

A novel integrated platform for the monitoring of cold supply chains via IoT, fuzzy logic and adaptive neuro fuzzy inference systems

Konstantinos Kokkinos

Department of Computer Science, University of Thessaly, Lamia, Greece

Nicholas Samaras

Department of Computer Science and Engineering, TEI of Thessaly, Larissa, Greece

Abstract: In this paper we deal with the efficient management and life cycle of aquatic products as their cold supply chain is directly affected by their transport under various climate conditions, their consumption and their ad-hoc demand in the domestic predominant market. Our primary concern is the adaptation of necessary procedures in order to guarantee efficient traceability of these products via appropriate tracking and monitoring mechanisms that handle the quality of the products. Furthermore, we are interested in the synergy of the fundamental links in the cold supply chain and how an overlooking wireless web service can manage the just-on-time inventory of wholesale locations which provide at the final destination consumers with fresh and healthy aquatic products. For the aforementioned reasons we propose in this work an integrated online platform equipped by distributed servers which store databases and services, a set of accessible smart devices that help in the monitoring process, a well-defined and responsive Wireless Sensor Network (WSN) that incorporates a variety of sensors via an Arduino platform and a dynamic Product Status RFID system used to uniquely identify every transport package informing for their current status and conditions. The proposed system complies with the EC legislation and bylaws regarding the consumer health, appropriate quality of aquatic products when they are transported and the sustainability of cold supply chain markets. The proposed platform is also equipped with a Decision Support System (DSS) based on soft computing methodologies that is able to predict the quantities of fisheries that need to arrive at certain locations satisfying the temperature conditions which guarantee product freshness. More specifically, the system is based on Fuzzy Logic (FL) and Artificial Neural Networks (ANN) that try to minimize the waiting time of aquatic products in the intermediate locations of the path from origin to destination.

Keywords: Cold supply chain, traceability, monitoring, wireless sensor network, RFID, Arduino, Fuzzy Logic, Neural Networks.

**Corresponding author:* Kokkinos Konstantinos (kokkinos@uth.gr)

1. Introduction

According to the European Union passed legislation about the guidelines on Good Distribution Practice (GDP) for aquatic products and fisheries intended for human consumption, published under the directive 178/2012 and updated in 2013, the responsibility for ensuring safety and high quality on aquatic product is depended totally on the producers and the retailers. Most of this legislation refers to the appropriate temperature conditions which must be maintained during product transport at any time (EC-Europa.eu, 2018). We must note that the functionalities of the aquaculture, the storage of fisheries, the distribution of the aquatic products and the transportation of these products under the necessary temperature conditions are very important for the regulated supply chain management (Todd, E. C., 2017). Moreover, the European Commission has set all legal and regulatory aspects that relates to food traceability and all the regulatory aspects for the controlling mechanisms that promote the food safety (Laguerre, Hoang, & Flick, 2013). This requirement,

commonly termed as “cold chain management” and describes a set of sequential and interdependent processes and procedures which must be involved to ensure the temperature preservation of perishables and other similar products in a safe, wholesome, and secure manner from production through to consumption. More specifically, perishable aquatic products have to be preserved in optimum temperature and relative humidity to keep the desired freshness.

Our experience that relates to the wholesalers and retailers of aquatic products can prove that most of these cold chains are operating in a “below ideal” state. As the matter of fact these malfunctioned procedures result in approximately one third of the food produced for human consumption being wasted across many of these supply chains. Most importantly, the same impression is resulted across the globe in similar chains. According to researchers the most critical factor that affects this waste is the inability to control/monitor the temperature across the transportation of these aquatic products. This is quite a challenge because, despite there being a plethora of technological solutions in monitoring, most systems lack an ability to either integrate all input for making decisions or to predict certain parameter measures in the case of data outlier occurrence and not-linking chain records adequately. Lately a variety of ITS technologies have been employed to abet the monitoring of the condition of the location and the condition of transported goods (especially for the temperature sensitive products and live animals). In the recent years, this has led to the concept of “intelligent cargo”, meaning that goods become self-, context- and location-aware as well as connected to a wide range of information services.

