Decision support solution for water quality management in shrimp aquaculture.

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Declaration

I declare that this dissertation is my own work and has not been submitted in any form for another degree or diploma at any university or other institute of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

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Date:

Dedication

To my family

With love and gratitude

Acknowledgement

I am heartily thankful to my supervisor, Mr. Chaman Wijesiriwardana for his supervision, advice and guidance from very early stage of this work till the last level as well as providing encouragements and support in various ways which enabled me to develop an understanding of this project.

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Abstract

Aquaculture industry is one of the booming industries in today's world. Since there is an appropriate environmental condition high amount of natural resources availability, positive socio economic impact and due to the great potentials for the development of aquaculture it popular in Sri Lanka also. Still expected target is far beyond due to various reasons such as failure of the harvest, high mortality, less growth and uncertainty of the production. Researchers have found that one of the major reason for the above mentioned problems are lack of management practices in the industry.

This project focuses on water quality management one of the key area in intensive shrimp farming. As an initial step this project is dedicated to introduce automated tool for proper data collection and timely accurate decision support for non-expert users. Permanent, stable data storage to store data for future decision making process is another advantage of the project.

Given solution contains two main sections. Smart phone application and decision making module. Around 2000 past records containing water quality parameters, observations and decisions and recommendations given by expert is analyzed to identify any past pattern. K-means clustering mechanism is used to group similar cases together and merged those groups with relevant decision and recommendation. When the new case comes system uses past experience to identify the new situation and help quick decision making process. Field workers input water quality parameters and observations using mobile interface. Collected data from different ponds transfer to central database through web server. Trained system process data to produce current pond status and recommendations as an output. This will help non expert users to get immediate attention over ponds. Use cross validation for the evaluation of an algorithm .system testing is done using 500 records of current culture to test the system.

Reliable fast remote data collection and decision support system for non-expert users have been implemented and at the same time implementation contributes to bridge the Information technology gap in the field of shrimp farming

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Abbreviations	
NAQDA	National aquaculture development authority
BMP	Best management practices
CIFSRF	Canadian International Food Security Research Fund
ICT	Information communication technology
DSS	Decision support system

Chapter 1

Introduction

1.1 Overview

The 'Athena Aquaculture' is a private establishment fulfilled by governmental support and operates in Puttalam district, does intensive black tiger shrimp farming in large scale. Intensive farming is commercially popular small land produce more harvest because of the high stoking density. These practices require the farmer to implement more control over the environment. High capital inputs, control of many critical parameters like water quality, and technical skills are needed.

A major issue in this farm is they are far behind the profit margins, High capital investment and operational cost, less production due to low growth rate and high mortality rate of the shrimps. National aquaculture development authority (NAQDA) has advised them to implement proper management procedures in farming. Specially proper management of water quality which researches identified as a key factor influence the shrimp health and mortality.

This is the era of Information and communication technology. This project is to find feasible solution for the identified issues in the "Athena Aquaculture' with the help of ICT based tools.

1.2 Background and motivation

Aquaculture is the farming of aquatic organism in natural or controlled marine environments. Since 20 years ago, Shrimp farming is blooming rapidly and has been identified as good source of foreign income to Sri Lanka. Government has encouraged private sector investors to enter shrimp farming industry because of the huge export market potentials. Farmed shrimp accounts 50% of the total income from fish exports in Sri Lanka [18] throughout last two decades there is a rapid expansion of shrimp farming industry in Puttalm district in north-western coastal region of Sri Lanka. Shrimp farming has become main sources of income of the communities live in this area. More than 400, 00[19] direct and in direct employment opportunities are opened through shrimp farming industry.

There are two types of prawn farming in Sri Lanka

- Fresh water
- Brackish water or saline water

  Brackish water resource readily available in Puttalm district and brackish water shrimp farming is very famous in the area.

Due to faster growth, large size attained and export potential, the black tiger shrimp, *Penaeus monodon* has been almost exclusively used in brackish water shrimp culture in Sri Lanka. Out of the 120,000 ha of total brackish water areas in the island, about 6,000 ha have been identified as potentially suitable for black tiger shrimp farming. Since the beginning of 1980's black tiger shrimp farming made considerable progress in Puttalam and Batticalo districts along the costal line. With the adoption of intensive and sophisticated culture practices, farming in natural environment turned into controlled environments by enhancing the production for export market. It is popular commercially more advantages minimum land more harvest because high stocking density. The intensive culture operation requires high financial and technical inputs. Culture practice mainly depends on hatchery-bred fry, high stocking density, use of formulated feeds, Application of aeration to increase the level of dissolved oxygen and intensive water quality Management in earthen or concrete ponds.

Now there is trend to shout down farms and leave the area because of the great loses in the industry Researches from NAQDA as well as other government bodies such as universities use their knowledge and experience to give innovative solution to overcome the challenges faced by the aquaculture industry and lead them to achieve cost effective production while ensuring the environment compatibility.

1.3 Problem in brief

The Athena Aquaculture is a private establishment operates in Puttalm district, does intensive black tiger shrimp farming in large scale. The company operates 60 ponds in over 200 acres. Water quality management plays a very important role in fish life and aquatic product quality [44].This is very critical in intensive shrimp farming, the fish are raised in artificial tanks at very high stoking densities and are subject to supplemental feeding and fertilization. Farmers must have a thorough understanding of the targeted species so that water quality, temperature levels, oxygen levels, stocking densities, and feed are set at the optimal levels to promote growth, reduce stress, control disease, and reduce mortality.[44].

Even though the company has identified water quality is a critical factor and implement management procedures, there were several occasions many shrimps have been found dead due to unbalance ecosystem of pond water. The inefficiencies of current practices in water quality management is identified as one of the main cause for such failures. Beginning of the shrimping season better harvest is expected, but these mortalities always curtailed the shrimp harvest and this sharp drop makes huge impact on profit targets of the company. According to the statistics growth rate was too low in last three seasons. The company was expecting 30g shrimps in 120 days but could not achieve the weight even in 150 days. The company has spent more than three million rupees to feed them for extra 30 days.

The inefficiencies of manual work, unavailability of relevant data at correct time and unavailability of expert to identify the situations which need quick attention identified as main issues. Experts in the field use water quality data, observation results and their past experience to make decision.

For instance, dissolved oxygen is a very sensitive parameter. Sudden drop will leads to increase the mortality rate. If the low oxygen level persisting couple of days may end up with killing the entire pond. With regular oxygen level data and observations of field workers, the expert can give his suggestions to avoid such disasters beforehand. There were several incident happened due to unavailability of data and unavailability of expert.

As a summary, following points have been identified as key disadvantages of existing system.

- Absence of proper water quality data recording system in regular intervals
- Difficulty of forming data for decision making.
- Difficulty of understanding occasions needs special, fast attention.

1.4 Aim and Objectives

1.4.1 Aim

The aim of this project is to introduce a decision support solution for water quality management in shrimp aquaculture.

1.4.2 Objectives

- Introduce a mechanism of reliable real time data collection.
- Introduce reliable data storage mechanism for future decision making.
- Introduce a automated method to identify problematic & non-problematic situations in pond water quality.
- Support non expert user for' real time decision making by giving suggestions and recommendation.

1.5 Proposed solution

Many articles have been written on the diagnosis and treatment of specific fish disease, prevention from low growth rate through good management of the farm is the best solution, which manly involves good water quality [44]. There is no cure for running mortality syndrome at the moment, but lots of consultants suggested to go for better farm management practices,[45]Proposed decision support solution is introduced to overcome identified in efficiencies in current practices in water quality management.

1.5.1 Decision support system for water quality management

As a result of a preliminary study, it is understood that implementation of basic real-time data processing system will overcome primary drawbacks of manual system and further studies illustrated that expert make decisions based on not only numerical parameters but also the observations and their past experiences.
Use of ICT for the betterment of any industry is the trend today. Automation of the aquaculture systems gives many benefits to the industry such as enhance product quality, environment control, reduce losses and production cost, enhance the efficiency. The study concluded that a decision support system which generates suggestions and recommendations based on numerical parameters, analyzing of observations and past

experience, will be more helpful to overcome current issues in Athena Aquaculture. The system will consist of two main components.

- **Real time data collection**

Smart phone application is used to collect real time data. The mobile application allows field workers to enter parameter data such as Temperature, pH level, Salanity dissolved oxygen level and his observations like bad smell and water color at pond. Mobile application will update the central database on time.

- **Decision support for non-expert users**

The desktop application will be used by the non-expert users in the farm. System will have the capability of identifying abnormal patterns based on inputs from field workers such as sudden decrease of dissolved oxygen, raise in salinity over couple of days. Based on past experience system will give suggestions and recommendations to get relived of such situation. Output is produced in a user friendly form for the non-expert users.

1.6 Project Outline

The paper is structured as follows. Introduction page briefly discuss introduction to project, problem, solution, aim and objectives. Second chapter describes the importance of the project what the problem what are the available solutions using related researches. Third chapter includes adopted technologies mobile application and decision support function. Chapter five includes the approach, how those technologies used implement decision support system and what are the steps. Chapter five includes design diagrams for proposed solution. Chapter six discuss the evaluation of given solution and said aim and objectives are met. Chapter seven Conclusion & Further work. Reference section indicates the used sources for the project. Then the last section appendix section.

1.7 Summary

Brief introduction to the whole project has been given. Aim and objectives of the project, problem in brief, background, motivation and structure of the documentation is included in this section. Next chapter discuss the about the problem and solution using relevant literature

Chapter 2

Need of proper water quality management in shrimp aquaculture in Sri Lanka

2.1 Introduction

Chapter describes the present situation of aquaculture industry globally as well as in Sri Lanka and its socio economic impact on humans; detailed description on one of the critical factors of the industry, water quality management identified main issues there and what are the available solutions are given with the help of the literature.

2.2 Overview of an aquaculture

2.2.1 Global aquaculture and importance

Aquaculture refers to the farming of aquatic organisms such as fish and aquatic plants. It involves cultivating freshwater and saltwater populations under controlled conditions and It is one of the major part in aquaculture field [16].the word farming refers breeding, rearing, and harvesting market sized species. Not only hatchery fish and selfish aquaculture includes ornamental fish as well as kind of aquatic plants species used in a foodstuffs, pharmaceutical nutritional and biotechnology industries. These species raised in a pond, tank or other natural habitat like river, lake or ocean till harvest. Species grown in to market size will be harvested. Aquaculture gives huge contribution on world fish production. Increasing food demand has made industrial aquaculture popular throughout world rapidly. "Between 1970 and 2000, FAO figures show, aquaculture's contribution to global fisheries (in terms of shellfish and finfish production, not plants) increased nearly seven-fold, from 3.9 to 27 percent of the total. In 2000, the sector provided over 36 percent of the world's food-fish supplies"[23]There are main groups in aquaculture Fish, shrimp farming, oyster farming, mariculture, alga culture(sea weed).

2.2.2 Shrimp farming

- **Global shrimp farming**

"Shrimp farming is very important in aquaculture today"[26] farmed shrimp now accounts for about 55 % of global shrimp production[27]Even though Asian farmers follow unsustainable methods for shrimp farming, Asian countries such as china, Indonesia ,Thailand do most of the shrimp farming and produce large portion of shrimp production in the world shrimp market. America and Australia is rapidly increasing the contribution.

- **Current statues of shrimp farming in Sri Lanka**

Shrimp farming plays the major role in aquaculture industry in Sri Lanka and provides significant contribution to the export market of Sri Lanka." Quantities of Fish and Fishery Products Exported Annual operating costs are in the region of LKR 22 million and the investment is expected to produce an annual output of 112 Mt of prawns.[29].there are different kinds of commercially available prawns species in Sri Lanka.

Shrimp farming industry has made positive social and economic impact on the rural communities in Sri Lanka .there are more than 40,000 employment opportunities are opened through shrimp farming industry. On farm direct jobs as well as other indirect jobs such as "manufacturers of products such as paddle wheels for pond aeration, containers for shrimp storage and transport, hatchery tanks, water pumps, chemicals for water treatment, and chemotherapeutics" [33].

Export market of prawns in Sri Lanka 2012

Species	Quantity MT	Market
BLACK TIGER PRAWNS	5000	USA,JAPAN
FLOWER PRAWN	2500	Mostly JAPAN
WHITE PRAWN	2500	USA,JAPAN
FRESH WATER PRAWN	2000	USA
COROMANDEL SHRIMP	0.2-0.3	Local market

Table 0.1 - Aquaculture production from different area

"Even though many large freshwater and brackish water resources available in the country Shrimp farming does not historical back ground like paddy cultivation in Sri Lanka. It was started in early 1970 Batticalo district in Sri Lanka until it is destroyed by the civil war Of Sri Lanka. The current shrimp aquaculture industry in Sri Lanka is mainly over north western coastal belt covering a farm area of more than 4 500 ha with 70 hatcheries, of the total farm area the ponds themselves occupy an area of around 3 000 ha"[29]."When compared to other provinces in Sri Lanka, major characteristics suitable for shrimp farming operations are found in the northwestern province, such as brackish water and appropriate soil type and topography."[31]

Aquaculture production is more cost effective than other livestock farming in Sri Lanka [28] farming plays significant role in aquaculture industry in Sri Lanka. Prawn farming is the most significant commercial scale aquaculture conducted in Sri Lanka.(investment proposal,2014)90% of harvested shrimp production is in the export market of Sri Lanka to Japan ,USA and countries of European union earning 50% of foreign exchange income.[29] one of the major aquaculture project funded by Canadian government bodies taking place in Sri Lanka. This collaboration project is called Promoting rural income from sustainable aquaculture through social learning in Sri Lanka. The aim of the project is to find innovative ways to deliver market, technology, and environmental information about aquaculture to households, farms, and businesses in Sri Lanka [30]one of the main outcome of this collaboration project is to Increased aquaculture productivity and income in Sri Lanka.[30]. Majority of farmers in Sri Lanka have selected semi intensive shrimp farming where the stocking density is 15—20 PL (post-larvae)/m[29] and brackish water farming is dominated in this area.

NAQDA is National Aquaculture Development Authority of Sri Lanka. This is the government body which is established 1999 with the aim of developing sustainable aquaculture and inland fisheries industry of Sri Lanka [32].NARA is The National Aquatic Resources Research and Development Agency. It is another responsible body for sustainable aquatic resource management in Sri Lanka. Mainly they conduct various types of researches related to the development of fisheries and aquaculture sector in Sri Lanka.

2.3 Issues in shrimp farming

Most of the studies show that Crop failures have been experienced by most of the counties in the world. China lost large part of the production in 1990 due to disease outbreak.1995 India had same experience. Vietnam and Bangladesh have also suffered crop failures in shrimp production [34].

Survival rates of farmed shrimp depend on a number of factors such as water quality, stocking densities and feed stock. Inappropriate management can induce stress, diseases and ultimately death in shrimp. Many studies found that lack of management practices in shrimp farming industry lead the problems. Economic losses through disease and poor management [1]there for best management practices (**BMP**) should be introduced[1].pond management is very important in intensive shrimp farming there are different areas in the pond management such as stocking density, seed quality, feed management, water quality management and sediment management.

2.4 Importance of water quality

Aquaculture refers to the farming of aquatic organisms such as fish and aquatic plants. It involves cultivating freshwater and saltwater populations under controlled conditions and it is one of the major part in aquaculture field [16]. Aqua culturists have defined quality of the water is the most important factor affecting fish health and performance in aquaculture production systems. [7].Since fish perform all their bodily functions in water. Because fish are totally dependent upon water to breathe, feed and grow, excrete wastes, maintain a salt balance, and reproduce, understanding the physical and chemical qualities of water is critical to successful aquaculture. [44].

Understanding the water quality requirements is very important especially in an intensive farming where the environment is controlled Fish is totally dependent on the water they live in for all their needs. There are many water quality variables could be measured, but for practicality, only the important variables should be measured. The variables of most importance in shrimp farming effluents are those most likely to cause deterioration of conditions in coastal ecosystems [22] Different fish species have different and specific range of water quality aspects (temperature, pH, oxygen concentration, salinity, hardness, etc.) within which they can survive, grow and reproduce [7].

most of the studies have proved that management of water quality is one of the main crucial factor in intensive shrimp farming [3] because it influence metabolism, oxygen to consumption, feeding rate, growth, mounting, survival and prevent many problems due to shrimp culture, sustainable tolerance to toxic metabolite several research studies have been conducted to exhibit the effect of water quality on fish health and performance in aquaculture production system [2]. Poor water quality management make immense impact on shrimp growth and survival on intensive shrimp farming where ponds shrimp with high stoking density. Well managed good quality water always defined as suitable water for the survival and growth of shrimp. [1] Fish is totally depends on the water they live in for all their needs. [2] Different species are having different and specific range of water quality aspects. Within optimum range they perform well and reproduce outside this optimum range. [2]There are several problems such as poor growth, abnormal behaviors and lead some of the infections if this situation remains for long time period then it will lead to high mortality rate.

