sea Control which is an integrated hardware and software platform for real-time monitoring of aquaculture farms and data visualization. The hardware is solar powered and can monitor dissolved oxygen at 4 depths, water current, turbidity, ph value, temperature, and salinity |
| 29 | Observe Technologies | UK | Aims to automate the feeding process monitoring. The platform works through the use of a camera to monitor the feeding processes live. This information would then be transmitted to the platform to inform the farmers when underfeeding and overfeeding occurs as well as notifying them of the best time to feed the fish. |
| 30 | Poseidon-AI | Singapore | Provides AI-based sustainable fish farming solution using RAC technology. The water sensing with highly integrated wireless sensors to monitor and operate a farm. |
| 31 | Pictafish | Indonesia | Provides water measurement kit by integrating AI camera and water sensors. Precise water quality data, early warning system, fish behaviour are the outputs. The data will be automatically transferred to the smartphone. |
| 32 | Quadlink’sAquadlink® | Taiwan | Smart Aquaculture Application System aims to help shrimp and fish farmers by monitoring aquaculture water and automating feeding systems. The Smart Water Quality Monitoring System uses sensors to check environmental conditions, such as ph and oxygen levels, in the fishpond. The floating device can also monitor for disease and breeding. |
| 33 | Qingytang | China | Provides IoT-based solutions using big data, artificial intelligence and block-chain technology to provide fishery monitoring, production, operation and farming solutions. |
| 34 | [Savitri Aquamonk](https://www.savitriaquamonk.com/) | India | Developed a device to collect data related to water ph values, temperature, oxygen content, and light sensitivity. The analytics dashboard then structures the data into actionable insights relating to feeding patterns, maintenance routines, and other activities. |
| 35 | Sensaway | Portugal | Developed management platform system to help fish farmers understand their water flow and help them to prevent problems instead of just fixing them. It manufactures solar-powered sensors that it says are easier to maintain and operate. |
| 36 | ScaleAQ | Norway | Developed system for monitoring of water quality and environmental factors in the pen culture. It uses sensors like oxygen, temperature, salinity, conductivity, sea current (magnitude and direction), turbidity, weather. |
| 37 | Senect | Germany | Developed a technology for online monitoring of sensor readings (e.g. O2, water level) and alarming, feeding automation, filter control, ozone dosage, temperature and light control. |
| 38 | Steinsvik | Norway | Develops fish feeding systems, underwater camera and sensor-based monitoring systems, water filtration and recirculation systems, other components. |
| 39 | SK Telecom | South Korea | Developed IoT technology enable farmers to remotely monitor their fish tanks in real-time through smart devices including smart phone. |
| 40 | Shrimp Hoard | India | Provides IoT based aqua farm monitoring solutions. It offers sensors that measure real-time parameters of water including ph, dissolved oxygen, oxidation-reduction potential, salinity, temperature, etc. The user can remotely monitor the farm aerator through the mobile application |
| 41 | Skylo | India | Delivers IoT solutions to marine fishing and aquaculture sectors including monitoring of oxygen and pH levels in ponds across the states to enhance fish yields and profitability for fish farmers. |
| 42 | The Yield | Australia | Is an IoT powered platform made especially for oyster farming industry uses sensors to collect climate related data like water temperature and depth, salinity, barometric pressure in the water and sea tide height which is then used for a three03 day weather prediction on harvesting conditions. |
| 43 | TechiFishes | Singapore | Offers technology solutions for real-time monitoring and controlling of fish farm operations, farm environmental factors, automatic detection of fish illness, fish nutrition, water quality monitoring etc. |
| 44 | Tepbac | Vietnam | The device monitors water environment indicators such as temperature, pH, oxygen, salinity 24/7 easily and automatically. |
| 45 | Umitron | Singapore | Developed umigarden. It uses sensors and machine learning to detect and determine when fish are ready to feed using computer vision to understand fish behaviour The platform also pulls in satellite imagery to provide data about environmental conditions, such as water temperature, which affects feeding behaviour. |
| 46 | WSense | Italy | Offers a system of wireless sensors and receivers that uses Internet of Underwater Things (IoUT) technology, capable of a bidirectional service that can both provide data and make adjustments to the environmental conditions of a fish cage |
| 47 | YosnaLab | India | Developed a system that maintains the living environment of fish and feeder system which feeds the fish at regular intervals of time and monitors and controls the whole system through IoT. |

Table 3 presents a comprehensive overview of Internet of Things (IoT) technologies in the domain of smart feeding and monitoring/control for fish farms, showcasing a total of 47 technologies within this category. It is evident that smart feeding and monitoring/control solutions dominate this area, with the highest number of technologies falling under this category.

