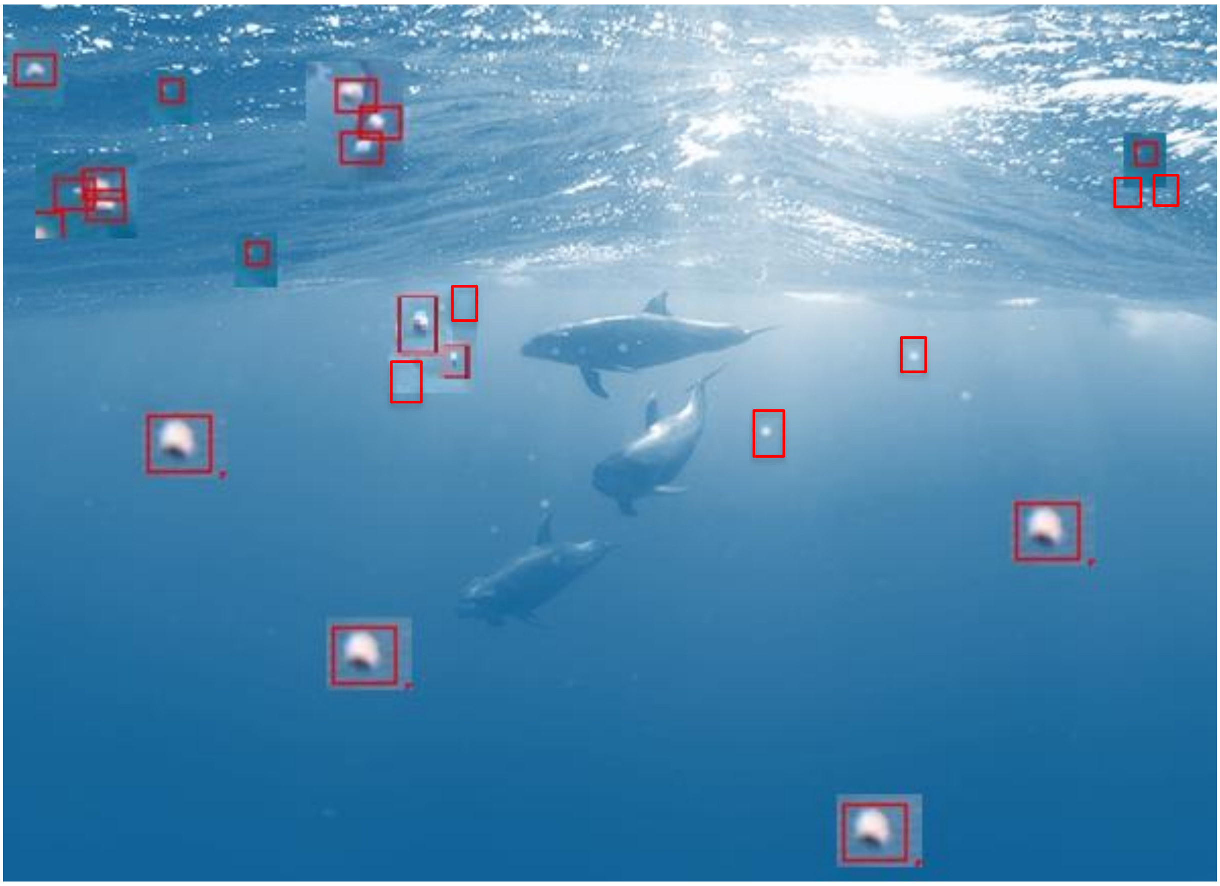
VESTLANDSFORSKING

Big Data in Aquaculture

Opportunities and challenges for Sogn og Fjordane region

Rajendra Akerkar, Minsung Hong



VESTLANDSFORSKING-RAPPORT NR. 6/2021

TITTEL
Big Data in Aquaculture

RAPPORTNUMMER 6/2021
DATO 09.06.2021
GRADERING Open
TAL SIDER 27

UNDERTITTEL
Opportunities and challenges for Sogn og Fjordane region

PROSJEKTTITTEL
TEKNOLØFT Sogn og Fjordane

PROSJEKTNUMMERR
6490

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EMNEORD
ICT, Big Data, Aquaculture

SAMANDRAG
The development of technology over the years has provided the opportunity to collect and store large scale aquaculture data from many different sources. It has become clear that this huge volume of data could provide valuable information if it were analysed in an appropriate way. This report discusses various sources of data generation from the aquaculture sector and its importance in analysis to make sense out of it. This report also presents the classification and features of big aquaculture data. The status of big aquaculture data is explored, and key challenges and opportunities are identified. This is a feasibility study for how we can identify and go on with interesting and useful data-driven R&D for the aquaculture sector in the Sogn og Fjordane. Target audience of this report is partners in the Teknoløft project and public and private aquaculture organisations.