Water quality is determined by physical, chemical and microbiological properties of water. Intensive system of P monodon culture Temperature, salinity, pH and dissolved oxygen is considered as some of the main parameters of the water quality.

2.5 Important water quality parameters

Dissolved oxygen, temperature, salinity, PH are identified as Vital water quality parameters [17] All penaeid shrimp species are highly susceptible to infection and it will lead high mortality rate [2] White spot disease (WSD) is one of the major problem in shrimp culture around the world. White spot syndrome virus (WSSV) is the root cause for this disease it causes mortality rate 100% within few days (3-4 days' time).some situations it will be very on different ponds. Present studies have been identified that water quality parameters have strong relationship with white spot outbreak. Some studies have been found [3] Lower temperature and high pH influence WSSV infection in cultured shrimps of P. monodon.[5]Temperature, PH and salinity level of pond water is considered to be major triggering factors for white spot disease outbreak. Laboratory level study has been conducted to demonstrate the effect of temperature and salinity in white spot virus in giant tiger shrimp Penaeus monodon. Different levels of temperature (16, 25, 27, 28, 30, 32 and 36 °C) and salinity (0.5, 5, 10, 15, 30 and 45 g l -1) they have found that high survival rate in 32 °C to 36 °C and high mortality rate have been reported in lower temperature and also sudden variation of temperature effects the immune system according to their study optimum range of the temperature is 25 to 31 °C for the black tiger shrimp. Black tiger prawn prefers low saline conditions [6]. Even though our study is mainly based on P.mondon another famous penaeid type in sri Lanka is P.Vannami there are some studies on P.Vannami temperatures of 20, 25, 30 and 35 °C and salinities of 20, 30, 35, 40 and 50%. Groups of 30 animals were used in each combination of conditions, in triplicate. The results clearly show that juveniles of this species have their best survival between temperatures of 20 and 30 °C and salinities above 20%. Best growth was obtained between temperatures of 25 and 35 °C, with little difference being noted among salinities. Survival and growth coincide best at around 28 to 30 °C and 33 to 40%.Calculated overall production was shown to be best in these conditions.

This may prevent or minimize the use of fresh water to dilute high saline water in shrimp farms. Moreover, it is generally recognized that high saline species are relatively more disease tolerant than are low saline species. When adopting the "switching over" strategy, the species should be carefully selected, taking into consideration the market trends.

If the dissolved oxygen depletes, the increased levels of total sulfides may cause environmental stress leading to fish kills. Such fish kills were reported in the Dutch Canal in early 1995. Moreover, reduced growth rates, lower production and disease problems in shrimp may be attributed to the stress caused by the polluted water source. [1]

The study on water quality management was done which specifically looked at the effects of dissolved oxygen saturation on fish growth. [11] According Mallaya dissolved oxygen is the Most important and critical parameter, requiring continuous monitoring in aquaculture production systems. This is due to fact that fish aerobic metabolism requires dissolved Oxygen. There for good oxygen-monitoring program is necessary. [12] If any changes noticed then immediate action is required. Dissolved oxygen concentrations should always be maintained above 3 ppm. At lower concentrations, stressful conditions and eventually mortality will occur. Levels of dissolved oxygen that are substantially higher than 3 ppm are recommended because chronically lower levels of dissolved oxygen throughout the growing season can markedly impact yields [12].

A high pH can cause mortality either directly by means of creating a pH imbalance relative to the prawn tissue or indirectly by causing a larger proportion of ammonia to exist in the toxic un-ionized form. Although freshwater prawns have been successfully raised in ponds where a pH has ranged from 6.0 to 10.0, a pH that remains within the range 6.5 and 9.5 is recommended. High pH values usually occur in water having a total alkalinity 0.5 to 50 ppm often stimulated by the existence of a dense algal bloom. Adding lime to the bottom soil of ponds that are constructed in acid soils can help to minimize severe and possibly lethal fluctuations that might occur during grow out.

2.6 Poor water quality lead fish stress

Poor water quality means low concentration of dissolved oxygen, undesirable temperature or pH, increased levels of carbon dioxide, ammonia and hydrogen sulfide and inappropriate concentration of salinity and hardness which all lead to fish stress. [44].Negative effect on growth, reproduction, and digestion are the results of long term fish stress. Another

Lower the ability of the immune system to respond effectively and fully. This lowered immune response is what allows parasites, bacteria, and fungi to infect a stressed fish and can cause eaven death.

Many studies have found that variation of water quality management techniques gives huge variation of production (238 kg/ha for improved traditional farms and 2500 kg/ha for semi-intensive farms) and survival rate (35-65%) [35]But major issue is shrimp farmers are not aware of it and continue with undesirable farming practices.

2.7 Water quality management in the field of aquaculture

2.7.1 Available systems

- **Remote water quality logging system**

Remote water quality logging system was introduced India to obtain real-time data on vital water parameters and to monitor the ponds.[17]this data logging system could be effectively used to improve the understanding of the processes occurring at sediment-water interface in aquaculture pond. Continuous loggers equipped with alarm systems could also act as early warning systems to the farm managers on the water quality conditions prevailing in different ponds and to take appropriate management decisions for water quality. [17]Bad water quality make the fish sick even to die, the survival rate of the fry was declined and the income of the fishery was seriously affected. Decision support systems have been introduced overcome water quality issues in aquaculture industry.

- **Decision support system for aquaculture water quality evaluation and early-warning**

(AWQEE-DSS) [8] This system is based on the monitored data in the aquaculture pond in North China for two year and the experience of the domain expert. AWQEE-DSS consists of six bases and four sub-systems. [8]

- **Expert System for Shrimp Aquaculture (ESSHA)**

An Expert System for Shrimp Aquaculture (ESSHA) has been developed to help the extension personnel with information on shrimp farming technology for knowledge management and onward dissemination to the aquafarmers. This computer program that uses knowledge base to solve problems, which emulates the decision-making ability of a human expert.[43]

Another expert system for water quality evaluation of aquaculture pond was developed which could inspect the factors of water quality in the aquaculture pond, analyze the water quality and evaluate them, and then diagnose the environment of the aquaculture water53. The expert system also provides feasible suggestions for the effective water quality management.[43]

2.7.2 Water quality management systems in shrimp farming in Sri Lanka.

According to the primary and secondary studies no proper management practices implemented in shrimp farming in Sri Lanka. All most all the farms uses manual systems and traditional methods for water quality management.

2.7.3 Current practices and issues identified.

Athena aquaculture company operators 60 ponds over 200 acres of the land. According to the current practices important water quality parameters were collected daily. This include PH, Temperature, Salinity, DO, turbidity and observations. Water quality parameters and very short description of observations are recorded using Excel work sheet. Growth of the shrimp also recorded in daily basis. One of the main problem is no proper maintenance of rata collection and recording there are big gaps in the excel sheets. No data reading and recording in some days. According to them reason is they record them manually end of the day. There for there are possibilities to forget them to do proper recording. No proper method for real-time monitoring and recoding information's. According to the data readers sometimes they have noticed in the affected ponds, shrimp were observed swimming lethargically at the water surface but they don't have knowledge to get right decision. It is too late when the experts get updates about the situation.

2.8 ICT Involvement in the field of aquaculture

Aquaculture industry can use ICT to get benefit with improved monitoring and control systems and better real-time information for managers [20] some ICT based tools can potentially provide early warning of disease outbreaks in the industry and allow precautionary actions to be put in place. ACP countries use ICT successfully to improve fisheries sector. Use of information technology in aquaculture field is very less in Sri Lanka. But this is the era of Information and communication technology and ICT can be used as a tool to empower all the stakeholders aquaculture industry , Slower growth than predicted, higher mortalities than expected or too high feed conversion ratios are some of the issues fish and shrimp farmers face occasionally. Many European countries as well as most of the Asian countries already offer ICT based solutions to address the above mentioned issues in aquaculture field. ICTs have had a significant positive impact on sustainable development and poverty alleviation [18].

2.8.1 Better management practice using ICT based models in Sri Lanka

Information and Communication Technology (ICT) has done the revolutionized change in the world by making big socio-economic impact on mankind.

There for each industry, organization or person has to concern their products and services more towards modernized and ICT related manner. It will lead more profitable shrimp farming industry in Sri Lanka. Use of Information technology in aquaculture field is still very reare in Sri Lanka. But now but government bodies introduce different programs to show the power of ICT for accelerate development of aquaculture in Sri Lanka.

2.8.2 Available systems in Sri Lanka

- **Mobilization program use of SMS and Internet**

Canadian International Food Security Research Fund (CIFSRF) helps shrimp farmers in Sri Lanka adapt their industry's best management practice to local needs. According to the research done by DeJage et,all. Funded by government of Canada, The government of Sri Lanka has introduced ICT based methods to help shrimp farmers to address problems and constraints in shrimp farming through better practice [24]. Mobilization program was used with 60 farmers, this includes SMS and web platform to alert them to critical factors affecting farm performance and risks, such as disease outbreaks and poor water quality. Actually stakeholders of shrimp farming is advised to overcome problematic situations. This is successful pilot project because as a result 80% of farmers took actions to implement 75% of the key practices recommended to improve production outcomes and very important part is positive response from farmers and other stake holders in the industry. Now this program has been expanded to cover 500 farmers and the receive warning and share knowledge using SMS and web portals.

2.8.3 Decision support systems

When the aquaculture industry is moving to words intensive culture, need of proper management practices also increased [17] Today's trend is use sensor technologies to monitor the environment aquaculture operations take place collect those data's and use them for management decision making process in farm.Use of sensor technologies to monitor the environment where aquaculture operations take place is a recent trend. The literature states a number of activities related to decision support systems in Aquaculture farm operations. There are number of DSS developed using different methods [16]. Now most of the business organizations have tend to build up or computerized information systems to support decision makers. Decision support system always increased employee productivity and more timely information for decision making. Readily available information's improve decision making effectiveness and better decisions. Cost effective through labor saving DSS support systems help decision makers to get better decision.

2.9 Summary

Water quality parameters are very critical factors in shrimp growth. Because it leads fish stress and fish stress is the key point to high motility and low growth. According the given literature most of the studies recommend proper management practices to overcome said issues.

There are ICT based models have been introduced to implement better management practices specially pond water quality management and solve problems in shrimp farming industry throughout the world. There are successful stories about using Decision support tools to overcome most of the problems in shrimp farming. Some systems are developed to replace expert users.. Next chapter discuss about adopted technology to make decision support tool.

Chapter 3

Decision support model using cluster analysis

3.1 Introduction

Today's business world has been deeply influenced by Information and Communication Technologies (ICT) and the application of ICT among business is widespread. Electronic data processing for decision making is more popular among industries need more time sensitive, effective and accurate decision making. Shrimp aquaculture industry in Sri Lanka is one of the industry operates in primary level in technology adoption. This solution attempts to bridge the technology gap in the shrimp farming industry in Sri Lanka. This chapter describes what are the technologies used to overcome the identified issues in the shrimp farm. Why these techniques are appropriate to solve the mentioned problem.

3.2 Overview

Solution contains Smart phone application for the field workers to collect remote data trained system using past data (daily collected records containing water quality of different ponds in the farm).online data transferring from mobile to database. Output produces using user friendly interfaces designed for non-expert users.

3.3 Smart phone application for field workers

There are numerous ways of collecting data from remote areas, these include paper based methods and electronic based methods most of the people use manual data collection mainly due to limitations of resources such as electric power and IT infrastructure. Electronic methods are sophisticated methods, which are used to enable collection and storing of data Even though infrastructure facilities are already available Athena shrimp farm uses manual paper based data collection.

Several studies have proposed mobile technology as the candidate technology in improving remote data collection in the developing world and even in isolated regions of developed world [36].

These methods involve the use of mobile devices such as PDAs, cell phones, smart phones, net book, notebook, tablets computer. Data collection technologies have been

further geared by the growing and advancement of smart phones technologies that offer high computing speed which facilitate capturing of data in short time compared to the time consumed by other methods.
As explained there are issues with the field data collection in Athena shrimp farm, proper method should be implemented to overcome the problems.

Smartphone application is introduced for field workers to collect and transfer real time water quality and observation to the system. Those collected data's are used for the real time decision making process; quick actions are very important and critical in this situation. Manual, paper based. Data collected through these manual methods are not standardized and therefore difficult to process for analytical and data mining purposes. Poor data collection methods have led to lack of clear understanding If the flow of data is not clearly understood by the decision makers, fulfillment of the plans and the policies that are created to improve the particular field might be difficult [1]

In order to improve the quality of the decision making process accurate and timely data is crucial. By using mobile phone reduce the time taken for the data to reach those who need it. Standard clear formats can be used with mobile interfaces. All the data object instances are having same format. Well-designed user friendly interface is optimized for data collection on Smartphone. Multiple field workers are attached to the data collection application can be deployed many devices. Mobile phones are portable field workers can carry them easily when they are monitoring shrimp ponds over *200 acres*. Native Android platform is used in the smart phone as best option since it is open source. Developed smart phone application has multilingual capability. But implementation part is done only for the English. Use of wireless communication is the best method to transfer data's in this type of large area. In this system, Use mobile communication network to transfer data online, the APACHE server serves as a web engine for translating mobile data and interacts with MySQL server database installed in farm head office. If signal drops half way through the data upload process data will be saved in a text file offline and continue upload when an Internet connection becomes available. It will avoid data lost.

3.4 Data processing for decision-making

Decision support systems (DSS) are a set of manual or computer-based tools that assist in some decision-making activity [42] According to the given situation, lack of quick decision-making is one of the major issues in shrimp farm. Mainly they need real-time identification of problematic situations in the pond water quality and give immediate attention without depending on the experts. There for this automated system should be interactive and user-friendly for the non-expert users.

Large set water quality, observation expert's decision and recommendations collected from three cultures are already available in excel form. There is a requirement to store them in more stable form. Finding the way to integrate available data in to an efficient and effective decision-making process was the key challenge.

- **Manual pattern recognition**

Nearly 2,000 past records are available. As mentioned earlier there are slandered ranges in water quality. There were number of situations or cases where individual values are out of the standard range. Still expert has given positive impact on the situation. If always expert has given negative results on the situations where the ranges are out, some set of rules or procedures could have been implemented to process available data. However, this situation is different. Further study throughout data set proves that there are probabilities of giving same results on similar combinations of values.

- **Solves a new problem applying previous experiences,**

Solution discussed something similar to predictive model use known results to develop (or train) the System that can be used to predict solution for new data with past knowledge. First step shod be find the methods to identify similar situations or group of records contains combination of similar parameter value.

- **Cluster analysis to identify groups with similar patterns**

Clustering is widely used in different field such as biology, psychology, and economics. There are methods have been proposed in the literature for cluster analysis. Among them k-means, method is the most popular method because it is simple and fast clustering technique. [37].

- **K-mean clustering**

K-Means is one of the simplest unsupervised learning algorithms that solve the well-known clustering problem [39]. Unsupervised Learning is about analyzing data and looking for patterns. Unsupervised method is the best method to analyze data in this situation. Water quality and observation data used for clustering does not have recognized pattern or predefined group. Unsupervised learning method is used to recognize those hidden groups with similar features.

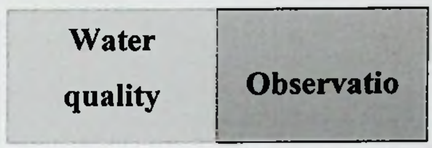


Figure 0.1 - Parameters for clustering

- **Impact of Normalization in K-Means Clustering**

Normalization standardize values of all attributes or features from different dynamic range into a specified range [40].It gives them equal weight, fall within a small specified range, reduce redundant or noisy data and enhance the accuracy of the result set .

Literature has proved that traditional k means algorithm does not always generate good quality result's K-Means clustering can generate effective results if data is preprocessed by applying normalization to the dataset. Large as well as values with different value ranges always gives the problems in the distance calculations in the clustering process.

Originally collected water quality parameter values are in different ranges.

After applying the normalization, scaled down all the data in to the standard range

Gaussian normalization is used to normalize.

- **Identify K using Rule of thumb**

One of its drawbacks is the requirement for the number of clusters, K to be specified before the algorithm is applied [37] the result of clustering sometimes depending on number of clusters varied time to time. One of the main challenges in cluster analysis is to identify optimal number of clusters to solve the problem in an efficient way. There are several approaches have been introduced to determine the number of clusters for k-mean clustering algorithm. The performance of a clustering algorithm may be affected by the chosen value of K. Therefore, instead of using a single predefined K, a set of values might be adopted [38].One method is to ask users to enter number of clusters. Issue is the expert domain knowledge over the underlying datasets because data points need to be analyzed visually and there can be some ambiguity. [39] There are several methods to identify K

i) By rule of thumb; ii) Elbow method; iii) Information Criterion Approach; iv) An Information Theoretic Approach; v) Choosing k Using the Silhouette and vi) Cross-validation.

- **Rule of thumb**

It is a simple method. This method can by apply to any type of data set [37].
k = (n/2)^ 0,5 n is number of elements in this case 1519.