A closer analysis of the data reveals that Indian origin companies have made significant contributions to the development of IoT technologies for smart fisheries and aquaculture systems, accounting for 8 out of the listed technologies. Following closely, Norway has contributed 5 technologies in this domain, showcasing its prowess in the field.

In terms of continents, Asia emerges as the leading region in the development of smart fisheries and aquaculture systems, boasting a substantial 26 technologies. Europe follows with 16 technologies, while North America and the Middle East and Australia each contribute 3 and 1 technology, respectively.

Among the IoT companies of Indian origin, notable players include Ambrotechs, cFog, Eruvaka Technologies, Savitri Aquamonk, Shrimp Hoard, Skylo, and Yosna Lab. Research by Dhenuvakonda and Sharma (2020) highlights the contributions of cFog and Eruvaka Technologies to the field.

Notably, individual Indian innovators have made 3 IoT technologies specifically tailored for fish farm monitoring.

China and Singapore also showcase their prowess in this domain, contributing 6 and 4 technologies, respectively. Other notable contributors include the UK, USA, Indonesia, and Spain, each developing 3 IoT technologies, while Germany has developed 2 technologies.

In other studies, Saha et al. (2018) utlined the monitoring of aquaculture water quality parameters such as temperature, pH, electrical conductivity and colour utilizing Raspberry Pi, Arduino, various sensors, smartphone camera and Android application. Nikitha et al., presented a system which allows to monitor temperature, dissolved oxygen, pH, water level. Krishna et al., (2019), Ramya et al., (2019), and Ya’acob et al., (2021) developed water quality monitoring system using pH, temperature and ultrasonic sensors. Meshram et al., (2019) Jadhav et al., (2020) developed IoT based automated fish feeder.

The contributions from various companies and individuals across different countries and continents demonstrate the global significance and potential of IoT in enhancing the efficiency and sustainability of fish farming practices. The scientific endeavors of researchers and innovators in this field pave the way for future advancements, with the potential to revolutionize the aquaculture industry and contribute to the broader goals of sustainable food production and resource management.

Smart Buoy Technologies:

Smart buoys equipped with sensors on board helps to collect real time data of temperature, salinity, oxygen, wave heights wind, pressure etc. These devices are also used to track the location of fish, find and recover the lost gear which helps in reducing the ocean pollution and preserve marine life.

Table 4: Smart buoy technologies developed for fisheries and aquaculture

|  |  |  |  |
| --- | --- | --- | --- |
| S. No. | Company | Country | Technology |
| 1 | NTT Docomo | Japan | ICT Buoy equipped with underwater cameras and sensors that could gather data and send it via wireless modules to cloud servers provides data on sea conditions, such as temperature and salinity concentration. |
| 2 | Karlsruhe Technological Institute (KIT) | Germany | Developed a multisensory buoy that allowed them to measure the quality of water at different depths like oxygen concentration, temperature or the presence of greenhouse gases. |
| 3 | Deeper | Lithuania | A small device is attached to fishing line and dropped into the water. Information from the device is then transmitted to a corresponding mobile phone app via Bluetooth connectivity. The data enables you to monitor the water temperature and subsurface activity, such as the location of fish and vegetation and can distinguish between clumps of bait and actual fish. |
| 4 | OPTiM | Japan | A sensor-equipped ICT buoy, which detects changes in water quality. Furthermore, drone imaging can detect damage in seaweed, such as colour changes or bite marks, as well as changes in water colour |
| 5 | Scatri | Switzerland | Developed satellite IoT tracking technology inside Scatri’s Smart Buoy. The fishermen can find and recover lost gear anywhere in the world. This will help fishermen avoid expensive replacement costs and the fuel wasted looking for gear, and also reduce waste in the oceans and preserve marine life. |
| 6 | Marine Instruments | Spain | M3i, M3i+ are smart echo sounder buoys, used to locate and track fish aggregating devices (FADs) used in tuna fishing. |
| 7 | Blue Ocean Gear Inc | USA | Developed smart buoy technology to help fishers track and monitor their gear, reducing the negative impacts on ocean environment. The technology enables real-time tracking and monitoring of fixed fishing and aquaculture gear, including offshore lines, traps and nets. The buoys also collect a variety of oceanographic data that support ocean businesses in more efficient and cost-effective operations, both on- and off-shore. |
| 8 | Smart Marine Systems | Australia | Developed Clever Buoy which provides real time information on marine life, oceanographic conditions, meteorological patterns etc., |
| 9 | Sofar | California | Developed Spotter which is a metocean buoy that collects and transmits real-time data of wave, wind, sea surface temperature, and barometric pressure |
| 10 | Artica | Finland | Smart buoy provides real time measurement of water quality measurements, dredging, turbidity measurements, salinity, temperature, oxygen content and algal pigment |