The most effective and modern technology that combines both Radio Frequency (RF) and Wireless Sensor Networks is becoming widely popular since it is proven very effective in the field of cold chain monitoring (Kumari, Narsaiah, Grewal, and Anurag, 2015). These systems are able to optimize aquatic product surveillance and thus to become beneficial in relation to product safety and quality as well as to cold supply chain optimization. These systems also are used as the basis data acquisition of temperature and humidity time series in order to calculate the optimal quantities of aquatic products for just-in-time inventory and therefore to minimize the waste of fresh produce (Shi *et al.* 2011). This combined technology has shown success due to the strategic complementarity of the two technologies and it is because of the fact that WSN lacks robustness while the Radio Frequency Identification (RFID) lacks reading ranges and possess limited sensing systems (reading distance up to 1m). Using this technology we are able to collect valuable information regarding the transportation path as a time-series of GPS locations, the package internal temperature time-series, the external of the package temperature time-series and the idle times between stations in the transportation path as this last information is very important and needs to be minimized since it affects all previous time-series (Costa et al. 2013).

In this paper, we propose a WSN composed by GPS and sensor tracking nodes where each node may be at fixed or not-fixed location monitoring the package external and internal conditions during the transportation of aquatic products. The system can be easily implemented using an Arduino board for controlling all sensors and providing data acquisition, synchronization and centralization. Processing of data is two-fold: (a) towards controlling the progress of the package within the supply chain sharing the information of all nodes to all other sites via the Xbee (Xbee, 2018) and Zigbee (Zigbee, 2018) protocol technology and (b) towards the implementation of prediction algorithms that take over in making a product lifeline decision policy when either outlier information is stored or lack of link sharing in the supply chain occurred. This holistic examination of aquatic product cold chain monitoring systems is presented with the objective of making an important contribution to optimal solutions in aquatic product supply chains. Besides, the improvement of systems is based on the real time monitoring and decision support systems that can prevent damage of perishable food products during transportation and provide warning functions on RFID data when instability in package conditions occurs.

2. Technologies and System Logical Architecture

In this section, we describe the logical architecture including the implementation details of the proposed aquatic product cold chain monitoring system. We will mainly concentrate on the software functionalities but whenever necessary we will mention hardware details to depict the configurations on the sensor cloud.

2.1 Internet of Things, (IoT): is the technology of physical device networking including embedded items with electronics, software, sensors, actuators, and connectivity which enables these things to connect and exchange data. This technology allows the direct integration and simulation of the physical world into a computer-based platform, resulting in efficiency improvements, economic benefits, and reduced human exertions. With the advancement of electronics technology that produced smaller devices of high processing capabilities and low power consumption, large networks of sensors can be created, having the ability to obtain and process voluminous information and act accordingly.

2.2 Arduino, Xbee: Arduino is an open source computer hardware and software technology of single-board microcontrollers and microcontroller kits for building digital devices and interactive objects that can sense and control objects in the physical and digital world. Arduino boards are equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion board circuits or sensors featuring serial communications interfaces, including Universal Serial Bus (USB) on some models, which are also used for loading programs from personal computers. The size of the whole board is not greater than 4 US quarter-dollar coins tiled together. With prices ranging 2-4 € per board including the Xbee wireless communication module, Arduino becomes a “must use” technology to accommodate sensor data acquisition, monitoring data communication and distribution as well as to overview and organize decision support functionalities for prediction of product conditions. Figure 1 shows a typical Arduino board depicting the Xbee wireless communication module and its size.