ANDRE PUBLIKASJONAR FRÅ PROSJEKTET
Rajendra Akerkar, Minsung Hong. Big Data in Electric Power Industry: Opportunities and Challenges for Sogn og Fjordane region. 5/2021, ISBN 978-82-428-0434-1.

VESTLANDSFORSKING, Postboks 163, 6851 Sogndal

ISBN: 978-82-428-0435-8

På framsida: Aquaculture collage

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Glossary

Abbreviation	Expression
ADV	Acoustic Doppler Velocity
ANSI	American National Standards Institute
Chl a	Chlorophyll a
FCR	Feed Conversion Ratio
PAIRS	Physical Analytics Integrated Repository and Services
PIT	Passive Integrated Transponder

1. Background

In Norway, the aquaculture industry[1] has become one of the largest industries. As shown in Figure 1, continued high salmon prices and a large volume of sold fish have increased revenue recently. Thus, the industry as a whole and the different value chain segments have attracted a lot of attention.

The development of commercial aquaculture in Norway began around 1970 since aquaculture has developed into a significant industry in coastal areas. Intensive farming of Atlantic salmon is by far the most essential activity, accounting for over 80 percent of the total Norwegian aquaculture production.

Ninety-five percent of Norwegian production[2] is exported with the EU being the primary market. Salmon products, however, are shipped all over the world. Farmed salmon is now one of the primary export commodities from Norway, and aquaculture and related industries contribute substantially to the country's economy, and it is believed that there is still considerable potential for future growth.

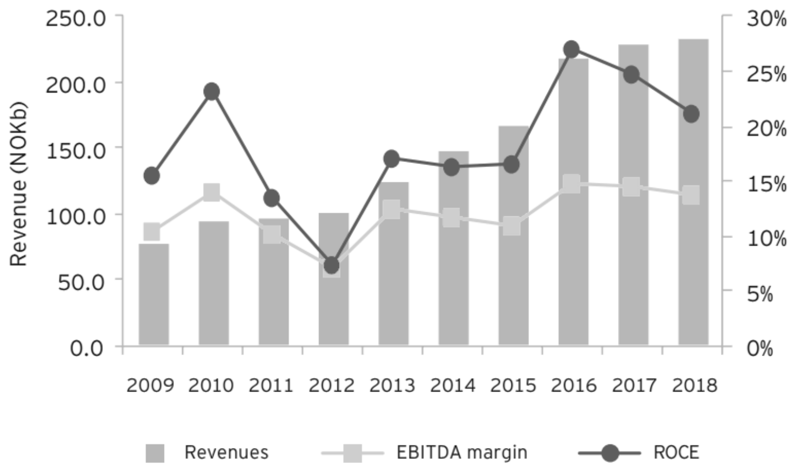

Figure 1 Norwegian aquaculture industry, aggregated revenues 2009-2018 (Moe, et al. 2019)

Big data technologies were introduced in the Norwegian aquaculture industry[3] in April 2017. Big data shared by large industry players make the aquaculture industry able to predict sea lice two weeks in advance successfully. The possibilities are growing as digitalization and use of Big Data become more and more widespread.

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[1] http://www.fao.org/fishery/countrysector/naso_norway/en

[2] https://www.ssb.no/en/fiskeoppdrett/

[3] The Norwegian aquaculture analysis 2017 https://mb.cision.com/Public/12397/2457990/818c800a18b3c888.pdf

2. Big Data Technologies

Big data has changed how we adopt in doing business, managements and explorations (Guidi, et al. 2020). Data-driven and -intensive computing is coming into the world that aims to provide the tools that we need to handle Big Data problems. It creates the shifts required to move from the traditional to the Big Data paradigm as follows.

All of the data

With the advance of technology, the target and available data moved from some of the data to all of the data. For example, clickstream and path analysis of web-based traffic, all data fields, timestamps, IP address, the geo-spatial location where appropriate, cross channel transaction monitoring from the Web.

Chaotic data

Also, the data is not always clean but is becoming more chaotic. In the past, data sets are typically relational, defined and delimited, but data sets are not still relational or structured nowadays.

Complex coupling

Data can be more coupled, duplicative, overlapping, incomplete, have multiple meanings, all of which cannot be handled by classical relational learning tools.

Discovery of insight

The purpose of using data has been moving on discovering insight from testing hypotheses. Defined data structures induce the generation and testing of ideas against known data fields and relationships. In contrast, undefined data structures induce exploration for the generation of insights and the discovery of relationships earlier unknown.

Real-time analysis of data

Although data needs to be defined and structured before use, and then captured and collated. The period of extracting data will vary but often involves a delay, data analysis takes place as the data is captured, for real-time data analysis.