Table 4 provides a comprehensive overview of IoT companies involved in the development of smart buoys, encompassing a total of 10 technologies in this domain. Intriguingly, the data reveals that none of these technologies originate from India, despite the vast potential for smart buoys hinting at untapped opportunities in this region.

Literature has highlighted pioneering research efforts in the design and development of cost-effective sensor buoy systems. For instance, Albaladejo et al. (2012) described a novel low-cost sensor buoy system capable of monitoring temperature and marine pressure. This research represents an important stride in advancing the deployment of smart buoys for environmental monitoring and data collection.

Furthermore, Curico et al. (2006) presented cutting-edge technology focused on the operation of reduced-cost self-positioning buoys, specifically designed for utilization in coastal or oceanic waters. This technological innovation holds promise for optimizing marine monitoring efforts and has the potential to contribute to various aspects of oceanography and maritime research.

Overall, table 4 serves as a valuable reference in understanding the current landscape of IoT companies engaged in the development of smart buoys.

Underwater ROV (Remotely Operated Vehicles) systems:

An ROV, which stands for remotely operated underwater vehicle, is like an underwater robot or drone. It's a small vehicle that can move around underwater without a person inside it. Instead, it's controlled by someone on a boat or ship on the surface. These ROVs have cameras on them, so they allow people to see what's going on underwater without actually going in the water themselves. These camera equipped vehicles allow users to get eyes underwater safely and efficiently (Ezhilarasi et al., 2021).

ROVs are used for lots of different things underwater. They can inspect fishing nets in cage culture, observe how fish behave and eat, and even check on the health of fish. They're also useful for collecting water samples and measuring the quality of the water.

In addition to these uses, ROVs have many other applications. They're used in things like disposing of explosives, in the oil and gas industry, for research and development, and in aquaculture. Basically, ROVs are handy tools that help us explore and understand the ocean without having to dive into it ourselves.

Table 5. Underwater Remotely Operated Vehicle (ROV) systems developed for fisheries and aquaculture

|  |  |  |  |
| --- | --- | --- | --- |
| Sl. No. | Company | Country | Technology |
| 1 | EyeROV | India | Developed underwater ROV system to perform visual underwater inspection of Dams, Bridges, Ports, Offshore structures, Ship Hulls, Pipeline and others. It goes up to a depth of 100m and gives live HD videos. |
| 2 | Deep Trekker | Canada | Developed under water ROVs to perform regular and efficient net inspections. It ensures mooring lines and anchor points are secured to guarantee structural integrity. It also monitors the feeding process, stock health and observe fish behaviour. |
| 3 | O-Robotix | USA | Developed remotely controlled underwater ROV for underwater exploration. It is a powerful and affordable sub-sea inspection robot – mainly targeted towards aquaculture and inspection of subsea infrastructures. |
| 4 | BlueRobotics | USA | Developed BlueROV2, for ocean research and exploration. It helps to study ocean creatures, measure water parameters, collect samples etc. |
| 5 | Deep Ocean Engineering | USA | Supports operations in ocean research, education, offshore oil and gas, fisheries, broadcast filming, nuclear inspection, military, security, law enforcement etc., |

Table 5 presents information on underwater Remotely Operated Vehicle (ROV) systems, and it reveals a total of five ROV systems. Among these systems, three originate from the USA, while India contributes one company, EyeROV, developing an ROV system. Research studies by Rohit et al. (2019) and Hajian et al. (2021) have produced underwater ROVs designed for diverse applications such as water quality monitoring, underwater exploration, scientific research, and oil sample recovery.