- **Distance calculation**

The center of a cluster is often a centroid, the average of all the points in the cluster A cluster is a set of objects such that an object in a cluster is closer to the "center" of a cluster, than to the center of any other cluster. Distance calculation metric is important to understand the relevant cluster. Euclidean distance calculation is used to calculate distance in this situation.

- **Euclidean**. The Euclidean distance is commonly used as a measure of cluster scatter for K-means clustering. This metric is preferred because it minimizes the mean distance between points and the centroids [41].

3.5 Decision support interface

This system is for non-expert users then interfaces should be very user friendly and easy to understand. Pond lay out is given using an image. Current pond statues of the active ponds and recommendations are given using color indicators (Red, Yellow, and Green) and string messages

3.6 Summary

Detailed description is given about the technology adopted to give successful solution for the said problem and justification for the selections. Next chapter will discuss how those adopted technologies are arranged to give effective solution

Chapter 4

Methodological approach of decision support system

4.1 Introduction

Preliminary study showed that lack of arranged data for analyzing for decision making and incapability of linking present data with expert knowledge and knowledge gained from past experience caused major losses in the industry. The scope of this project covers implementation of decision support system for water quality management as it has been identified as one of the key factor in success.

This chapter describes the methodology that is being used to make this project complete and working well. How to use adopted technology explained in above chapter to solve the said problem

4.2 Method in brief

Athena aquaculture private establishment in Puttalam area, does intensive black tiger farming. Out of 60 ponds 30 to 40 active ponds are found in one culture. One culture period is 3 months approximately 120 days. Select 3 cultures from 2013 to 2015.2000 past recodes were found. There are around 60 employees from different levels of the company. Five field workers two from management, two officers in the office who is responsible for recording data and give necessary instructions to the field workers regarding the recommendations given by expert people in the field were interviewed focusing on current management practices mainly water quality, their feedback on current practices, farm infrastructure, ICT awareness of the system users and language skills. Two experts from the field also interviewed to understand the subject area. Observations including field visits and document review also conducted to analysis the situation farming site and operations as well as the surrounding environment.

Data set is divided in to two groups training set (1500) and test set (500).use data mining techniques clustering to process data and train the system clusters with similar record patterns grouped together. Develop smart phone application for remote data collection. Decision support system produces the solution and recommendations to the non-expert users. Use test set to test the system.

4.3 Back ground study

4.3.1 Analysis current practices

- **Document review**: Reviewing exiting documents helps to understand the type of data is being collected and what are available data. Paper based data collection forms and electronic form excel sheets were used here.2013 to 2015 data is available one culture period is 3 months
- **Observation**: 3 days on-Site visit to the shrimp farm. On site observation was very helpful to understand the activities, operations, processes and issues of the current situation.
- **Interview** helps to understand the end users view point of the system: Informal interview: with field workers, relevant officers. Formal interview with experts in the field and with the management. Experts helped to gain knowledge about the subject area and technical background. Management helped understand available resources and infrastructure facility.

4.3.2 Identified facts in current practices

NAQDA has advised all the farmers to collect water quality data's and keep records. Experts check those collected data provide decisions and recommendations. There are 60 pounds in the farm all the ponds do not operate for one culture 30 to 40 ponds are active in one culture.10 – 15 field workers are assigned to ponds. One field worker has to take care of 1 to 4 ponds. They collect water quality data using manual meters record them manually in a paper based format. After examining all the assigned ponds, field worker go back to the office hand over those papers to the officers in the main office. Officers use electronic format excel to store them.

Experts check those data sheets and give their decisions and recommendations for the current situation of the pond.

4.4 Planning and designing

The solution is designed based on identified facts.

Automated real time remote data collection system for field workers.

Decision support module to help non expert user's for their decision making process.

Automated reliable stable data storage to store data for future decision making process

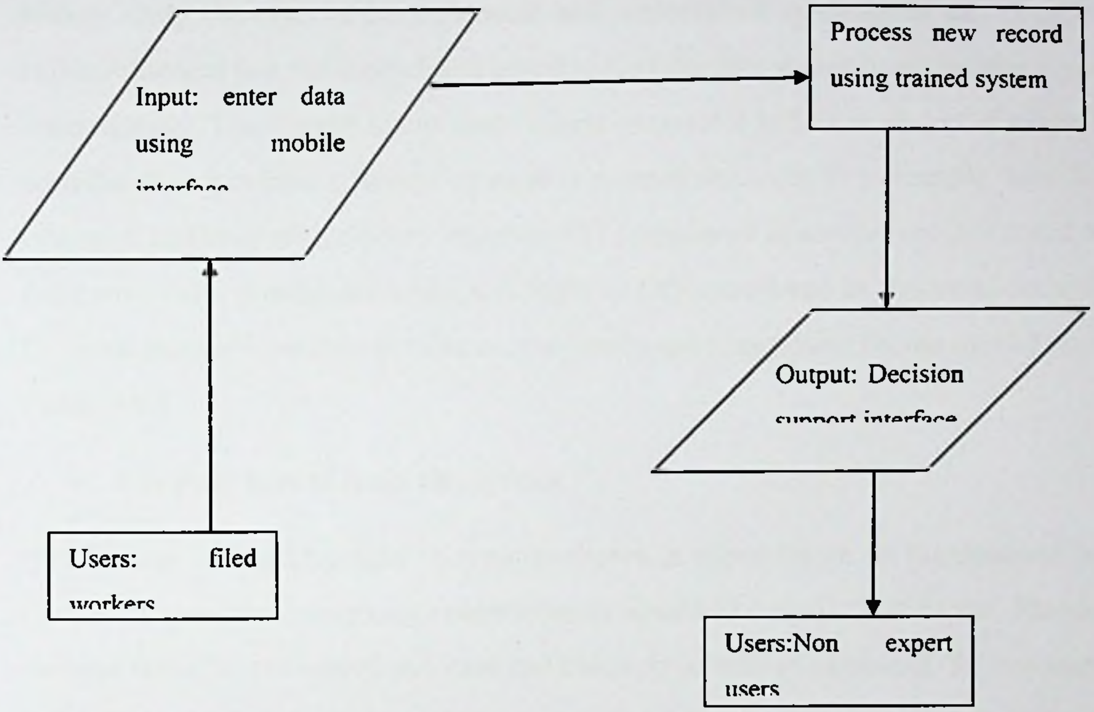


Figure 0.1 -Input output process and users

- **Automated real time remote data collection system for field workers**

Since infrastructure facility electricity and 4G signals are available in farm area. The smart phone application is the on-site data collector in this solution. That facilitates field workers to record parameter values and his observations. Parameter values are always numerical and Smartphone application has a scaling mechanism to convert observations into numerical form. For instance water color may change from light green to dark brown. Smartphone application converts this range to numerical range of 0 to 5 which light green represents by 0 and dark brown by 5. All readings are tagged with date and time, pond id and culture id. Data will be kept in temporary file until successfully transfer to main database through wireless data connection.

- **Decision support module to help non expert user's for their decision making process.**

According to the researches in the field, 7.5-8.5 pH, 4-6ppm Dissolved Oxygen, 24-34 C water temperature, 10-30ppt Salinity are the identical parameters of water in aquaculture shrimp pond. Other than said numerical figures, water color, water smell behavior of shrimp also give more sense to draw a picture about the pond.

Rough study on over 1,500 parameter and observation readings in last couple of cultures showed that static condition based judgments do not help to get an idea of pond water quality. There were many cases where parameter values were out of range but considered as a normal situation or slightly normal situation. For example there were couple of incidents where below 4ppm of DO considered as normal condition and also there were several incidents where 4-4.5ppm of DO considered as abnormal condition. Final conclusion is parameter value combinations are responsible for the overall statues of the pond.

- **Use past data to train the system**

At this stage a record has four sections as shown in above figure. In the database each record has identified using unique identifier as described early in this chapter. Proposed systems consider one record as a case and uniquely identified as case id. So that case id links with record id. Here the system starts with around 1,500 past complete records in 30 different ponds in same farm. When the system receives next record, it is a job of find identical or closely identical record among past data. To make the process more efficient and fast, system group similar records into different (clusters) groups based on similarity measure.

K-mean clustering has been used to group cases in this system. Before records enter to clustering, they have been normalized using Gaussian normalization techniques to improve efficiency of clustering. K-mean clustering algorithm partitioning n records into k number of clusters. It is always important to decide n records into how many clusters. Rule of Thumb is the technical used to decide k but will be replacing with one of information criteria approach (AIC or BIC) with likelihood function to get more accurate and random assignment for k.

Cases will be arranged into predefined k clusters. Here a vector represents a record as it hold multiple elements. Centroids element will be calculated per cluster which denotes the entire cluster. Here centroids record represents more identical record for its records. For instance a cluster does not contain mix of normal and abnormal conditions.

When the new record comes (here we consider 1501 record), it calculate the straight distance to each cluster centroid and determine the closest one. Then system consider state of the new record as same as the nearest centroid record's state.

4.5 Implementation

Build mobile app using *Xamarin's* cross-platform development software which build native apps for multiple platforms on a shared *C#* codebase.

Arrange 2000 data training set and 500 for testing set. Use 1500 data to train the system use c# to develop the training algorithm

4.6 Testing

- System testing: use 500 data set to test the system
- Functional testing
- User acceptance testing is done

4.7 Summary

Chapter has given explanation how technology used to solve the said problem. What are the steps used and what the order of solving them is?

Chapter 5

Design of Proposed System

5.1 Introduction

The previous chapter described the Decision support model using cluster analysis to identify and generate recommendations for shrimp pond water quality management. The presented approach runs from collecting data from field and generating recommendations based on past records. This section described how each component has been designed and integrated. The top level designed of the system gives an abstract view to the design phase while the other respective sections describe the each module in detail.

5.2 The top level architecture

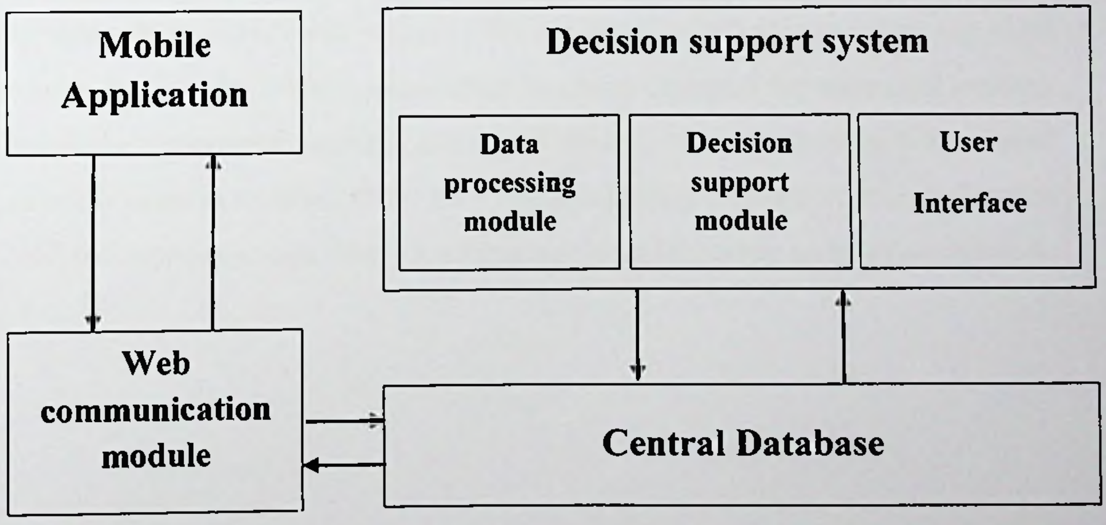


Figure 0.1 - Top level architecture of the proposed system

The top level architecture of the proposed system comprises of four main components, namely Decision Support System, Central Database, Mobile Application and Web Communication Module. These components are different from each other by their functions and technologies involved. Figure 5.1 shows the interaction among them.

Decision support system and central database are the two main components of the system. Apart from the database, main component consist of three modules, 'Data Processing Module', 'Decision Support Module' and 'User Interface'. Data Processing Module analyses past incidents, expert's decision and recommendation to build a source model that system used for generating recommendations for future incidents. Decision Support Module analyzes new records and generate decisions and recommendations based on the outcome of data processing module. User Interface is a graphical model which presents interfaces for users to interact with the system. Relational database holds both past and present data.

This solution addresses different type of users in two different ends. Said decision support system used by technical people with high literacy level and who are novice to shrimp aquaculture field. Field worker's literacy level is very low and they pay blind attention to the figures. Mobile Application has been designed for such field workers to transmit their parameter readings and observations to the system and get the overall picture of the pond in simplest form. Data communication between mobile application and database happen through Web Communication module using mobile data network.

5.3 Design of Mobile Application

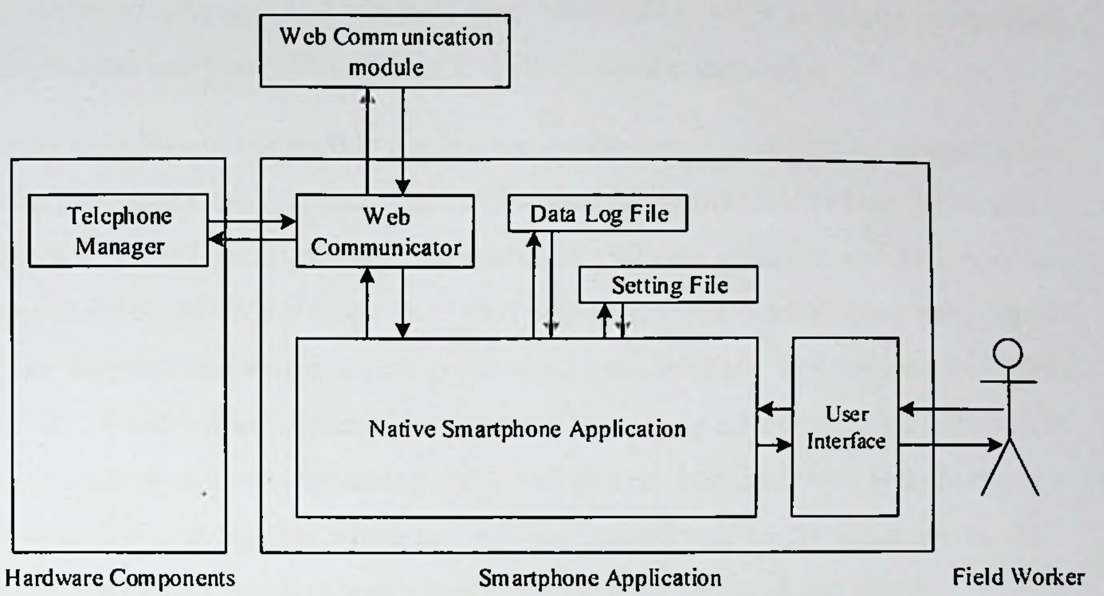


Figure 0.2 - The architecture of Mobile Application

Design of the Mobile application or the smartphone application has different hardware and software components as shown in Figure 5.2. The Smartphone application has been designed as a native application which has the capability of performing certain mandatory functionalities without any connection to main system.

User Interfaces have been kept as a separate module to accommodate changes as much as possible to make it more user friendly. Further all interfaces have been designed in three languages (English, Sinhalese and Tamil) to select by user's preference. 'Web Communicator' is a separate module running as a background service in the smartphone which is responsible for data communication between native application and Web server. When the application loads for the first time, it reads the 'Setting File' stored in internal storage and gets server side information. Basically it has the server address and connection duration. Then it passes that information to Web Communicator module and starts the service. Web Communicator module access the hardware interface of the smartphone and check the available outbound connectivity. If the device is out of the wifi coverage, it tries mobile data.. If both are not available service move to postpone status and wait for some time. This cycle will execute until a successful connection present. If any outbound connection is present, application sends device's IMEI number to server to check whether the device has been registered at the main system. Non registered devices will not allow to continue and only registered devices will allow users to login. As it described earlier, users with registered devices will allow to select their preferred language and use their user credentials to login to mobile application. Authenticated users have three things to do with mobile application.

Primary objective of the mobile application is effective data collection of pond water quality parameters and user observations. The option "Water Quality Data" allows field workers to record pond pH, DO, Temperature, Salinity readings and his important observations Smell, Water Color and Wind with respective pond id. User enter data to the user interface and native system get the data from interface layer and store in "Data Log File". Field worker can carry on his work inspecting different ponds. Meanwhile Web Communicator service running in the background checks whether is there any new record available in log file which has not been transferred to the main server. Such records will be transferred to web server combine with device id and user id.

Field workers pay their blind attention to water quality parameter reading. Most of them have no understanding of these figures and acceptable ranges. "Pond Condition" is the second option provided by the mobile application which categories ponds into three risk levels based on overall decision made by main system based on field readings. For instance dissolved oxygen reading of pond number 10 is 3.2 which is very low and need immediate treatments. Field worker just enter his DO reading as 3.2 and move to the next pond. Once the record is transmitted to main system, it analyses the record and mark pond number 10 has a critical issue and need immediate attention. Same time web server communicates the message to mobile devices in the field and alert field workers pond number 10 has a problem. Likewise mobile application highlight healthy ponds in Green, ponds need attention in Yellow and ponds in critical condition in Red colors. This makes field workers aware with present situation of ponds.