It is essential to mention that vast and distinct datasets or technologies processing such datasets can be presented while discussing the concept of Big Data. In literature, Big Data is classified into two different types: big static data and big real-time data. These two kinds of datasets can be structured or unstructured (Akerkar, et al. 2014). We define Big Data as follows:

> *"Big Data is using* ***big volume, big velocity, big variety*** *data asset to extract* ***value (insight and knowledge)****, and furthermore ensure* ***veracity (quality and credibility)*** *of the original data and the acquired information, that demand cost-effective, novel forms of data and information processing for enhanced insight, decision making, and process control. Moreover, those demands are supported by new data models and infrastructure services and tools which is able to procure and process data from a variety of sources and deliver data in a variety of forms to several data and information consumers and devices."*

Table 1 provides various business benefits which can be realised by utilizing Big Data tools and technologies in the aquaculture sector:

Table 1 Aquaculture business benefits using Big Data solutions

Improved operations	Drive combined insights from a single data management platform for structured, unstructured and real-time data. Reduce the operational non-productive time and fish health, safety and environment, regulatory compliance cost due to 'real-time risk management'.
Unified ontology for the aquaculture sector	Provide personnel with access to searchable institutional knowledge that compensates for limited expert staffing and achieving accuracy and helping personnel find what they are looking for more quickly. Given the shortage of experts, the time saved in accessing and loading data is important.
Faster production rate	Accelerate time-to-production by minimising data bottlenecks that reduce asset team productivity. Enable faster decision-

	making by sea farmers and feed providers as risk profiling and forecasting is performed.
Asset development	Improve asset uptime and predict the need for assets related to operational demands.
Enhanced safety and efficiency	Enhance safety and efficiency in aquaculture operation by linking well and aquaculture data with physical models. This development is also paving the way for integrating these systems into the control system, which in turn can/will facilitate autonomous feeding.

By the combination of Big Data and advanced analytics in aquaculture activities, professionals and authorities can accomplish strategic and operational decision-making.

2.1. Characteristics of Aquaculture Big Data

There is a global push to track small-scale fishing farms and vessels. In the new few years, aquaculture monitoring centres will have to adjust from monitoring a few hundred boats to tens of thousands of ships and considering the weather and environments. Such a massive increase, together with more equipment on large vessels, means enormous quantities of data (Li and Li, Intelligent aquaculture 2020).

To make sense of all this data and valued information, it must be suitably analysed. Data management could have easily been a neglected subject compared to high-tech equipment, even though data are valuable assets. Big data offers vital tools for managing aquaculture. For example, fishing trips could be tailored to meet quotas in the shortest time frame, reducing fuel consumption and crew costs. Real-time catch data could help administrations close a fishing zone immediately once a quota is reached, rather than weeks later.

Effectively making use of data means more than installing software. Anyone applying Big Data must address the five "V"s: velocity, variety, volume, veracity and value. This means that to generate useful information and insight, we must address the velocity (speed) of data processing, handle the wide varsity of data types, manage a massive volume, ensure accuracy and confirm that the data have value for the output desired.

2.2. Types of Aquaculture Data

The input and output variables related to aquaculture data are classified as follows:

- **Continuous**: measured quantities expressed as a float (e.g., average weight);
- **Discrete**: count expressed as an integer (e.g., number of fish);
- **Regular categorical**: data including non-ordered classes (e.g., species bream/bass);
- **Original**: classes that can be ordered in levels (e.g., estimations poor/fair/good);
- **Variables that do not change over time**, often identifying population attributes (e.g., identifications such as 'year' or 'hatchery');
- **Variables that can change over time** but do not change within a sampling period (e.g., batch);
- **Variables that change daily**, taken into account when samplings occur (e.g., average weight).

As shown in Table 2, the AQUASMART project (Costa, et al. 2016) identified the input data of variable changing between samplings and changing through time but not between samples.

Table 2 Type and nature of the input data

	Variables	Type
Variable changing between samplings	Fish Number	Integer
	Average weight	Float
	Biomass	Float
	Model feed	Float
	Actual feed	Float
	Temperature	Integer
	Feed ratio	Float
	Mortality (number)	Integer

	Mortality (Kg)	Float
	Sampling average weight	Float
	Fasting	Integer
Variable changing through time but not between samplings	Harvest (number)	Integer
	Harvest (Kg)	Float
	Adjustment (number)	Integer
	Adjustment (Kg)	Float
	Culling (number)	Integer
	Culling (Kg)	Float
	Transfer number (-)	Integer
	Transfer number (+)	Integer

The input data can be classified according to the impact they assure:

1. **Identification data**: is the data that permits the fish farmer to manage the production and correctly identify the fish;
2. **Daily data:** is the data that is provided by the fish farmers resulting from their everyday data input (e.g., date, average weight, actual feed, etc.);
3. **Sampling data**: at predetermined points of the fish growth timeline, a sample of the fish is done to confirm the model values and make the appropriate adjustments;
4. **Life to date**: is cumulative data that is calculated from when the fish enters the net as a fry to the date of data collection and will last until the date of the harvest.