Smart fishing rods:

Smart fishing rods equipped with the sensors provides information on fishing locations, environmental data, number of casts, cast timings, number of fishes caught, alarms when fish is caught etc.

Table 6. IoT technologies for Smart fishing rods in fisheries and aquaculture

|  |  |  |  |
| --- | --- | --- | --- |
| Sl No. | Company | Country | Technology |
| 1 | Anglr Tracker | USA | A smart fishing rod attachment provide vital information such as the best location for fishing, tips on which bait to use, cast timing, and other statistics to catch the fishes more efficiently. |
| 2 | Dynatac | USA | Smart Fishing rod attachment that assists fishermen during fishing a smart device that helps fishermen retain fish on the hook and alerts them when the fishing line is about to break. |
| 3 | CyberFishing | USA | Developed smart rod sensor that and counts number of casts, number of fish caught, fishing locations. It also gathers environment data like temperature, precipitation, wind speed, wind direction and pressure. |
| 4 | Cirago | USA | Developed iFisher which is a fishing bite alarm that will notify us on mobile and led lighting on alarm, when a fish is hooked. |
| 5 | Tackobox | USA | Developed smart rod, which gives light and sound alert when a fish is caught. |

Analysis of information in table 6 reveals the presence of five IoT-enabled smart fishing rods, all of which originate from the United States, signifying the concentration of technological development in this region.

One notable study by Yaseen et al. (2019) elucidates the design of an autonomous fishing rod, showcasing its capacity to facilitate the entire fishing process, ranging from fish detection to extraction from the water. The development of such advanced fishing rods exemplifies the ongoing efforts to integrate IoT technologies into fishing practices, ultimately enhancing efficiency and effectiveness in the domain of fisheries.

Supply chain management:

IoT technologies in supply chain management can be used to maintain the quality of fish by removing antibiotic residues from supply chain, offers a harvesting and tracking system, helps in data-based operational decisions, traceability, monitoring and tracking of fish containers, increase transparency for consumers etc.

Table 7. IoT technologies developed for Supply chain management in fisheries and aquaculture

|  |  |  |  |
| --- | --- | --- | --- |
| S. No. | Company | Country | Technology |
| 1 | Celaqua | China | Developer of sustainable smart-farming solution for producing seafood. It removes antibiotic residues from the fish farmer’s supply chain for chemical-free fish. |
| 2 | Smart Catch Systems | Canada | Offers a harvesting and tracking system that provides production forecasts for producers and processors. Also, enables harvesters to maintain water quality and traceability solutions. |
| 3 | Maritech | Norway | Provides supply chain solutions for the seafood industry. It provides solutions for data-based operational decisions, traceability, and more. |
| 4 | ORBCOMM | USA | Provides critical monitoring of containers and other marine assets for shipping lines, commercial fishing boats and merchant fleets travelling global waters |
| 5 | Prediktor | Norway | Developed Apis Platform that greatly increase product quality and production efficiency through a unique production tracking system and advanced machine integration. This enables recipe management, statistical process control (SPC), Overall Equipment Effectiveness (OEE). |
| 6 | Silent infotech | USA | Temperature, humidity, NH3, NH4 sensors are used in cold chain logistics for real time monitoring and traceability. The temperatures in transportation vehicles can be kept favourable according to the species. |

The comprehensive examination of Table 7 elucidates the existence of six distinctive IoT technologies catering to the optimization of fish supply chain operations. Among these technologies, two originate from Norway, two from the United States, and one each from China and Canada, highlighting the global reach of IoT-based solutions in this domain.

In a study Xu (2017) postulated that a seafood product traceability system leveraging IoT technology can effectively enhance the quality management capabilities, logistics management competencies, and overall competitiveness of both domestic and international seafood trade through seamless traceability mechanisms.