"Incident Data" is the third option. Main system generates recommendations and treatments for non-healthy ponds. Field workers can see non-healthy ponds in second option and see the treatments under third options. For instance in above scenario, recommendations could be, increase number of paddle wheels, use oxygen powder, etc.

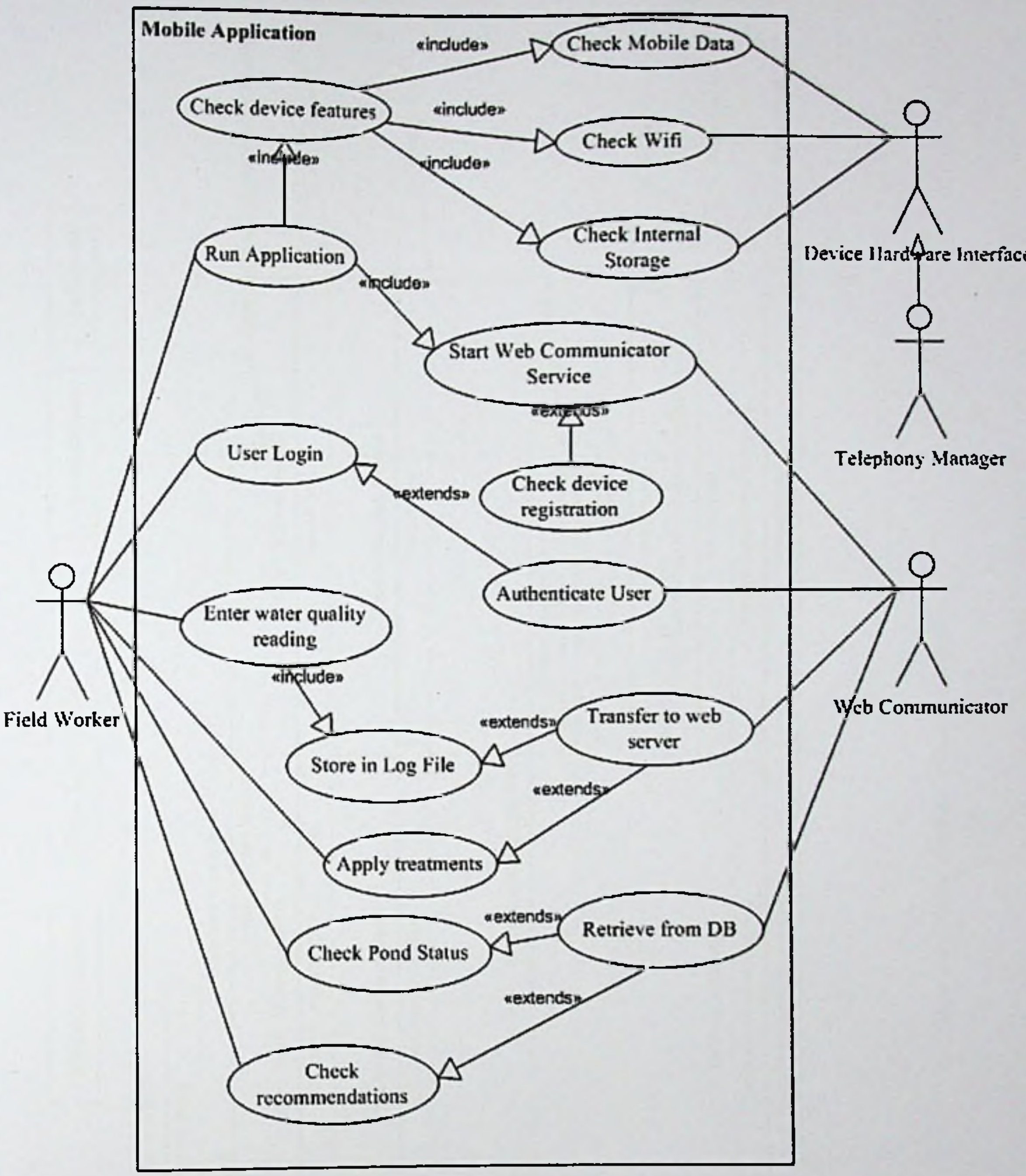


Figure 0.3 - Mobile Application Use Case Diagram

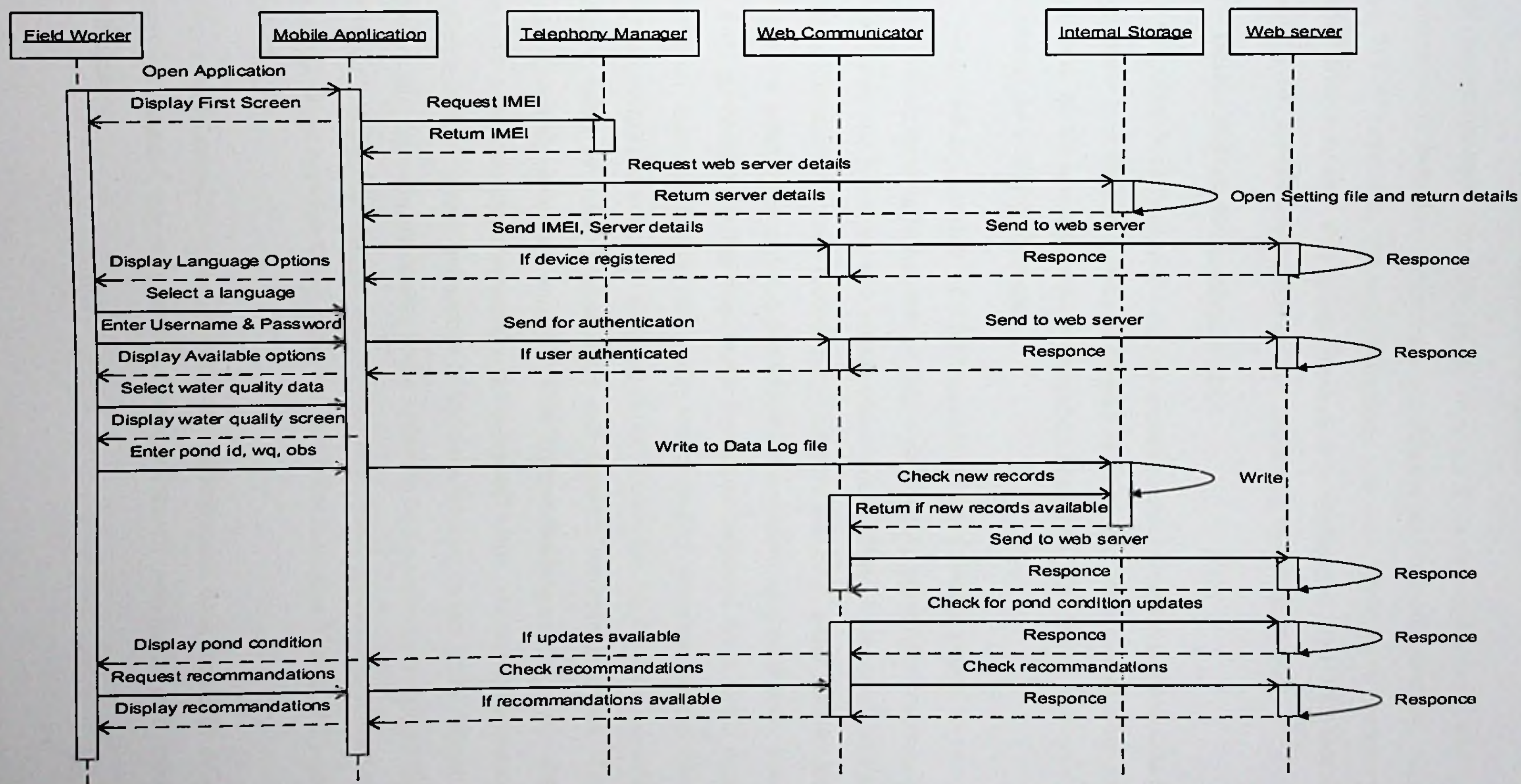


Figure 0.4 - Mobile Application Sequence Diagram

5.4 Design of Web Communication Module

Web communication module is a non GUI web application which initiate communication between smartphone application and system database. Smartphone sends HTTP request to the web application and web application generate database queries. Retrieved data will be passing to mobile application via HTTP responds. This module avoid mobile application directly accessing system database.

5.5 Design of Data Processing Module

As it described in early chapters, data processing module applies k-mean data clustering mechanism to understand patterns of past records and their relationship to expert's comments. As the whole process is depend on available data, design of this module first considered the available data set.

Available data set consists of 1,520 records of 33 different ponds in two different cultures. Each data tuple consists of four water quality parameter readings (pH, DO, Temperature and Salinity), two human observations (Pond water smell and color) and expert's comment for each record. Record's date and time, pond number and culture number are some other additional information available on data sheets. According to the facts gathered from the field and information collected form fields experts, it is understood that previously said four water quality parameters and two human observations are the source for deriving expert's outcome. So the data clustering should basically focus of those 6 parameters and expert's recommendations. Turning the dataset into analyzable form was one of the biggest challenge faced in this stage. Other than four water quality parameters in the datasheet were in string form contains one or couple of words. 'Smell' parameter in the data set had values from 'Slight Smell' to 'Smelly' and the color parameter had a variation of 5 values from 'Slight light green' to 'Brown'. Before the data go into the database, Smell and color parameters turned to numerical range between 0 and 5 where 0 holds the least and 5 holds the highest value. Figure 5.5

Expert's recommendations are the other most important data stored in string format. Expert's comment has two things. Pond's overall condition and recommended treatments.

Date	Pond Number	Culture Number	pH (7.5-8.5)	Dissolve Oxygen (DO)/ppm(4-6)	Temperature °C (24-34)	Salinity / ppt (10-30)	Smell	Color
2014-09-19 06:00:00	3	1402	8.4	7.6	31.2	13	No Smell	Light Green
2014-09-19 06:00:00	4	1402	8.5	7.2	31.2	13	Slight Smell	Light Green
2014-09-19 06:00:00	5	1402	8.6	7.0	31.2	13	No Smell	Slight Light Green

Continue as numeric — Convert to numeric

Figure 0.5 - Raw dataset parameter figures

In the dataset pond's overall condition has been categories in to three categories namely 'Good Condition', 'Need attention' and 'Need Immediate attention'. 'Need attention' and 'Need immediate attention' categories have top priorities and more recommended treatments. Ponds in Good conditions have no such recommendations. There categories can be separately considered when analyzing data. 'Water Condition' and 'Expected Growth' are two things remain as string. In last two cultures expert has given combinations of seven different treatments for different situations. Each treatment has considered as one entity in data processing. Figure 5.6

Date	Pond Number	Expert's comment
2014-09-19 06:00:00	3	Condition good, water quality good, growth normal, full feed, pwd4, pwn4
2014-09-19 06:00:00	8	Need attention, water getting basic, less growth, limited feed, pwd6, pwn6, probiotic, oxygen powder
2014-09-19 06:00:00	40	Need attention, water not clear, less growth, stop feed, pwd6, pwn8, remove seaweeds

Convert to separate fields

(Separate fields for each treatment)

Figure 0.6 - Raw dataset expert's comments

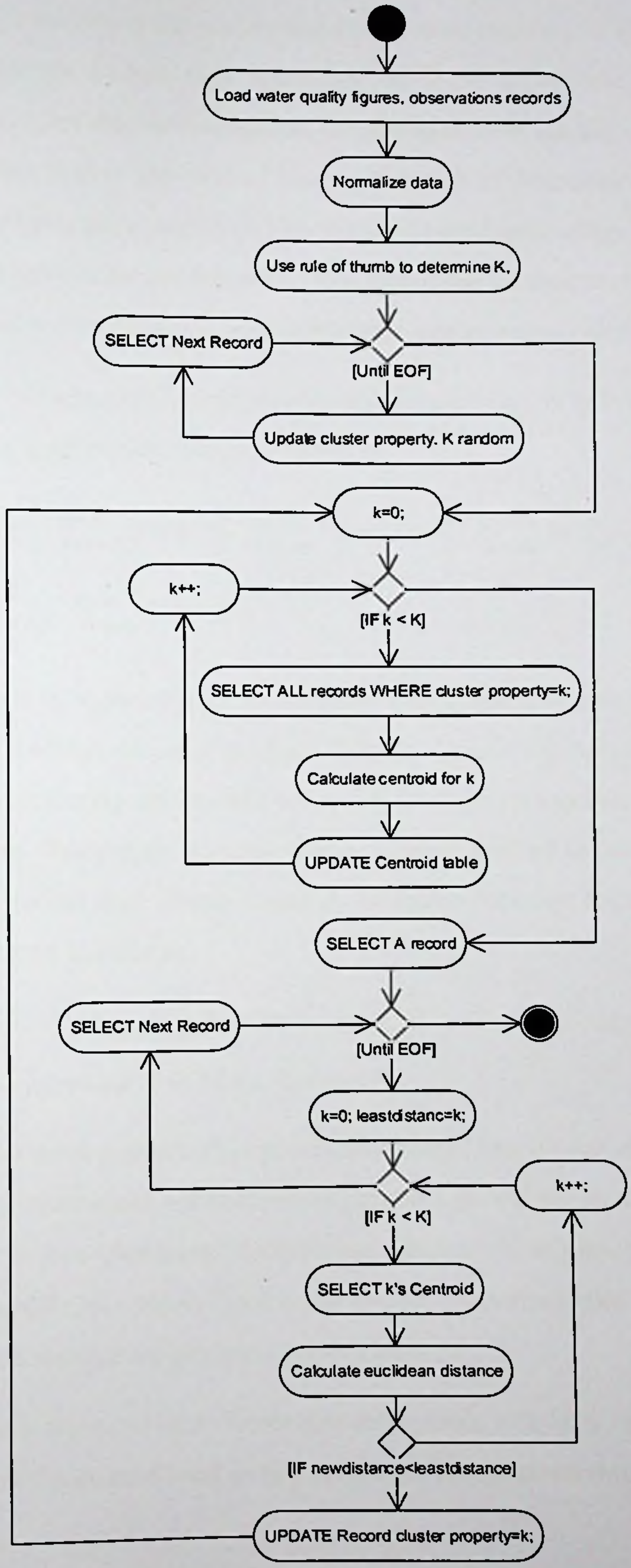


Figure 0.7 - Activity Diagram of data processing module

The clustering process uses water quality and observation records. As these parameter values are in different ranges, data normalization to be done before starting the clustering process. After data normalization, clustering need to initially assign number of clusters so in this project uses rule of thumb algorithm to determine initial number of clusters. Then all available records (1,520) should be randomly assign to clusters and clusters with zero records are not possible. Each record has an unique record identifier and cluster properties are updated in a separate table against record identifier.

Now each cluster has some amount of records and the next step is to find centroids for initial clusters. For each cluster, cluster centroid is

$$\{(\tfrac{1}{n}.\sum_{i=0}^{n} pHi), (\tfrac{1}{n}.\sum_{i=0}^{n} DOi), (\tfrac{1}{n}.\sum_{i=0}^{n} Tempi), (\tfrac{1}{n}.\sum_{i=0}^{n} Sali),$$

$$(\tfrac{1}{n}.\sum_{i=0}^{n} Smelli), (\tfrac{1}{n}.\sum_{i=0}^{n} Colori)\}$$

Centroid are stored in separate table in database with respective cluster id. Now all records with initial cluster ids need to check distance against cluster centroids to find nearest cluster. In clustering records with more similarity group together and they stand close to each other. This project uses Euclidean distance method to calculate distance between original record and cluster centroid. Distance between record and cluster centroid can be shown as follows

$$\text{Distance(rec, cen)} = \sqrt{}(pH_{rec}-pH_{cen})^2 + (DO_{rec}-DO_{cen})^2 + (Temp_{rec}-Temp_{cen})^2 + (Sal_{rec}-Sal_{cen})^2 + (Smell_{rec}-Smell_{cen})^2 + (Color_{rec}-Color_{cen})^2$$

If any record find a nearest cluster than previously assign, that cluster id should update in cluster property column and whole clustering process should restart from calculating centroids for all clusters. Clustering process stops when no further assignments and no cluster property update take place. Final set of cluster centroids stored in the database will be used in next module for grouping present records.

Clustering process is done and each cluster contains records with high similarity factors. Cross validation is the method used in this project to ensure clustering has been done properly.