The data classification 2, 3 and 4 are felled into three categories:

- **Direct values**: are correspond to the direct observation of the aquafarmers on either variable's values, including small errors measured in the field (e.g., sampling measures such as average weight) or previse values provided by external sources (e.g., water temperature or oxygen level);

- **Calculated values**: are dependent on many other observed values (e.g., life to date values calculated from the daily data);
- **Derived values**: values deriving from previously available calculation tables (e.g., feed conversion rate calculated from the table, given average weight and water temperature).

2.3. Sources of Aquaculture Big Data

The type of data that can eventually form Big Data in the aquaculture central, neighbouring & connecting industry and information of related organisation can be classified into various categories by industry types as shown in Table 3 (Choi, et al. 2020).

Table 3 Aquaculture data classification by industries

Division	Industry classification	Data content	Offer
Central industry	Fishing	Fishway, Total Allowable Catch (TAC), related permission, fishing boat administration, etc.	Public and private information
	Aquaculture	License, facilities, growth, development, breeding, business management, etc.	
	Marine Product (processing and distribution)	Product item, company, scale, state support, fish type, production, buyer, distribution scale, policy & statistics, etc.	
Neighbouring & Connecting industries	Shipping	License, production, owner, busying a fishing boat, inspection, etc.	
	Marine product (equipment, trade)	Production, material, patent & dispute, importation & exportation, quarantine, cold chain transportation, etc.	
	Private fishing	Fishing training and boat reservation, boarder, equipment, etc.	
	Aquaculture policy	Related documents, statistics, associated ministries, etc.	Public information

Information of related organisation	Ocean space	Marine satellite, readout of fish farms, etc.	
	Marine environment	Ocean purification, marine ecology, etc.	
	Sea weather	Tides, digging, weather, water temperature, etc.	
	Fishing village policy	Statistic of return to the fishing village, policy of support, etc.	
	Fishing port and village	National fishing harbour & other fish port management information, statistics and information of village development, etc.	
	Disaster	Red tide, shellfish toxin, jellyfish, radioactivity measurement, etc.	

2.4. Data Flows

Efficient fish feeding is currently one of the biggest challenges in aquaculture to enhance fish quality and quantity production. Information fusion based on Big Data in aquaculture is a growing field of research that is used to improve the performance of an "industrialized" ecosystem (Hassan, Hasan and Li 2016). Here we investigate data flows in five significant areas in aquaculture, such as water quality monitoring, fish feeding in aquaculture, fish behaviour monitoring, fish disease diagnosis and feed waste management.

Water quality monitoring

Currently, sensor and computer vision technology are widely used tools to monitor water quality, supporting immediate action when problems happen. To improve the system and increase efficiency, data-driven technologies should be introduced. Big aquaculture data-based analytics can be applied to water quality monitoring to assess water quality and its different parameters. We can monitor water quality only when we calculate and fuse the parameters efficiently to make a significant decision. In fish farming, water quality measurement is a crucial factor in aquaculture, and fish behaviour changes concerning changes in the aquatic environment. The data flow for the water quality monitoring system aquaculture is presented in Figure 2. to show how aquaculture Big Data are fused and analysed based on multiple sensors, computer vision technology (Li, Fu and Duan 2002).