In a related study Qi et al. (2011) pioneered the development of a Wireless Sensor Network-based circular aquaculture traceability system, further exemplifying the potential of IoT in streamlining the supply chain processes within the aquaculture industry. The amalgamation of IoT into fish supply chain management fosters a novel approach towards optimizing efficiency, sustainability, and transparency throughout the seafood value chain.

Drones:

Drones, also known as unmanned aerial vehicles (UAVs), have a wide range of applications in various fields. They find utility in fishing, search and rescue operations, maritime protection, military activities, disaster management, and more (Ubina and Cheng, 2022). Upon reviewing Table 8, it becomes evident that two drone technologies have been developed to cater to specific tasks in different domains.

Ubina et al. (2021) introduced a cost-effective and cloud-based autonomous drone system for visual surveillance purposes. This system efficiently monitors fish feeding activities, detects nets, moorings, cages, and identifies suspicious objects.

Reshma and Kumar (2016) proposed a drone-based automation of feeding activities in aquaculture. This technology ensures regular feeding of aquatic animals while maintaining uniform distribution of feed in cages, minimizing feed wastage. Additionally, the system can be customized to deliver other necessary farm inputs such as medicines, vaccines, and fertilizers. These developments signify the promising potential of drone technology in enhancing monitoring, efficiency, and precision in various sectors, including aquaculture and surveillance operations.

Table 8. Drones in fisheries and aquaculture

|  |  |  |  |
| --- | --- | --- | --- |
| S. No. | Company | Country | Technology |
| 1 | DJI | China | Phantom 4 – Fishing Edition (drone) can be operated from up to 100 meters above water level with a controller that boasts a range of over a mile. An integrated remote camera presents views of fish to help targeting. Integrated sensors will indicate when the bait has been bitten. The drone will then automatically rise into the air, allowing its commander to guide it back inshore to deliver the catch. |
| 2 | Marine Instruments | Spain | M5D- AirFox, fixed wing solar powered drone developed by Marine Instruments. Its versatility, great autonomy, and small size allows the use of these drones surveillance and security, protection and border control, control and management of natural disasters, sea search and rescue, maritime protection, environment management, animal observation, ground reconnaissance, surveillance missions, target search. |

Grading and counting:

IoT technologies are developed for grading of fishes according to size, identify unhealthy fish, counting of shrimp larvae and fingerlings. Grading and the quality control can be done through AI programs equipped with visual image sensors and cameras (Chandrasekar, 2021) From table 9, it is clear that there are 3 IoT technologies that provide solutions for grading and counting.

Table 9. IoT technologies for grading and counting in fisheries and aquaculture

|  |  |  |  |
| --- | --- | --- | --- |
| S. No. | Company | Country | Technology |
| 1 | XpertSea | Canada | Developed XperCount, IoT-enabled device helps in counting shrimp larvae. |
| 2 | Kindai University’s Aquaculture Research Institute | Japan | Developed a technology for counting the fingerlings and culling out the odd-shaped one with a combination of image analysis, AI, and ML technologies |
| 3 | VAKI | Ice land | Developed the SmartFlow System which allows the farmer to simultaneously control and monitor the complete pumping, grading and counting process from one device. The SmartFlow System gathers and stores information on the selection of size and quantity for all the graded and counted fish. |

Others:

There are other IoT technologies which are developed to monitor and track fishing activities and fishing gear, detect harmful algal blooms and oil spills, fuel monitoring, locate fish schools and also fish processing systems.