Cross validation has to be done using set of different fields that has not been used for clustering. In this project none of the water quality parameters and observations can be taken for cross validation. Most suitable data parameters could be 'Overall Status' and 'Water Condition' figures which give more meaning to the record. For example one cluster cannot contain data records which holds the overall status of 'Good' and 'Need immediate attention' because water quality parameter readings and observations for Good condition and Need immediate attention are two different and cannot contain in one cluster. Since the clustering is not 100% accurate, there can be such erroneous records but such incidents should be a minimum percentage. If the cross validation is not acceptable range, that's mean clustering is not successful. In such cases clustering should be re-execute by giving different values to initial K. This solution initially assign value to K using rule of thumb method and if the error rate is not in acceptable range, it increases or decreases K by one and re-execute clustering and see the error rate. Likewise it changes the K value and re-execute clustering until the cross validation is come to acceptable range.

Cluster ID	pH (7.5-8.5)	Dissolve Oxygen (DO)/ppm(4-6)	Temperature °C (24-34)	Salinity / ppt (10-30)	Smell	Color	Overall Status	Water condition
3	8.8	4.9	30.4	12	0	2	1	Less aeration
3	8.8	4.7	29.7	15	0	2	1	Less aeration
3	8.8	4.6	28.1	13	0	2	1	Less aeration
3	8.8	5.1	29.1	13	0	2	0	Good
3	8.7	4.5	29.1	16	0	2	1	Less aeration
3	8.7	4.5	29.1	16	0	2	1	Less aeration
3	8.8	4.5	29.0	17	0	2	1	Less aeration
3	8.8	4.8	29.2	16	0	2	1	Less aeration
3	8.8	4.9	29.1	16	0	2	1	Less aeration
3	8.8	4.5	29.5	18	0	2	1	Less aeration

All records belong to same cluster

Cluster 3

Most of the records have similar values

Record 4 has different status and water condition. Record 4 should not be a member of cluster 3

9 out of 10 records have same overall and water quality. Similarity is 90%

Cluster 3's overall status is 3 and water quality is 'Less aeration'

Figure 0.8 - Clustering cross validation

5.6 Design of Decision Support Module

Data processing module processed past records and found that data belongs to how many different clusters. Centroids were stored in database to represent each cluster.

Decision support module uses stored centroids to analyze present records and find their behaviors.

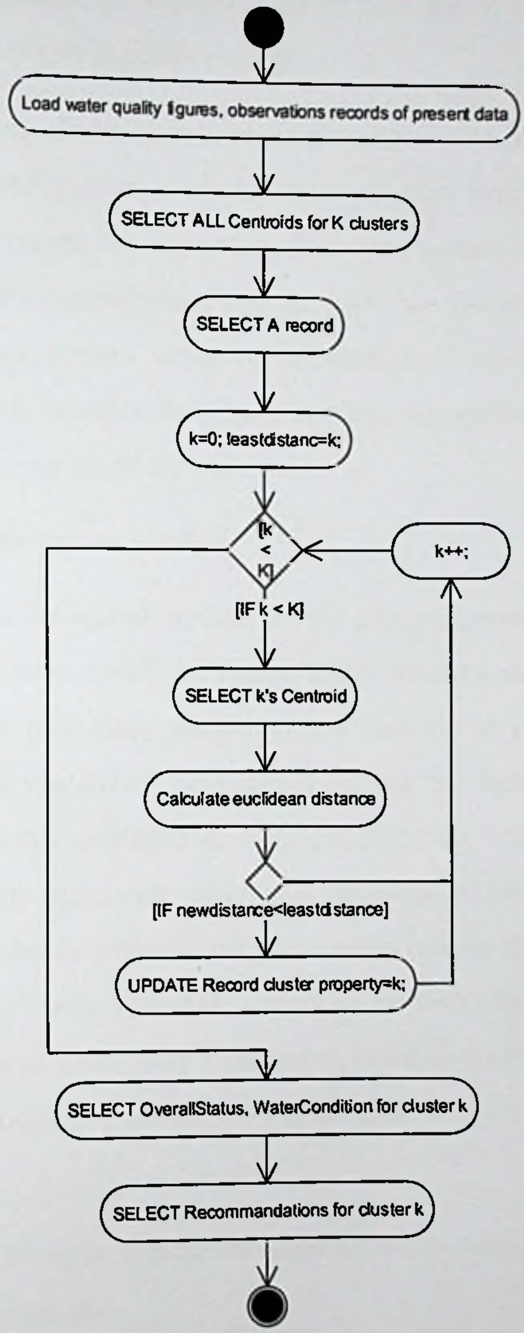


Figure 0.9 – Activity Diagram of Decision Support Module

When a new record comes from mobile application to database, decision support module calculate Euclidean distance between new record and all available cluster centroids to find nearest cluster. During the past data processing stage, system identify longest possible distance of past records. (As all past records were verified by expert)

Decision support module ignore new records have longer distance than longest possible distance in past records. For example maximum distance found in past records is 4.99932 and nearest distance to closest cluster of new record would be 20.5. System ignore such records as unrecognizable records.

As it describe earlier one cluster should contain a single overall status and pond water condition. Also a cluster contains a single set of solution with recovery time period. Once it identified new record belongs to which cluster, system refers its overall status, water condition and recommendations and pass to User interface module to display user. At the same time system sends recommendations to mobile application by expecting their respond, whether they have applied the solution, at what time they applied, etc to see the progress of the solution.

5.7 Design of User Interface Module

User interfaces of decision support system are for administration purposes, for the use of non-expert users to interact with the system and for testing purposes. For the testing purposes clustering of past data, assigning new records to clusters by calculating distance function have visualized. Non-expert user or the technical people have the facility of checking records coming from mobile application. Also they have the facility of entering water quality parameter values and observations directly to the system for analyzing. System has design a dashboard where users can see the overall status of each pond in highly graphical form. That makes users aware with ongoing problems of farm. System displays status of each pond considering latest available record. Also system displays recommendations for non-healthy situations with estimated time frame for recovery.

Authorized users can use main system for administration purposes like creating users, registering mobile devices, etc.

5.8 Design of System Database

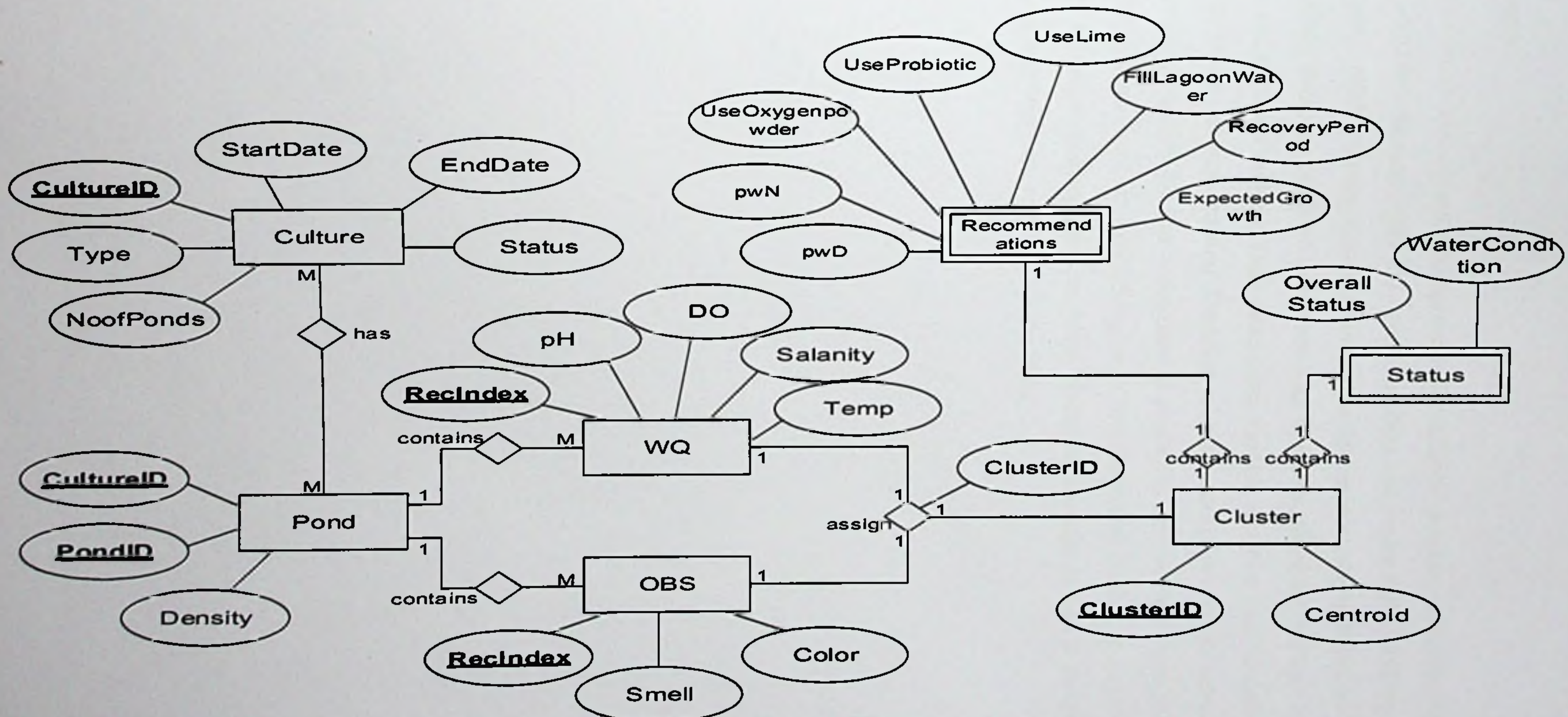


Figure 0.10 - Entity Relationship Diagram

5.9 Summary

Design of this system has four main components for different purposes. Mobile Application component helps to real time, efficient data collection and make field workers aware of pond conditions. Web communication module bridge mobile application with system database. System database holds all necessary data in a structure way that can be used for fast analysis and decision making. Data processing module analyses past records an build a structure for future decision making. Decision making module works on structure build by data processing module by analyzing present scenarios and putting them into correct groups. Identifying new records, identifying pond condition and issuing recommendations are duties of decision making module. User Interface module brings a dashboard for everybody to get a clear picture of the whole farm.

Chapter 6

System Implementation

6.1 Introduction

The previous chapter described the system design of the proposed solution in detail. Design has four main components, each component has different module to be implemented by using suitable technologies. This chapter describes how available software and hardware technologies used for the implementation. Respective sections describe how each module described in design chapter are implemented.

6.2 Implementation of Smartphone Application

Design phase of the project decided to implement mobile application for field workers to collect data and immediately update main system from field. The implementation of the solution need to look into available and feasible options. Since field workers go 2 – 3 Km away from main office there should be a mechanism to transfer data. Currently Puttalam district is covered by many cellular operators so data transfer over mobile network is possible. It is understood that most feasible option is the Android platform due to initial investment for the devices and familiarity of people. This project has a light weight design. So basic requirements for hardware device are,

- Android 4.1 or higher version (API17)
- 4" touch screen display
- 512MB RAM
- 50MB fee space in internal storage
- Mobile data connectivity

So any basic Android device can install data collector application.

There are various technologies available for android native application developments. This project selected C# mobile application development technologies with Xamarin frame work due to several reasons.

- Cross platform support.
- Use Native API.
- Starter version is free of charge and it has all necessary features for this implementation.
- Xamarin provide test could which has thousands of virtual devices.

Mobile application has been designed to have all its interfaces in three languages to select field workers by their preference. Development of the application has divided interfaces into three layers and load one layer at a time. If the field worker select his preferred language as Sinhalese, only Sinhalese layer will load in memory. All interfaces are implemented in Unicode compatible form so any special font installations are not required.

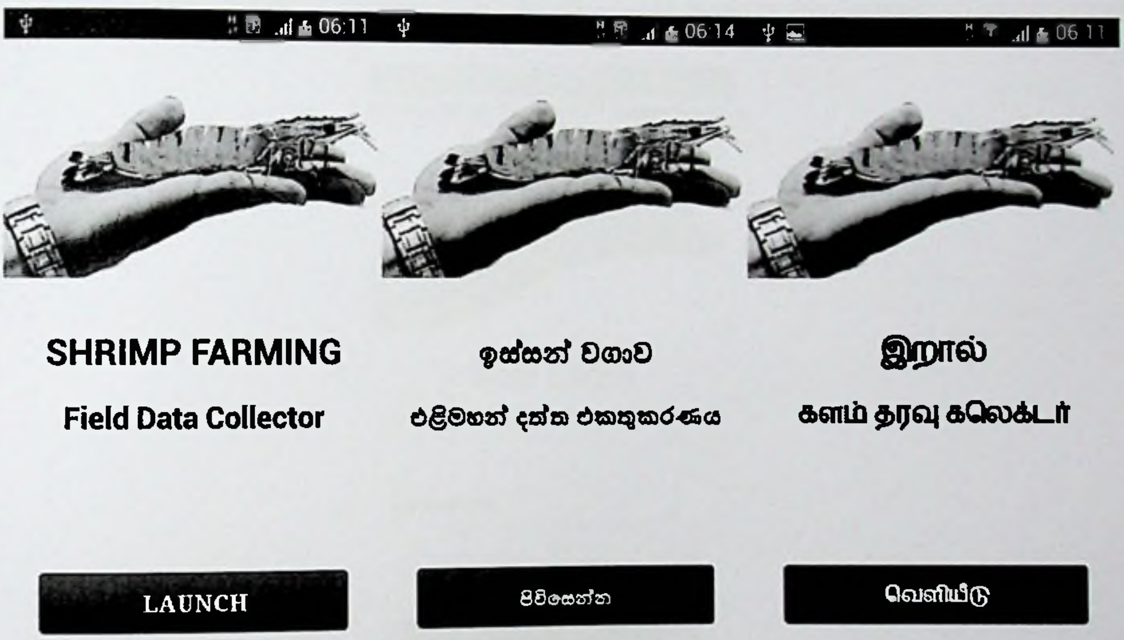


Figure 0.1 – Mobile Application first screen

Figure 6.1 shows the welcome screen and the language selector of the mobile application. All three screen rotates with 5 second intervals. Users have to press the button to continue with their preferred language.

Soon after user select the language, system call a separate class called 'Webcommunicator' which is the 'Web Communication module' in design. Main class read data from

'Settinfile' and send server information to Webcommunicator class. Then Webcommunicator send a request the see webserver is available, database server is available and the device IMEI is registered at the database.

http://serveripaddress/shrimpfarm/androidResponder.php,10000,10000

Webserver php page url, server time out, retry interval

Figure 0.2 - Mobile Application server path

http://serveripaddress/shrimpfarm/androidResponder.php?command=getIMEI&imei=35 5884059449965

Figure 0.3 - Mobile Application verify device registration

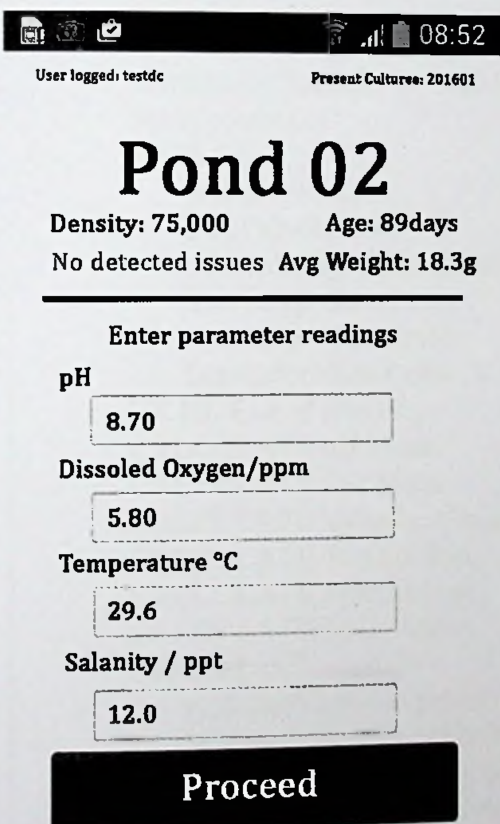
Once device registration is verified users are allowed to login to the system

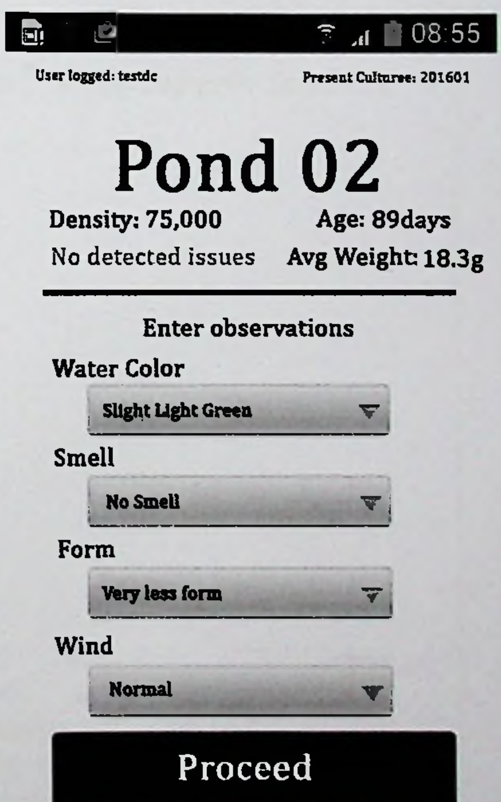
Figure 0.4 - Mobile Application user login

Authenticated users are allowed access three options. "Pond Condition" shows the overall status of all pods for field workers to know which ponds need their attention. "Water Quality Data" and "Incident Data" options are more specific to a pond. Field workers use "Water Quality Data" option to enter daily water quality parameter readings and his observations. "Incident Data" option will be used by field worker when they apply recommended solution suggested by system.