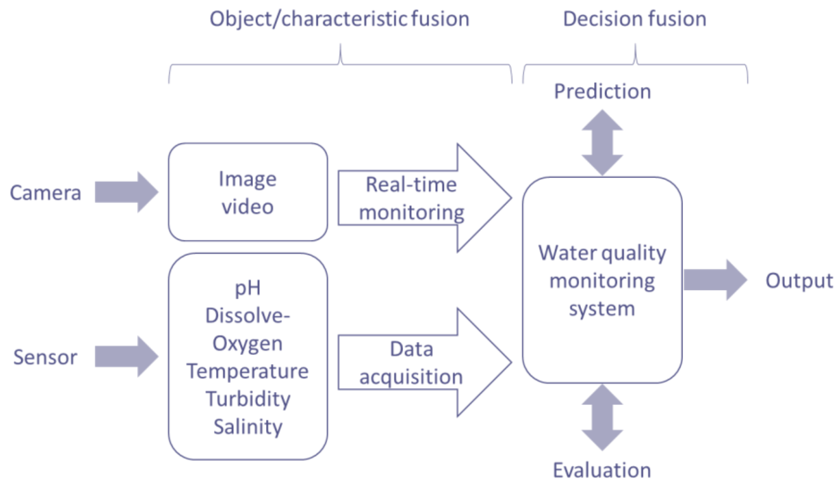

Figure 2 Data flow in water quality monitoring systems

Fish feeding in aquaculture

Fish feeding not only provides food to fish but also involves various vital factors in the feeding process. Efficient integration of these factors would be beneficial for this process. The data flow of Big Data analytics based on multi-sensor and computer vision to fish feeding in aquaculture can be summarised, as shown in Figure 3. The various methods can be fused with feed intake models following the different levels of information fusion. In fish feeding, consumption and growth of the aquatic animal are essential for production. The most important and challenging task is creating a model according to the requirements for estimating the feed and growth rate. Decision level fusion (modelling) is one of the best solutions to meet the needs. However, there is no perfect proposed model that meets all the requirements because of aquatic animals' different environments and behaviours (Wang and Li 2009).

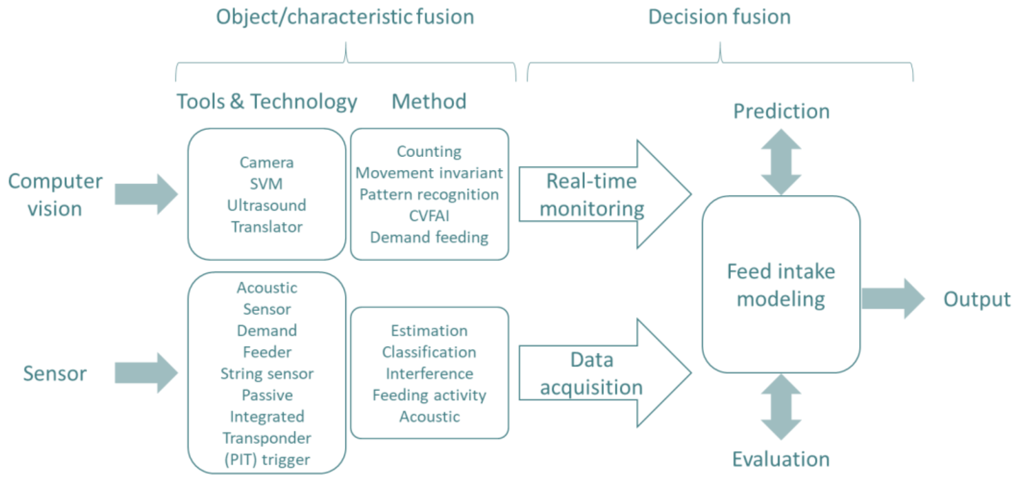

Figure 3 Data flow in fish feeding systems

Fish behaviour monitoring

In aquaculture, monitoring and tracking fish behaviour are essential in fish feeding, growth and production. In the last few decades, various technologies have been primarily incorporated into aquaculture to monitor fish's behaviour individually or on a group basis. Underwater video monitoring is based on tracking, counting or recognizing the fish behavior pattern in fish feeding, and monitoring the water quality. Radiotelemetry has been used to monitor the muscle activity, feeding demand, movements, physiology and behaviour of free-swimming fish in different environments and under certain conditions (Ferriss and Essington 2014). The acoustic Doppler velocity (ADV) technique has been used to measure the swimming behaviour of fish, and the passive integrated transponder (PIT) has widely been used in aquaculture because it is portable, less expensive, and easy to integrate with any environment (Johnston, Bérubé and Bergeron 2009). In figure 4, various methods are shown such as multi-tracking, feature extraction, motion pattern and image processing to monitor fish behaviour. Moreover, different sensors like PIT, telemetry and ADV can be used for data acquisition, and these technologies for fish behaviour monitoring incorporated in the subsequent levels of fusion (Luo, Yih and Su 2002).