Table 10. Other IoT technologies in fisheries and aquaculture

|  |  |  |  |
| --- | --- | --- | --- |
| S.No. | Company | Country | Technology |
| 1 | Aquaai | USA | Developed a fish like platform, which is equipped with cameras and sensors for data acquisition. It provides precise, reliable and affordable data on depth, temperature, dissolved oxygen and salinity. |
| 2 | Blue Tracker | Slovenia | BlueSenz is a collection of wireless sensor devices mounted directly to the fishing gear (winches and nets) allowing an Fisheries Monitoring Centres to track and monitor fishing activities of any of the vessels in their fleets |
| 3 | Catalina Sea Ranch | USA | Developed a submersible device called an image flow cytobot that analyzes particles in the water using an onboard microscope and machine vision. The device serves as an early-warning tool for detecting harmful algae blooms. |
| 4 | Chelsea Technologies | UK | Helps in assessing primary productivity in ocean waters, detecting harmful algal bloom, monitors oil spill. |
| 5 | Range Business Services | Australia | Deployed an IoT solution for fuel monitoring that connects Dobroflot’s vessels and onshore operations. The solution helps to optimize fuel consumption, analyzing weather and vessel position, to save up to ten percent of fuel costs, and also helps to prevent unauthorized fuel usage. |
| 6 | Swahilibox | Kenya | Developed gadget attached to the fishing gear which would either respond to an App on the fisherman’s phone or have a secondary unit on the boat that would communicate with it and display coordinates of the fishing gear which would be of use to the fishermen in tracking the gear. |
| 7 | 4Deep | Canada | Developed submersible microscopes for monitoring and quantifying oil in water, harmful algae monitoring, ship bilge and ballast tanks, oceanographic research, aquaculture and algae-biofuel production. The submersible microscope is essential for applications that require real-time, continuous, in-situ monitoring of water. |
| 8 | InCEve | India | Developed Internet of Things (IoT)-based sonar device, helps fishermen fish effectively, saving fuel cost, time, and improving the quality of the catch. The technology helps to automate fishing process and capture the right information to catch fish schools. |
| 9 | Optimar | Norway | A global leader for automated fish processing systems for use onboard fishing vessels, on land, and in the aquaculture sector. These systems are installed as turnkey projects, either independently or in connection with third-party products. |

From Table 10, it is evident that there are a total of nine IoT technologies offering solutions in the fisheries and aquaculture sector.

Vollen and Haddara (2019) presented a case study on an internet-based refrigerated sea water (RSW) system implemented aboard the fishing vessel in Norway. In another development, Muslihi and Achmad (2019) designed a sophisticated system that detects the stock of wild fish at docks using cutting-edge technology such as load cell weighing sensor, GPS, and microcontroller. This system offers precise monitoring capabilities, aiding in efficient management of fish stocks and ensuring sustainable fishing practices. Furthermore, Murugan et al. (2020) devised an embedded system equipped with IoT and RF transmitter receiver to notify the sea borders of India. This system enhances maritime security by providing real-time updates and monitoring capabilities, contributing to the safeguarding of coastal territories.

These IoT technologies showcase the immense potential of digital innovation in the fisheries and aquaculture domain, presenting novel solutions for preserving catch quality, managing fish stocks, and enhancing border security, among other critical applications.

**Conclusions**

By embracing cutting-edge innovations such as blockchain, artificial intelligence (AI), Internet of Things (IoT), and mobile applications, the fisheries sector industry can propel its growth trajectory further. The findings of this study hold valuable implications for the scientific community, enabling them to comprehend the landscape of existing IoT technologies in fisheries and aquaculture. For existing and prospective fishers and aquaculture farmers, the insights gleaned from this research offer crucial guidance towards adopting smart farming practices. Monitoring water quality, animal health, and feeding behavior through IoT-based solutions can significantly improve production yields and cost-benefit ratios, thus fostering sustainable growth in the industry. It is evident from this investigation that a majority of IoT technologies are focused on smart fisheries, particularly pertaining to fish pond water quality monitoring and automated fish feeding. However, it is noteworthy that the number of IoT technologies developed for other aquaculture systems, such as RAS (Recirculatory Aquaculture System), Aquaponics, Biofloc technology, and Cage culture, remains comparatively limited. Given the recognized efficiency and effectiveness of these systems in resource utilization, greater emphasis should be placed on expanding IoT developments in these areas.

Additionally, this study underscores the potential for IoT development in diverse fields within the fisheries sector, including fish processing, supply chain management, grading, and counting, with a paramount focus on enhancing the safety and well-being of fishers. Consequently, the fisheries professionals should familiarize themselves with the array of available IoT technologies and research institutions ought to nurture experts with specialized knowledge in this domain.

In light of the evolving technological landscape, the study advocates for the capacity development of young fisheries professionals in the realm of emerging information technologies, encompassing AI, blockchain, IoT, and mobile applications. This proactive approach ensures the industry's readiness to leverage the transformative potential of these innovations, propelling it towards enhanced efficiency, sustainability, and economic growth.

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