Sample record entry

Pond No	:	02
pH	:	8.70
Dissolved Oxygen	:	5.80
Temperature	:	29.6
Salanity	:	12.6
Smell	:	No Smell
Color	:	Slight Light Green
Form	:	Very Less Form
Wind	:	Normal





6.3 Implementation of Data processing Module

As it described in design chapter, Implementation of data processing module is the implementation of K-mean clustering for past records. Here it applies clustering for pH, DO, Temperature, Salinity, Smell and Color parameter and keep overall status and water condition for cross validation. This system has been developed using C# desktop application development technologies which has more features for data analysis.

System loads past records stored in Para_Water and Para_Obs tables in the data base. Since data in different ranges first system execute Gaussian Normalization to bring all data filed into a common range.

Gaussian Normalization

```
 LOAD Data from Database
SumpH=0; SumDO=0; SumSalanity=0; SumTemp=0; SumSmell=0;
SumColor=0;
REPEAT
    SumpH=Rec.pH
    SumDO=Rec.DO
    SumSalanity=Rec.Salanity
    SumTemp=Rec.Temp
    SumSmell=Rec.Smell
    SumColor=Rec.Color
UNTIL End of Record
CALCULATE pH.Mean
CALCULATE DO.Mean
CALCULATE Salanity.Mean
CALCULATE Temp.Mean
CALCULATE Smell.Mean
CALCULATE Color.Mean
REPEAT
    pHSum=Sqrt(Rec.pH-pH.Mean)
    DOSum= Sqrt(Rec.DO-DO.Mean)
    SalanitySum= Sqrt(Rec.Salanity-Salanity.Mean)
    TempSum= Sqrt(Rec.Temp-Temp.Mean)
    SmellSum= Sqrt(Rec.Smell-Smell.Mean)
    ColorSum= Sqrt(Rec.Color-Color.Mean)
UNTIL End of Record
```

Figure 0.5 – Pseudo code - Gaussian Normalization

Gaussian Normalization Cont.

```
        REPEAT
        NorpH=pHSum/RecordCount
NorDO=DOSum/RecordCount
        NorSalanity=SalanitySum/RecordCount
        NorTemp=TempSum/RecordCount
        NorSmell=SmellSum/RecordCount
        NorColor=ColorSum/RecordCount
UNTIL End of Record
```

K-Mean Clustering

```
         LOAD NormalizedData Set
        DETERMINE K Using Rule Of Thumb Method
        REPEAT
             ASSIGN ClusterProperty to NormalizedData K.Random
        UNTIL End of Record
        REPEAT
             REPEAT
                   sumpH=sumpH+Rec.pH
                   sumDO=sumDO+Rec.DO
                   sumSalanity=sumSalanity+Rec.Salanity
                   sumTemp=sumTemp+Rec.Temp
                   sumSmell=sumSmell+Rec.Smell
                   sumColor=sumColor+Rec.Color
             UNTIL End of Record
                 CENTROID={sumpH/RecCount, sumDO/RecCount,
                 sumSalanity/RecCount, sumTemp/RecCount,
                 sumSmell/RecCount, sumColor/RecCount }
        UNTIL End of Clusters
        REPEAT
             REPEAT
                   EUCLIDEAN DISTANCE Sqrt(RecPoint^2-CentPoint^2)
             UNTIL End of Clusters
             IF newKdistance<initialKdistance THEN
                   UPDATE Cluster Property
                   GENERATE Centroids again
             ELSE
```

```
K-Mean Clustering Cont.

        EXIT LOOP
        END IF
    UNTIL End of Record
      RUN Cross validation
      IF Error rate >10% THEN
        REPEAT
            K=K+1
            RUN Clustering process again
        UNTIL Error rate <10%
      END IF
```

Figure 0.6 - Pseudo code - K-mean clustering

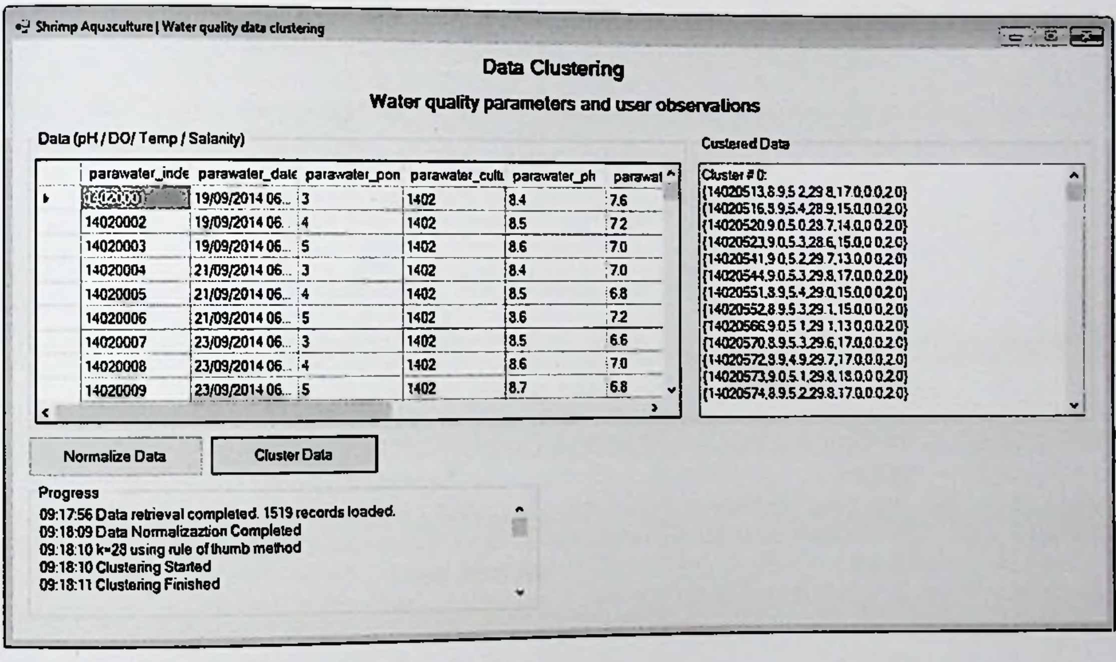


Figure 0.7 - System interface of data clustering

1,519 records loaded to data processing module from database. Normalization has been done using Gaussian method. Number of cluster determine by rule of thumb method is 28 for 1,519 records. The cross validation results is 97.73%.

Progress
09:18:11 25 1 High temperature 100
09:18:11 26 2 Water basic 98.48
09:18:11 27 0 Good 98.15
09:18:12 Cross validation Done
09:18:12 Overall clustering accuracy 97.73

Figure 0.8 - Cross validation result

Finalized cluster records are stored in Cluster_centroid table and cluster status are stored in Cluster_Status table. Recommendation are stored in Cluster_Recommandations table. Each cluster contains unique set of recommendation combinations.

clusterID	ph	do	temp	salanity	smell	color
0	8.9	5.0	29.3	15.0	0	2
1	8.0	6.0	29.9	9.3	0	2
2	8.5	7.1	30.3	11.5	0	1
3	8.7	4.8	29.2	14.5	0	2
4	8.8	7.1	31.2	11.0	0	2
5	9.2	6.9	29.6	11.6	0	2

Figure 0.9 – Finalized Cluster centroid (Cluster 1-5)

clusterID	clusterStatus	clusterWQCondition	clusterRecSimilarity
0	1	Water getting basic	96.39
1	0	Good	96.08
2	0	Good	92.50
3	1	Less aeration	95.24
4	1	Less aeration	97.62
5	2	Water basic	98.75

Figure 0.10 - Finalized cluster status (Cluster 1-5)

Cluster_id	expectgrowth	feeding	recoveryperiod	pwday	pwnight	useprobiotic	useoxygenpowder	uselime	removeseaweeds	addlagoonwater
0	Drop	50%	36	4	6	1				
1	Normal	100%		4	6					
2	Normal	100%		6	8					
3	Drop	75%	48	6	6					
4	Drop	50%	48	6	8					

Figure 0.11 - Finalized cluster recommendation (Cluster1-5)

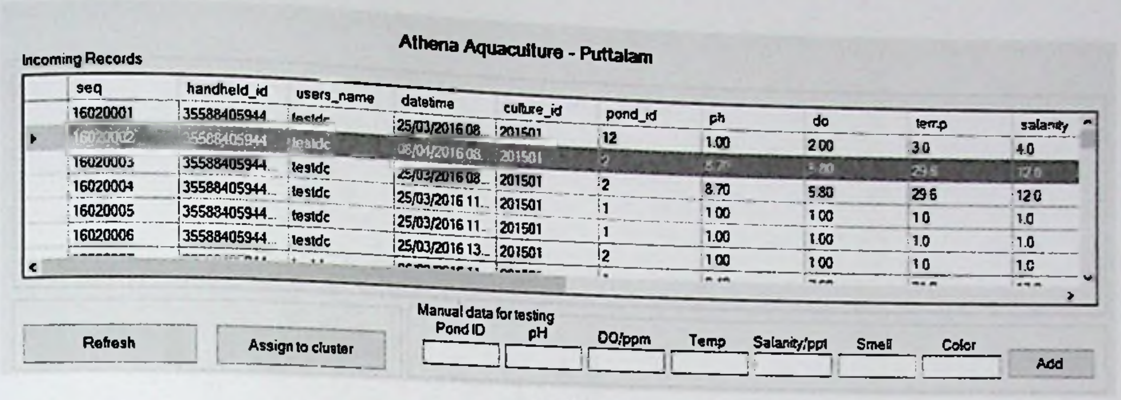
6.4 Implementation of Decision Support Module

Decision support module deals with present records coming to database from mobile application or direct inputs through main system. When a new record comes, system loads previously finalized centroid data from database and calculate Euclidean distance function against all available clusters to find the nearest cluster. Then system issues status and recommendations related to that cluster with recovery period. If the particular pond recovered within recovery period, system evaluate its decision as a correct decision and add water quality, observation and system generated decision to past data. When the next time data processing module process data, it has extra one record. Likewise past data set keep on growing with the time.

K-Mean Clustering for new data

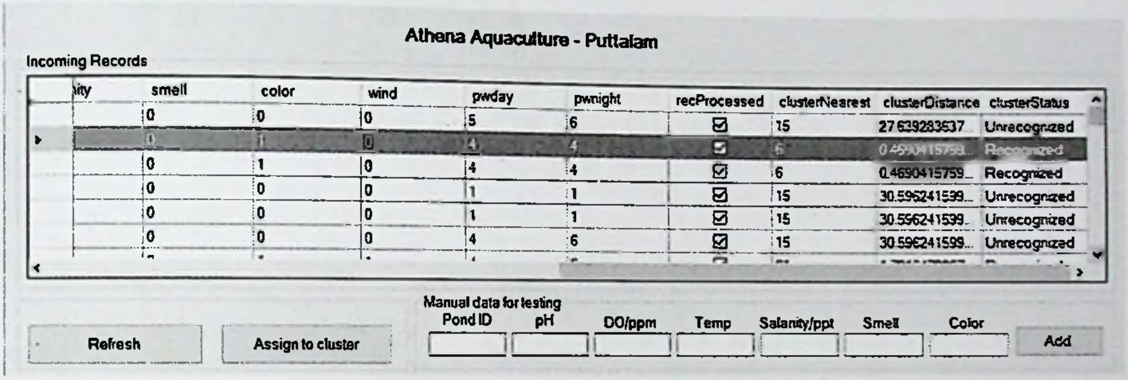
```
LOAD NewRecord
LOAD All Centroids
REPEAT
    EUCLIDEAN DISTANCE Sqrt(NewRecPoint^2-CentPoint^2)
    UNTIL End of Clusters
    IF newKdistance<previousKdistance THEN
        UPDATE Cluster Property K
    END IF
UNTIL End of Clusters
LOAD Status, water condition and recommendations of K
DISPLAY Status and Water Condition to user
DISPLAY Recommendations to user
WAIT UNTIL User apply recommendations
WAIT UNTIL Recovery period finishes
IF Pond back to Normal condition THEN
    RATE Systems recommendation as success
    ADD to Past records
END IF
```

Figure 0.12 - Pseudo code - Cluster new records



	seq	handheld_id	users_name	datetime	culture_id	pond_id	ph	do	temp	salanity
	16020001	35588405944	testdc	25/03/2016 08...	201501	12	1.00	2.00	3.0	4.0
▸	16020002	35588405944	testdc	08/04/2016 08...	201501	2	8.70	5.80	29.6	12.0
	16020003	35588405944...	testdc	25/03/2016 08...	201501	2	8.70	5.80	29.6	12.0
	16020004	35588405944...	testdc	25/03/2016 11...	201501	1	1.00	1.00	1.0	1.0
	16020005	35588405944...	testdc	25/03/2016 11...	201501	1	1.00	1.00	1.0	1.0
	16020006	35588405944...	testdc	25/03/2016 13...	201501	2	1.00	1.00	1.0	1.0

Highlighted record is the test records entered from mobile device



	...ity	smell	color	wind	pwday	pwnight	recProcessed	clusterNearest	clusterDistance	clusterStatus
		0	0	0	5	6	☑	15	27.639283537...	Unrecognized
▸		0	1	0	4	4	☑	6	0.4690415759...	Recognized
		0	1	0	4	4	☑	6	0.4690415759...	Recognized
		0	0	0	1	1	☑	15	30.596241599...	Unrecognized
		0	0	0	1	1	☑	15	30.596241599...	Unrecognized
		0	0	0	4	6	☑	15	30.596241599...	Unrecognized

The record has recognize as a valid record and assigned to cluster 6. Overall status is "Good", water condition is "Healthy" and system recommended to use 4 paddlewheels during the day and 6 paddlewheels during the night time.