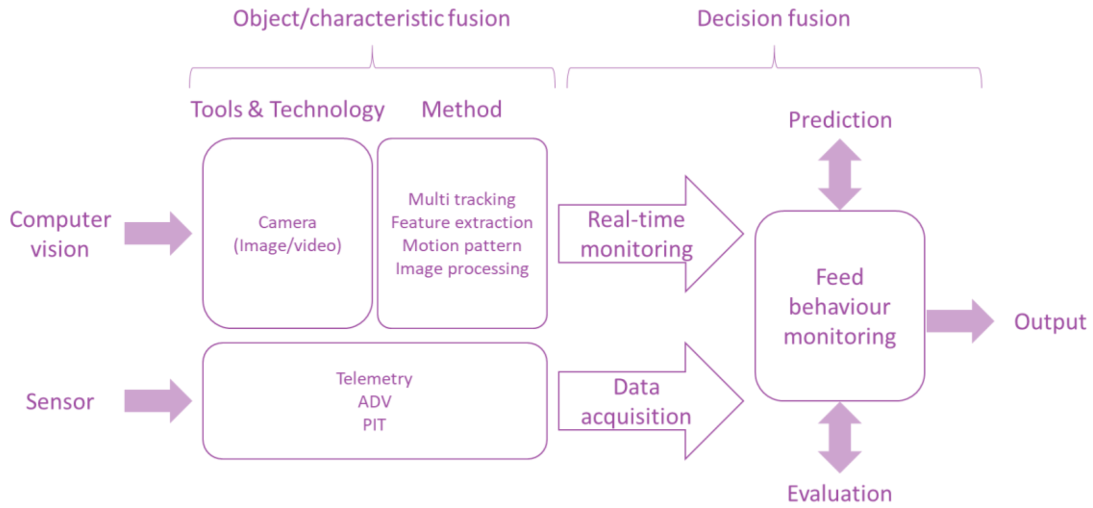

Figure 4 Data flow in fish behaviour monitoring systems

Fish disease diagnosis

In the last few years, efforts have been made by different researchers and aquaculture experts to improve the diagnosis and treatment of fish diseases. However, disease outbreaks occur due to misdiagnosis or mistreatment. Sustainable development of aquaculture is affected by many factors, and fish disease is one of these factors. Different species often show various symptoms of the same disease; therefore, it is better to classify the species before the disease diagnosis. In figure 5, aquaculture Big Data-based fish disease diagnosis is based on various technologies and methods, such as image comparison and biosensor techniques for real-time monitoring and expert system analysis followed by fusion at different levels (Wang and Li 2009).

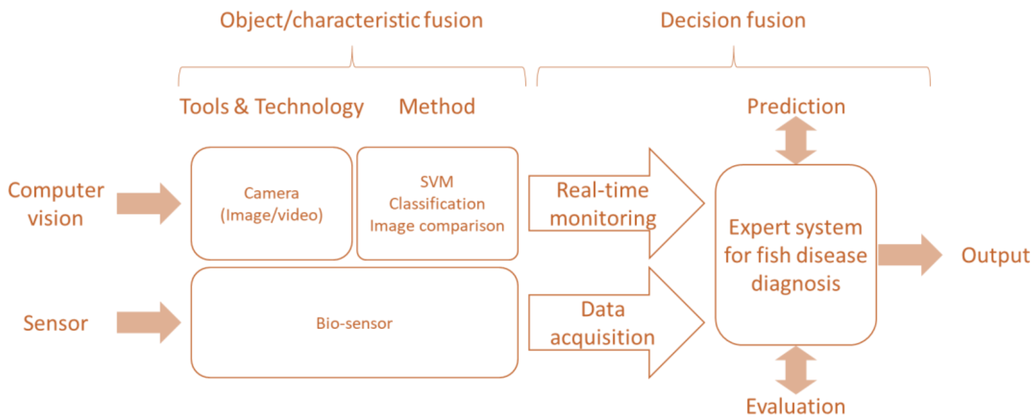

Figure 5 Data flow in fish disease diagnosis systems

Feed waste management

Feed waste management in aquaculture is necessary to reduce the environmental impact and to achieve good production. There is a great need to improve the accuracy of feed waste measurement. For this purpose, data technology of wireless sensor networks in aquaculture can be used to determine the wasted feed (Lloret, et al. 2015). Figure 6 summarises the data flow of waste management systems in aquaculture as follows: the first level of fusion, involves pellet detection, solid wastes and dissolved oxygen measurements by computer vision and signal/noise detection sensors; the second level of fusion involves modelling techniques according to the different levels of fusion (Luo, Yih and Su 2002).