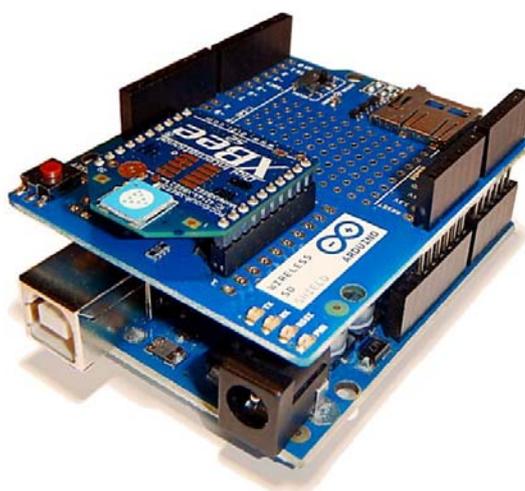


Figure 1. Arduino data logging shield with an Xbee wireless communication module

2.3 Radio Frequency Identification (RFID): is a technology that uses electromagnetic fields to identify and monitor tags that are attached to objects and carry multilevel stored information. RFID etiquettes may be passive or active allowing operation from many centimeters to hundreds of meters from the RFID reader. Applications of RFID tags mainly track the progress of materials or objects through an assembly line or when attached or implanted in livestock, possessions or even people may transfer valuable information about the condition of the carrier. Apart from the raised privacy concerns, this inexpensive technology (around 5 € per hundred of etiquettes) shown in Figure 2 provides a reliable methodology for monitoring, traceability, reader authentication, and over-the-air privacy.



Figure 2. A passive RFID tag depicting the embedded electronic circuit and its size

2.4 Logical architecture of the proposed platform: Based on previous experience referring to cold supply chain management, the major steps are shown in Figure. 3 and described as follows:



Figure 3. Cold supply chain management steps for aquatic product catching processing and selling

- Fishing in the catch area. After catching, fresh fish is mainly sent to processing plants for further processing.
- Processing divided into two categories: (a) Processing without segregation of the catch; and (b) Processing by segmentation of the catch.
- Storing aquatic products in refrigerated chambers while maintaining suitable temperatures.
- Transfer the products to retail outlets.
- Sale of the product by wholesalers and retailers and consumption by the customers.

To accommodate the monitoring functionalities needed for the supervision of the aforementioned steps in the cold supply chain, there is a need for a WSN installation using the technology of Arduino and Zigbee/Xbee mentioned before. For this configuration we use a sensor *Waspnote* to be mounted on each cargo vehicle. Prior to cargo loading, each product package is tagged with a unique RFID tag. The device measures the temperature and periodically updates the temperature timestamped time-series on the RFID tags. A local area network for the continuous monitoring of the transportation paths is set up by various nodes on the different checkpoints on the journey path. The *Waspnote* transmits data to the main server, updates time-series on the RFIDs of the packages and maintains the control of the local WSN during the whole journey. When cargo vehicles reach either intermediate checkpoints or final destination, the *Waspnote* on the new location takes over to reconfigure their WSN to accommodate the arrived packages (RFIDs) and therefore new GPS locations and the local temperatures are logged. However, apart from the local WSNs which are set for each of the cargos and all the sites, the integrated framework is built as a three-layer logical architecture diversifying between: (a) the top application layer, (b) the server-side core system and (c) the database (storing) layer. These layers are virtually divided by the GUIs that execute web services for all the system functionalities, the tools for getting data responses and decisions, the management modules for monitoring all nodes and RFIDs, the subroutines for getting remote

information from other sites of the system and the applications for the smart devices (phones, tablets) that are used from the network users. On the other hand, the server side back-end includes all the web-services to accommodate the functionalities on the first layer as well as the sensor flow management/synchronization and the set of Artificial Intelligence algorithms needed to run for the Decision Support System (DSS). All modules of the framework (both from the user layer and the server-layer) store information on three databases that maintain the integrity of location data, sensor information data and management data related to the platform. Figure 4 illustrates this architecture.