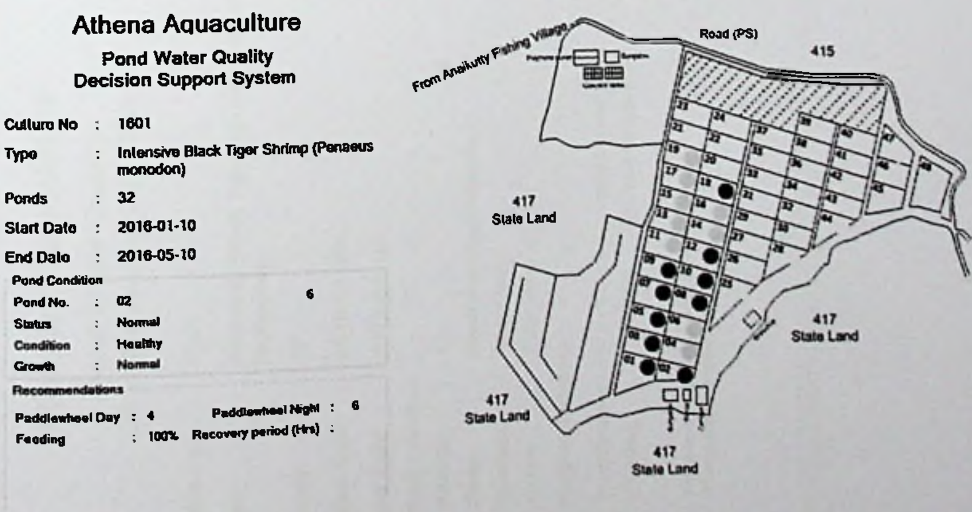


Figure 0.13 - Sample record analysis

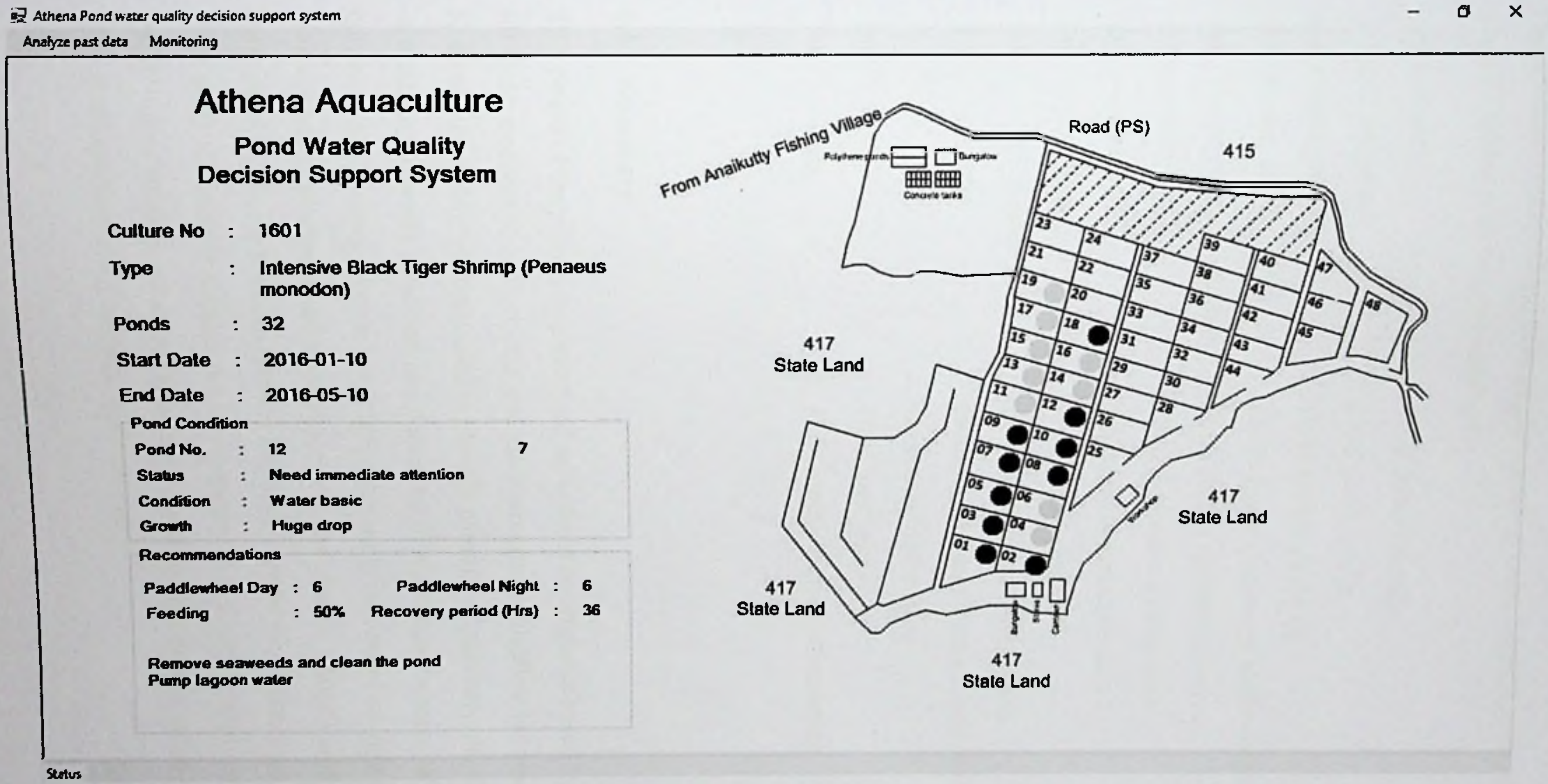


Figure 0.14 - System dashboard

6.5 Database Implementation

The relational database has been implemented by using MySQL technologies. Basically it has 13 tables with key relationships.

tbl_culture	:	Hold culture details
tbl_culture_pond	:	Hold pond details
tbl_cluster_centroid	:	Hold cluster centroids
tbl_cluster_status	:	Hold cluster status and water condition
tbl_cluster_recommendation	:	Hold cluster recommendations
tbl_pastdata_wq	:	Hold past water quality data
tbl_pastdata_obs	:	Hold past observation data
tbl_pastdata_decision	:	Hold past decisions
tbl_pastdata_cluster	:	Hold past cluster information
tbl_presentdata	:	Hold present data from mobile or direct interface
tbl_users	:	Hold user information
tbl_userlevels	:	Hold user levels
tbl_handheld	:	Hold mobile device information

6.6 Summary

This phase of the project implemented an Android smartphone based mobile application for field workers to collect data and maintain communication between main systems. K-mean clustering has been used to identify patterns of past records. Each patter has an overall status, water condition and unique set of recommendations. When a new record comes to the system, system put it into relevant group based on distance function and give recommendation based on the facts in same cluster. Cross validation showed that data grouping using K-mean method has high accuracy in this scope. C# Xamarin has been used for mobile application development, C# desktop application development technologies used to establish K-mean clustering and finally relational database has been implemented using MySQL technologies.

Chapter 7

Evaluation

7.1 Introduction

The purpose of an evaluation is to assess the system to see if it does what it was supposed to do, that it is working well, and that everyone is happy with it. This section describes the evaluation of the solution using different techniques. Check whether the given solution is strong enough to meet all the objectives and all the algorithms and logics used to reach the solution are accurate. System evaluation with users also described here.

7.2 Clustering algorithm evaluation

Clustering evaluation demands an independent and reliable measure for the assessment and comparison of clustering experiments and results. In this project, evaluation is done manually with experts as well as automatically.

Effectiveness and accuracy of the clustering algorithm evaluated using cross validation.1519 records (cases) are available for training.

One case contains

Case ID	WQ	Observation	Status	Recommendations

WQ and Observation is used for clustering.

WQ	Observation

Expert's decision and recommendations are used of validation

Status	Recommendations

After clustering each and every case is belong to one cluster and assign cluster ID there

WQ	Observation	Cluster ID

Access expert's decision and recommendations using **Case ID** 90% of experts decision is map with clustered groups. Sample data sheet is attached in to the appendix section.

All relevant decisions and recommendations cross checked with experts manually. Request expert to check the case groups and give decisions and recommendations. Cross checks the answers with given solutions get 90% of accuracy.

Clustering efficiency checked with the time taken for clustering.

7.3 System Usability

Applications can be tested to determine the usefulness to a user's project needs [43] Observations, group discussions used to evaluate this section.

- **Evaluating the decision support interface**

There are ten system users for the system. Select two of them prepare dummy data set

Allow them to work with the system and collected feedback i.

- **Evaluating remote data collection using smart phone.**

Randomly selected sample group from the field workers contain three. Dummy data sets were given to the field workers in order to discover the ability of the field workers to complete important tasks with the application in real environment and collected feedback. Send data's from outside farm area to check offline data transferring accuracy.

7.4 Field test for signals

3G and Wi-Fi signal coverage, which can cause intermittent signal loss or very low transmission speeds is another important factor to evaluate. Three locations are identified in the field.

Location	3G	Wi-Fi
Pond 40	Strong	yes
Pond 19	Strong	yes
Pond 3	Low	yes

Table 0.1 - Field test for Wi-Fi signal and 3G coverage

7.5 Evaluation of an objectives.

Instrument used to evaluate the project objectives

Interview, group discussion and observations

7.6 Summary

Evaluation is needed to ensure whether the solution is appropriate to solve given problem whether all the stake holders are happy with the solution. This chapter described the evaluation methods and how those methods used to evaluate the solution

Chapter 8

Conclusion & Further work

8.1 Introduction

This project is to give solution to overcome some of the issues in a commercial shrimp farm which does Intensive shrimp farming in large scale. This section conclude the project describing the overall image how the given objectives are achieved as well as limitations of the project and recommending further work.

8.2 Overview

The success of a commercial aquaculture industry depends on providing the optimum environment for rapid growth at the minimum cost of resources and capital investment. One of the major advantages of intensive farming systems is the ability to manage the aquatic environment and critical water quality parameters to optimize fish health and growth rate.

Farming environment is complicated echo system contains number of parameters but researchers have identified some parameters as major role players. Most critical water quality parameters

Identified in this project is PH,DO,Water temperature and Salinity. Each individual parameter is important, but there is very strong interrelationship among them. Each water quality parameter interacts with and influences other parameters, sometimes in complex ways. Concentrations of any one parameter that would be harmless in one situation can be toxic in another situation.

Immediate attention is very critical in some cases and good subject related knowledge is a must to understand complicated situations and give the solutions. Therefore all the times experts help is very important in water quality management in shrimp farming. The one of identified major issues is lack of available expert knowledge. New system is introduced as real time decision support system to help non expert user's decision making process.

A decision support system can be introduced as a type of Expert System, which is simply a computer program or other means for capturing the knowledge of experts in a form that can be used by non-experts. One of the main challenges of designing DSS is easy-to-use and transparent. This means that a DSS must encompass a large range of process knowledge as well as data, but these forms of knowledge must be presented to the user in a form that can be easily understood because they are not familiar with subject.

As per the explanations given in the literature review many data mining techniques have been used in the field of an aquaculture. Clustering is one of the major branch of data mining. This system is based on popular clustering mechanism centroids based K-means clustering. Use past cases (water quality records) that are represented as combinations of parameters which affects the fish health and survival. Clustering helps grouping them, similar ones together. Train the system using past cases and link them with given experts solutions and recommendations. When the new case entered it will calculate the distance and assigned with cluster with the minimum distance. Relevant statues and recommendation is given by the system using user friendly GUI developed for non-expert users.

Another identified issue of the current practices is the inefficiency of manual data collection.Paper based data collection has been the standard method for decades but errors are frequent, storage costs are prohibitive, and the costs of double data entry are high. Electronic methods of data collection have been developed in order to merge the process of data collection and data entry. Wireless and mobile phone technologies have the potential to overcome some of these limitations. Use of mobile phones is widespread even in remote areas of rural Sri Lanka today.

All the records collected through smart phone application transferred central permanent storage device. This can be used to enhance decision making processing in future.

8.3 Project objectives

Objectives set to give the solution for the said issues

- Introduce a mechanism of reliable real time data collection.
- Introduce reliable data storage mechanism for future decision making.
- Introduce a automated method to identify problematic & non-problematic situations in pond water quality.
- Support non expert user for' real time decision making by giving suggestions and recommendation.

Smart phone based remote data collection tool, Decision support tool for non-experts, permanent data storage has fulfill the needs to achieve all the given objectives.

8.4 Limitations

- New recommendation or solution cannot be added to the system.

Decision support system was trained using 1500 past records which contains WQ, observations and statues and recommendations. The problem is scientists can find some new better solutions for said problems. Example if DO drops suddenly experts have recommended to increase number of paddle wheels and apply some amount of oxygen powder but if better solutions is introduced current system doesn't have enough capability to recommend new solution. Considerable amount of past records is needed to train the system.

- No method to add new field

New water quality parameter or new observation is identified as an important factor, no method to add them to the system.

Example if N2 identified as critical no available data to train the system

8.5 Further work

Daily records are added to the system and continue the clustering process. After around three years' time collecting large amount of data then further research can be done to identify patterns based on different months.

Early warning systems to the officials in the farm on the water quality conditions of the different ponds will helps immediate decision making. Example ssudden drop of one or more parameters can be indicate using alarm system for immediate attention.

There are field workers from different language back ground. Initial step trilingual interfaces developed using Unicode. English language implementation is already done. Sinhala and Tamil versions can be implemented further.

Deployment of smart phone application for remote data collection and decision support system for non-expert users potentially contributes to increase in farm production through better practices in farm management. ICT has become very powerful tool to solve issues in many areas including aquaculture. In Sri Lanka ICT involvement is still on ground level. This project will also contribute to bridge the gap between aquaculture industry and ICT.

8.6 Summary

Project conclusion is given in this chapter. Summary of the project limitations and the way project can be enhanced to make more effective for the decision making process.

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Appendix A – Data Sheets

A.1 Past data in original form

Date	Time	Pond Number	pH (7.5-8.5)	Dissolve Oxygen (DO)/ppm(4-6)	Temperature °C (24-34)	Salinity / ppt (10-30)	Smell	Color	Comment
19/09/2014	6:00:00 AM	3	8.4	7.6	31.2	13	No Smell	Clear Green	Good
19/09/2014	6:00:00 AM	4	8.5	7.2	31.2	13	No Smell	Clear Green	Condition Good, Growth normal
19/09/2014	6:00:00 AM	5	8.6	7.0	31.2	13	No Smell	Clear Green	Good
21/09/2014	6:00:00 AM	3	8.4	7.0	30.9	13	No Smell	Clear Green	Good
21/09/2014	6:00:00 AM	4	8.5	6.8	30.9	13	No Smell	Clear Green	Normal Condition
21/09/2014	6:00:00 AM	5	8.6	7.2	30.8	13	No Smell	Clear Green	Normal Condition
23/09/2014	6:00:00 AM	3	8.5	6.6	30.5	13	No Smell	Clear Green	Need more aeration, Growth drop
23/09/2014	6:00:00 AM	4	8.6	7.0	30.6	13	No Smell	Clear Green	Good
23/09/2014	6:00:00 AM	5	8.7	6.8	30.5	13	No Smell	Clear Green	Good
25/09/2014	6:00:00 AM	3	8.6	7.2	30.8	15	No Smell	Clear Green	Good
25/09/2014	6:00:00 AM	4	8.6	6.8	30.6	15	No Smell	Clear Green	Used probiotic acid 3 hrs
25/09/2014	6:00:00 AM	5	8.5	6.6	30.5	14	No Smell	Clear Green	Need more aeration, Growth drop
27/09/2014	6:00:00 AM	3	8.6	7.4	31.3	13	No Smell	Clear Green	Condition Good, Growth normal
27/09/2014	6:00:00 AM	4	8.6	7.6	31.3	13	No Smell	Slight Clear Green	Condition Good, Growth normal

A.2 Past data prepared for analyzing

Index	Date	Pond Number	Culture Number	pH (7.5-8.5)	Dissolve Oxygen (DO)/ppm(4-6)	Temperature °C (24-34)	Salinity / ppt (10-30)	Smell	Color
14020025	2014-10-05 06:00:00	3	1402	8.9	7.3	28.2	12	0	2
14020026	2014-10-05 06:00:00	4	1402	8.9	7.3	28.2	13	0	2
14020027	2014-10-05 06:00:00	5	1402	9.0	7.2	28.2	13	0	2
14020028	2014-10-07 06:00:00	3	1402	8.8	7.2	31.0	12	0	2
14020029	2014-10-07 06:00:00	4	1402	8.9	7.1	31.0	13	0	2
14020030	2014-10-07 06:00:00	5	1402	9.1	7.2	30.9	13	0	2
14020031	2014-10-09 06:00:00	3	1402	8.8	6.7	32.1	12	0	2
14020032	2014-10-09 06:00:00	4	1402	8.9	7.3	32.1	13	0	2
14020033	2014-10-09 06:00:00	5	1402	9.0	6.4	32.1	13	0	2
14020034	2014-10-09 06:00:00	30	1402	8.6	6.6	32.3	9	0	2
14020035	2014-10-09 06:00:00	31	1402	8.7	6.5	31.7	11	0	2
14020036	2014-10-09 06:00:00	32	1402	8.7	7.3	31.8	10	0	2
14020037	2014-10-09 06:00:00	33	1402	8.7	6.4	32.1	9	0	2
14020038	2014-10-09 06:00:00	34	1402	8.7	6.6	32.3	10	0	2

Index	Overall Status	Water condition	Expect Growth	Feeding	Recover period hrs	Paddel Wheels Day	Paddel Wheels night	Use Probiotic	Use Oxygen powder	Use Lime	Remove Seaweeds	Change water (Lagoon water)	Change water (Fresh water)	Sodium hydroxide (NaOH)	Calcium carbonate (CaCO3)	Dolomite
14020025	2	Water basic	Drop	60%	48	8	8	1								
14020026	2	Water basic	Drop	60%	48	8	8	1								
14020027	2	Water basic	Drop	60%	48	8	8	1								
14020028	1	Less aeration	Drop	50%	48	6	6									
14020029	1	Less aeration	Drop	50%	48	6	6									
14020030	2	Water getting basic	Huge drop	50%	48	6	6	1								
14020031	1	Less aeration	Drop	50%	48	6	6									
14020032	1	Less aeration	Drop	50%	48	6	6									
14020033	2	Water basic	Drop	25%	24	8	8			1						
14020034	1	Water getting basic, high temperature	Normal	100%	48	8	8									
14020035	1	Water getting basic, high temperature	Normal	100%	48	8	8									
14020036	1	Less aeration	Drop	50%	48	6	6									
14020037	1	Water getting basic, high temperature	Normal	100%	48	8	8									
14020038	1	Water getting basic, high temperature	Normal	100%	48	8	8									

A.3 Clustered data set

Index	Date	Pond Number	Culture Number	pH (7.5-8.5)	Dissolve Oxygen (DO)/ppm(4-6)	Tempemture °C (24-34)	Salinity / ppt (10-30)	Smell	Color	Cluster ID
14020025	2014-10-05 06:00:00	3	1402	8.9	7.3	28.2	12	0	2	26
14020026	2014-10-05 06:00:00	4	1402	8.9	7.3	28.2	13	0	2	26
14020027	2014-10-05 06:00:00	5	1402	9.0	7.2	28.2	13	0	2	26
14020028	2014-10-07 06:00:00	3	1402	8.8	7.2	31.0	12	0	2	4
14020029	2014-10-07 06:00:00	4	1402	8.9	7.1	31.0	13	0	2	4
14020030	2014-10-07 06:00:00	5	1402	9.1	7.2	30.9	13	0	2	5
14020031	2014-10-09 06:00:00	3	1402	8.8	6.7	32.1	12	0	2	4
14020032	2014-10-09 06:00:00	4	1402	8.9	7.3	32.1	13	0	2	4
14020033	2014-10-09 06:00:00	5	1402	9.0	6.4	32.1	13	0	2	21
14020034	2014-10-09 06:00:00	30	1402	8.6	6.6	32.3	9	0	2	24
14020035	2014-10-09 06:00:00	31	1402	8.7	6.5	31.7	11	0	2	24
14020036	2014-10-09 06:00:00	32	1402	8.7	7.3	31.8	10	0	2	4
14020037	2014-10-09 06:00:00	33	1402	8.7	6.4	32.1	9	0	2	24
14020038	2014-10-09 06:00:00	34	1402	8.7	6.6	32.3	10	0	2	24

A.4 Each cluster contains different status and unique set of recommendations / treatments

Cluster ID	Overall Status	Water condition	Expect Growth	Feeding	Recover period hrs	Paddel Wheels Day	Paddel Wheels night	Use Probiotic	Use Oxygen powder	Use Lime	Remove Seaweeds	Change water (Lagoon water)	Change water (Fresh water)
4	1	Less aeration	Drop	50%	48	6	6						
5	2	Water getting basic	Huge drop	50%	48	6	6	1					
21	2	Water basic	Drop	25%	24	8	8			1			
24	1	Water getting basic, high temperature	Normal	100%	48	8	8						
26	2	Water basic	Drop	60%	48	8	8	1					

Appendix B – Testing

B.1 Unit Testing

B.1.1 Mobile Application

Mobile application testing has been carried out using the device IMEI 355884059449965 which was registered with the system before and used the user account 'testdc'. System did not accept connections from non-registered devices nor unauthenticated users. Mobile data connection and connectivity to server were tested before accepting user credentials. Failures highlighted in Red and Successes in Green.