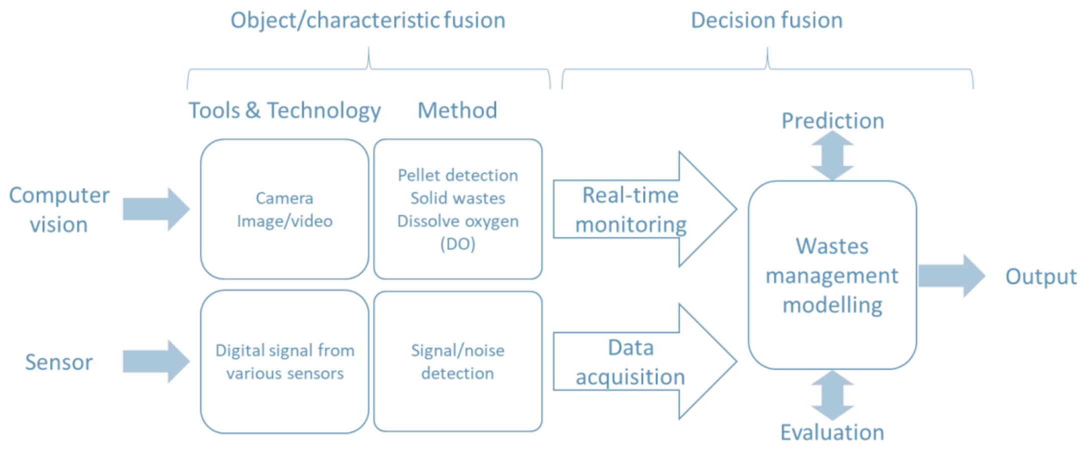

Figure 6 Data flow in feed waste management systems

3. Big Data Challenges in Aquaculture

There are several challenges in the aquaculture sector. It is an imperative task to extract business-critical intelligence and insights from large volumes of data in a complex environment of diverse legacy systems and fragmented and decentralized solutions that are common in the sector. Generally, companies are concerned with managing the substantial complexity of aquaculture data such as fish, water, feed and production. Furthermore, upstream data is growing exponentially in the form of both structured as well as unstructured data.

Data availability and quality in data collection and fusion

Data collection and fusion aim to create intelligent automation for the extract, transform, and load stages. The original data received from the fish farmers must be cleaned and processed before analytic computations. At present, the data is obtained from the farmers as an excel file in general. All special characters are converted to standard ANSI characters. After that, the cleaning process correcting apparent errors and less apparent mistakes against the formulas and known variable dependencies are needed. There are two main typical problems in data availability and data quality. Data availability refers to the percentage of data that we were expecting vs. the actual data that we have in the datasets.

On the other hand, data quality refers to the percentage of good data vs. damaged data. In that, the problems of data cleaning are as follows. The data can include characters/words in the local alphabet, which need to be converted to standard ANSI. Problems can occur when converting Excel files to CSV files (CSV is a preferred file format for data analytics). Also, files can be corrupted during the transfer or input.

Sustainability with Big Data

Never before has sustainability received so much attention. Aquaculture will have a crucial role in feeding the growing global population going forward. But, in order to feed an increasing population, the environmental impact and animal welfare have to be emphasized. As growth is dependent on environmental factors, sustainability will be the primary enabler for an increase in production volumes. According to (Moe, et al. 2019) report, a knowledge-based technique built on Big Data is one of the key technologies to improve feed conversion ratio (FCR). Technological advancements in terms of, for instance, automated feeding stations and the use of Big Data and analytics could be applied to reduce the FCR. While the feed for salmon farming is low compared to several other agriculture farming operations, it is still the single-largest cost component for a fish farmer. More efficient feeding solutions could possibly reduce the feed wastage and advancements in the feed itself could reduce the amount needed.

Data curation and homogenisation

For rapid analysis and processing of satellite and geoscience data, curating and homogenising all data layers is required before being uploaded to the platform to eliminate the time needed for data pre-processing. Data curation requires to validate, verify as well as spatially and temporarily align the data to be integrated into physical and machine learning models without the need for data download, validation and pre-processing. For example, Physical Analytics Integrated Repository and Services (PAIRS) as a geo-spatial Big Data platform has been studied to process petabytes of data and address the spatial and temporal complexity associated with heterogeneous data integration (Klein, et al. 2015). The PAIRS architecture automatically downloads, curates and stores geo-spatial data stream in a scalable storage table. The platform provides various query functions to retrieve data in multiple ways: (1) single point across large interval to create time series, (2) spatial query across an arbitrarily sized area and (3) filtered spatial and temporal query.

Geo-spatial data

Geo-spatial datasets pertinent to aquaculture include sea surface temperature (SST), ocean waves and chlorophyll a (Chl a) monitored daily from multiple satellites circling the globe (O'Donncha and Purcell 2019). Besides, weather, climate and ocean models compute the current system state several times per day to enable insight into interactions between atmosphere and ocean as well as provide means to monitor and predict macro-scale events. Traditionally, these data have not been fully leveraged by stakeholders due to their vast volumes and heterogeneous and concerns over nearshore accuracy and spatial resolution.

Fear to invest in advanced techniques

Innovations are usually two-sided medals and hence blockchain, data mining, and artificial intelligence pose challenges to all participants of fishing enterprises, including fishers, trader, consumers, management authorities, and scientists. Fishermen may not be willing to instigate further control mechanisms, whereas traders and management authorities may fear the extra costs and effort of installing and maintaining new infrastructures (Probst 2020).

Trust and transparency threaten caused by human resources

And finally, consumers may need to engage in the blockchain by downloading apps and spending time to get informed on their product (Visser and Hanich, 2017). But, neither blockchains, smart contracts, nor data mining algorithms are free of fraud, error and uncertainty. It is therefore naive to assume that these technologies will entirely prevent illegal or unreported fishing. One of the most crucial steps of the aquaculture supply chain will remain the haul of the catch on board of the fishing vessel and the subsequent designation of labels. Both processes will stay in the hands of the vessel crew. It will be difficult to verify whether all catches are labelled correctly outside the fishing vessel, whether discarding has occurred or whether catches are landed unreported or illegally. Labelling also becomes easier to manipulate when fish and seafood products are not sold as whole but are processed into different product categories such as steaks, filets, loins and minced meat.