Test Data

Pond No	:	02
pH	:	8.70
Dissolved Oxygen	:	5.80
Temperature	:	29.6
Salinity	:	12.6
Smell	:	No Smell
Color	:	Slight Light Green
Form	:	Very Less Form

Wind	:	Normal

Pond No	:	04
pH	:	9.1
Dissolved Oxygen	:	5.0
Temperature	:	29.7
Salinity	:	9.0
Smell	:	No Smell
Color	:	Light Green
Form	:	Very Less Form
Wind	:	Normal

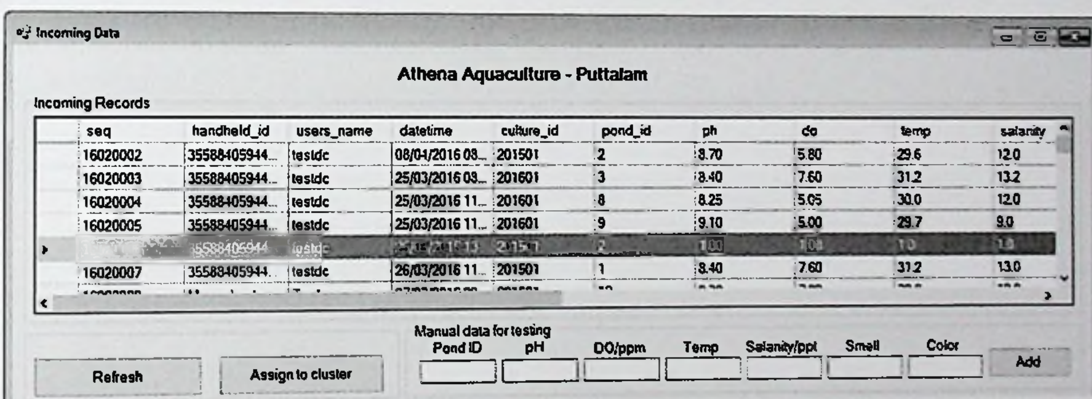
Pond No	:	03
pH	:	8.4
Dissolved Oxygen	:	7.6
Temperature	:	31.2
Salinity	:	13.0
Smell	:	Slight Smell
Color	:	Slight Light Green
Form	:	Very Less Form
Wind	:	Normal

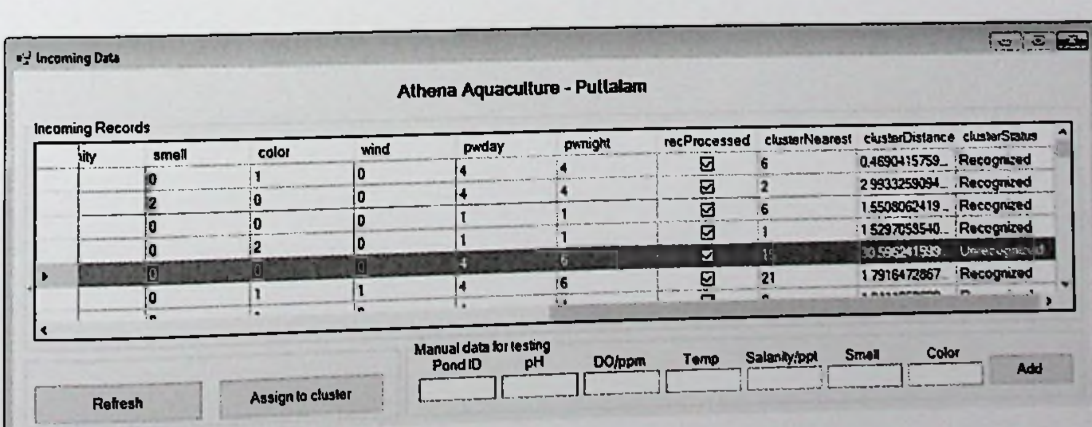
Pond No	:	08
pH	:	8.25
Dissolved Oxygen	:	5.05
Temperature	:	30.0
Salinity	:	12.0
Smell	:	No Smell
Color	:	Slight Light Green
Form	:	Very Less Form
Wind	:	Normal

Pond No	:	02
pH	:	1.0
Dissolved Oxygen	:	1.0
Temperature	:	1.0
Salinity	:	1.0
Smell	:	No Smell
Color	:	Slight Light Green
Form	:	Very Less Form
Wind	:	Normal

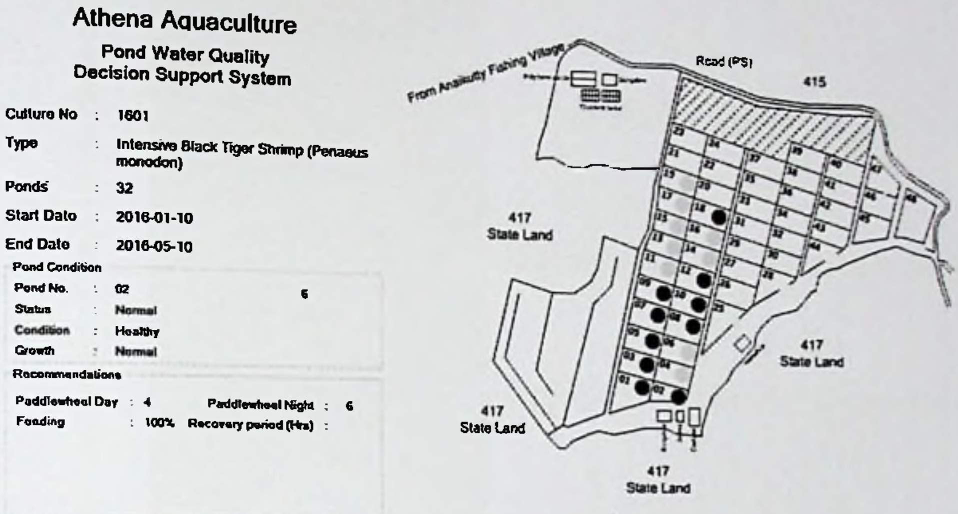
B.1.2 Decision Support module testing

Five data sets inserted to database from mobile device for testing. Four records were legal out of five. Decision support module should recognize first four records as legal and last records as illegal.





Nearest cluster has been identified using straight distance method. All legal records were within below 5 distance and illegal records has encountered distance 30 which wasn't identified as a legal record.



Dashboard has been updated with the results of latest entry per pond. Status, condition and recommendations were verified by the expert.

B.2 System Testing

System has been tested using 496 records of present culture. Sample records of input and clustered set of output from database attached below.

Index	Pond Number	pH (7.5-8.5) 6.00am	Dissolve Oxygen (DO)/ppm(4-6) 6.00am	Temperature °C (24-34) 6.00am	Salinity / ppt (10-30)	Smell	Color	Wind	Paddlewheel Day	Paddlewheel Night
16010001	1	8.8	6.6	31.2	12	0	2	0	4	4
16010002	2	8.8	7.0	31.3	12	0	2	0	4	4
16010003	3	9.0	7.2	31.3	12	0	2	0	4	4
16010004	1	8.4	7.6	31.2	13	0	2	0	4	4
16010005	2	8.5	7.2	31.2	13	0	2	0	4	4
16010006	3	8.6	7.0	31.2	13	0	2	0	4	4
16010007	1	8.4	7.0	30.9	13	0	2	0	4	4
16010008	2	8.5	6.8	30.9	13	0	2	0	4	4
16010009	3	8.6	7.2	30.8	13	0	2	0	4	4
16010010	1	8.5	6.6	30.5	13	0	2	0	4	4
16010011	2	8.6	7.0	30.6	13	0	2	0	4	4
16010012	3	8.7	6.8	30.5	13	0	2	0	4	4
16010013	1	8.6	7.2	30.8	15	0	2	0	4	4
16010014	2	8.6	6.8	30.6	15	0	2	0	4	4

RecIndex	DateTime	PondID	ClusterID	Distance	Status
16020001	25/03/2016 08:50	4	1	1.529705854	Recognized
16020002	08/04/2016 08:55	2	6	0.469041576	Recognized
16020003	25/03/2016 08:53	3	2	2.993325909	Recognized
16020004	25/03/2016 11:22	8	6	1.550806242	Recognized
16020005	25/03/2016 11:26	9	1	1.529705854	Recognized
16020006	25/03/2016 13:55	2	15	30.5962416	Unrecognized
16020007	26/03/2016 11:22	1	21	1.791647287	Recognized
16020008	27/03/2016 09:55	10	2	1.841195264	Recognized
16020009	27/03/2016 10:01	10	22	1.224744871	Recognized
16020010	27/03/2016 10:53	10	2	2.078460969	Recognized
16020011	27/03/2016 10:58	10	2	2.147091055	Recognized
16020012	27/03/2016 10:58	10	2	2.156385865	Recognized
16020013	27/03/2016 11:00	9	2	2.156385865	Recognized
16020014	03/04/2016 11:33	6	8	1.72626765	Recognized
16020015	03/04/2016 11:35	5	2	2.156385865	Recognized
16020016	04/04/2016 02:04	4	1	1.529705854	Recognized
16020017	04/04/2016 05:00	4	1	1.529705854	Recognized
16020018	04/04/2016 05:10	3	2	2.88444102	Recognized
16020019	04/04/2016 05:29	5	27	0.509901951	Recognized
16020020	04/04/2016 05:34	4	15	1.473091986	Recognized
16020021	04/04/2016 08:08	8	6	1.550806242	Recognized
16010169	29/01/2016 06:00	1	24	1.276714533	Recognized
16010168	29/01/2016 06:00	18	1	0.591607978	Recognized
16010167	28/01/2016 06:00	17	1	1.483239697	Recognized
16010166	28/01/2016 06:00	10	1	1.341640786	Recognized
16010165	28/01/2016 06:00	9	1	0.509901951	Recognized
16010164	28/01/2016 06:00	10	1	1.479864859	Recognized
16010163	28/01/2016 06:00	9	1	1.36381817	Recognized
16010162	28/01/2016 06:00	8	1	1.424780685	Recognized
16010161	28/01/2016 06:00	18	1	1.931320792	Recognized
16010160	28/01/2016 06:00	17	19	1.655294536	Recognized
16010159	28/01/2016 06:00	18	19	2.439262184	Recognized
16010158	28/01/2016 06:00	17	1	1.224744871	Recognized
16010157	28/01/2016 06:00	16	1	1.385640646	Recognized
16010156	28/01/2016 06:00	15	1	1.264911064	Recognized
16010155	28/01/2016 06:00	14	1	1.240967365	Recognized
16010154	28/01/2016 06:00	13	1	1.067707825	Recognized
16010153	28/01/2016 06:00	12	19	1.503329638	Recognized
16010152	28/01/2016 06:00	8	19	1.113552873	Recognized
16010151	28/01/2016 06:00	7	19	1.568438714	Recognized
16010150	28/01/2016 06:00	6	1	1.109053651	Recognized
16010149	28/01/2016 06:00	5	2	0.6244998	Recognized
16010148	28/01/2016 06:00	4	2	0.529150262	Recognized
16010147	28/01/2016 06:00	3	1	0.974679434	Recognized
16010146	28/01/2016 06:00	2	1	0.888819442	Recognized

B.3 Acceptance Testing

The main purpose of this test is to evaluate the system's compliance with the business requirements and verify if it has met the required criteria for delivery to end users.

Evaluate the mobile application with field workers who collect data

Candidate Name:	Mr Chamara	Date of Interview:	02/02/2016
Position Title : Technician			

Do you think this application make your work easy can you explain Yes Small portable device looks good easy to keep rather than carrying bundle of papers for each pond. High accuracy data entry screens are user friendly
If you compare with manual system how is the speed of current system. Less work comparatively manual system so this is fast
Do you need further training to enter data Not necessary
Do you have any difficulty when you entering data No
What are the improvements you need Good to access past data

Interview with non-experts

Candidate Name:	Mr Siri Niwasan	Date of Interview:	6/5/2015
Position Title :Officer			

How long do you have experience in this field 2 years
Can you briefly explain your role Monitoring farm process take necessary actions. Analyze daily collected data's form ponds lead them to field expert for necessary feedback and recommendations. Take necessary actions based on expert's recommendations.
Can you explain the current practices in relation to water quality monitoring process Field workers are assigned to different ponds manually collect data
What think as the major issues in current practices Lots of mistakes
What major challenges and problems did you face when you play your role No way to get immediate action experts are not available all the time
Do you have any suggestions to overcome above mentioned problems Real time availability of an expert
Do you use computers for your work Use excel sheet to store data

Appendix C – Fact finding

C.1 Requirement gathering

Interview with field experts

Candidate Name:	Mr Gamini kumara	Date of Interview:	10/5/2015
Position Title :Aquaculture specialist			
Description: An aquaculture specialist is a skilled professional who works on issues affecting sustainable commercial aquaculture practices.			

How long do you have experience in this field 15
Can you briefly explain your job duties Maintaining the aquaculture system, monitoring analyzing and giving necessary recommendations and feedback.
What are the main critical factors in shrimp farming Water quality management Feed management
What are the identified key issues Low growth, high mortality
What are the main reasons for those said issues Good quality water is usually defined as the fitness or suitability of the water for survival and growth of shrimp. Shrimp farming, management of water quality is of primary consideration particularly in ponds with higher stocking rates. Degradation of water quality is detrimental to shrimp growth and survival. Water quality influences the level of growth that can be achieved with lower concentrations, stressful conditions and eventually mortality will occur.
What are the main water quality parameters Salanity,PH,Tempeture,Dissolved oxygen

Do you need to get quick decisions Yes **If so Describe a situation where you had to make a quick decision** Sudden changes of water quality make big impact on fish life so need necessary actions immediately to control the water environment.
Do you have any suggestions to overcome the identified problems Intensive culture shrimp farming done in a controlled environment water quality monitoring and maintain is very important in this situation. Proper water quality management would be a better option.
Did you use any special information technology application in aquaculture email internet and MS office

Interview with field experts

Candidate Name:	Mr Aruna Thilakarathne	Date of Interview:	10/5/2015
Position Title :Aquaculture specialist Description: An aquaculture specialist is a skilled professional who works on issues affecting sustainable commercial aquaculture practices.			

How long do you have experience in this field 18
Can you briefly explain your job duties Maintaining the aquaculture system, monitoring analyzing and giving necessary recommendations and feedback. Prepare necessary reports.
What are the main critical factors in shrimp farming Water quality management Feed management
What are the identified key issues Low growth, high mortality
What are the main reasons for those said issues Water source is the most critical consideration when determining a facility location and the production capacity of the System. Inadequate water quality and quantity will cause above mentioned issues.
What are the main water quality parameters Salanity,PH,Tempeture,Dissolved oxygen There are standard ranges for above parameters in normal condition

Do you need to get quick decisions

Yes

If so Describe a situation where you had to make a quick decision

Example: Low pH, meaning they are acidic. These often range from 4.5-6.5, due to weak acids from the soil leaching into the water. If the water becomes too acidic also it will not be able to support the growth of plants, fish, or invertebrates need immediate treatments.

Do you have any suggestions to overcome the identified problems

Water quality is an essential requirement for fish farming. Need real time proper monitoring

Did you use any special information technology application in aquaculture

No special applications other than using email internet and MS office