4. Recommendations

For the regional aquaculture industries, it is important to emphasis the application of Big Data technology and processes instead of designing and developing essential technologies by itself. The following recommendations are provided to be implemented in regional aquaculture industry and also potential project development under Teknoløft project. These recommendations are prioritized for primary use cases in the aquaculture industry in the Sogn og Fjordane region.

Water quality monitoring

Monitoring water quality in aquaculture is generally solved by classical techniques while using sensors or monitoring the behaviour of the organisms with underwater cameras, combined with various algorithms to improve the accuracy and efficiency of the data from these technologies. Nevertheless, there is a great need to fuse these technologies and use the acquired big aquaculture data to transform them into a comprehensive form and obtain maximum efficiency and better results for the benefit of aquaculture.

Fish feeding in aquaculture

Various systems and techniques have been used to make fish feeding more efficient, but further feed waste reduction needs to be achieved. Given that feed waste is one of the biggest aquaculture problems, different sensors and underwater vision technologies have been developed. However, these technologies require further improvement through data-driven methods with big aquaculture data. There are currently different automatic demand feeders and online monitoring systems available to improve the feeding process's accuracy, but adequate technology is still not available. Some fusion technologies have been used and provided better results. However, fish feeding accuracy will not be sufficient until the appetite time and amount of feed required are more clearly identified. In the future, considerable effort with Big Data analytics in aquaculture should be made to overcome these problems to make feeding more productive.

Fish behaviour monitoring

Continuous monitoring of the fish behaviour of aquaculture organisms can make a difference for productive aquaculture. Different approaches using sensor technology and underwater cameras for monitoring fish behaviour and patterns have been developed in the last few years. However, there is still a need to integrate these with Big Data technologies and transform the information to achieve better results. Using sensors and computer vision technology, fish behaviour can be monitored, and decisions about water quality and different fish movement patterns can be made more and more accurate. There is a great need to use an efficient Big Data analytics algorithm to manage these technologies to achieve better and more efficient systems for the aquaculture environment.

Fish disease diagnosis

The diagnosis of fish disease is a critical problem in aquaculture because many fish die, resulting in major production loss and pollution. The research in diagnosing fish diseases has only produced moderate advances, which is a significant limitation. Only a few researchers have used the vision technology-based expert system to overcome the diagnosis problems. However, the technology is not mature enough for use in productive aquaculture, and there is a great need to find new ways to use big aquaculture data for fish disease diagnosis by proper integration of the available resources, which would be beneficial to the industry.

Feed waste management

Both improved welfare of fish and improved productivity can be achieved by improving the management of waste in aquaculture because the high rate of food waste causes pollution and disease in aquatic organisms. To overcome the food waste problem, different strategies and technologies have been used in recent years, but feed loss remains one of the biggest aquaculture challenges. Only a few diet strategies and computer vision monitoring techniques have been used to overcome this problem. From our knowledge and perspective, information fusion techniques remain underutilised in solving this problem and could be used (with additional research) to overcome the feed waste problems more intensively.

Ensuring trust and transparency with advanced techniques

Data mining and artificial intelligence appear to be handy tools to monitor and control fishing vessels/companies by gaining knowledge on catches and ensuring compliance to management rules at sea. Thereby both techniques are acting mainly on the first link of the supply chain, the producer, i.e., the fishing vessel. In contrast, blockchains and smart contracts are useful to ensure transparency along the supply chain (Probst 2020).

5. Conclusion

With the growing adoption of Big Data analytics in aquaculture, it is now the time to bring data-driven aquaculture practices to a new level of development and understanding. However, the business questions' specific challenges in aquaculture highlight particular needs and problems that must be appropriately addressed. Considerations must be given to the state-of-the-art statistics and data mining methods that permit deeper insights into the aquaculture reality through the collected datasets, either from daily data or from sampling-to-sampling data. This must also be tuned to the expert knowledge of the fish farmers, their procedures and technology in use today.

In this *Teknoløft* project report, we discussed how we could leverage Big Data tools and technologies in aquaculture domain. In particular, we focused on the characteristics and sources of big aquaculture data. Five cases of the use of Big Data in the aquaculture industry were presented with their data flow and advanced methods, and recommendations for these cases. Moreover, Big Data challenges in the aquaculture sector were discussed. The recommendations are provided in order of priorities. As a next step, the recommendations can be converted into small and/or medium scale projects for actual business in the Sogn og Fjordane region.

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