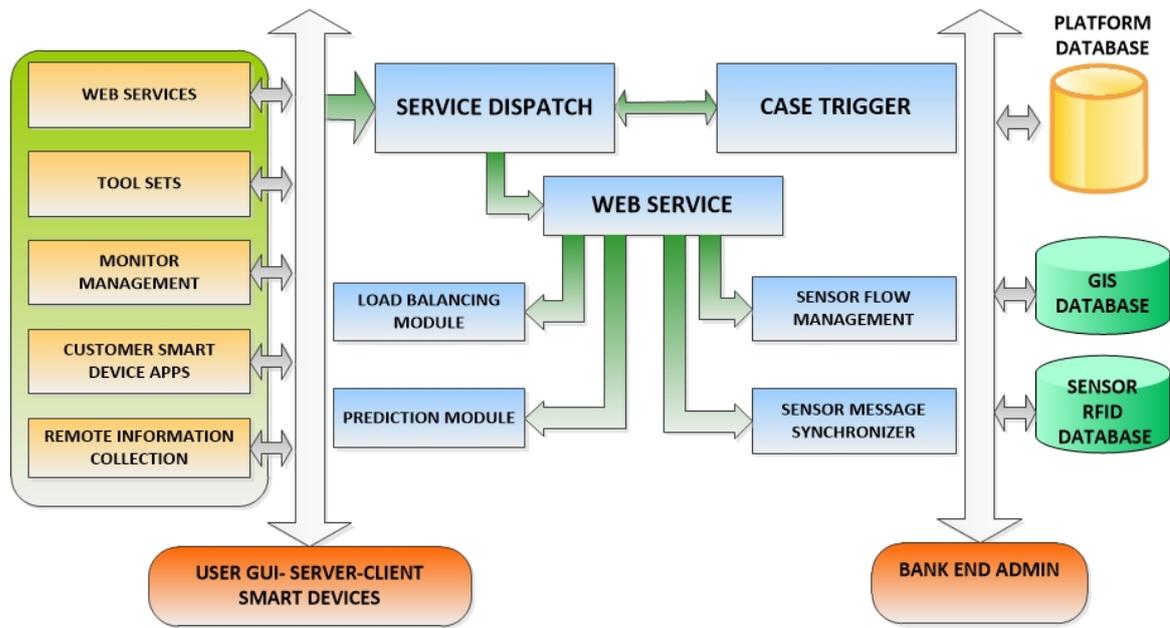


Figure 4. Logical architecture of the monitoring of cold supply chain management

3. Functionality of the Decision Support System using Fuzzy Logic and Adaptive Neuro Fuzzy Inference Systems.

In this section, we consider the methodology for predicting minimum just-in-time inventory by predicting the corresponding time intervals in the transportation paths as well as the prediction of the freshness of the products using the time series of internal and external temperature and the package humidity. Our goal is to help the retailers and wholesalers to ship the products on time and also to predict (one-step ahead prediction) what is going to be the next temperature and humidity conditions of the aquatic products when they transported. For this reason we use the Adaptive Neuro Fuzzy Inference System (ANFIS) methodology in the prediction module and the DSS module of our integrated platform.

The ANFIS methodology deploys a hybrid approach consisted of Fuzzy Logic and Neural Networks with the primary goal to build an artificial intelligence hybrid system that has high accuracy performance on time series data and especially for multivariate data sets. Fuzzy Inference is the process of formulating the mapping from a given input to an output using fuzzy logic (Adriaenssens et al., 2004). The fuzzy inference process involves three important concepts: membership functions, fuzzy set operations and inference rules. A Fuzzy Inference System (FIS) is able to represent non-exact data and uncertainty efficiently (Jang et al., 1997; Kasabov, 1998; Azeem, 2012). It defines a non-linear matching between one or more input variables and one output variable. Actually, it involves fuzzification, inference and defuzzification.

The ANFIS benefits from both technologies to construct a set of membership functions parameters that define the prediction problem at hand. These initial parameters are then adjusted and fine-tuned using a back-propagation neural network algorithm. The performance of the system is measured using the well-known Root Mean Squared Error (RMSE) of the predictions after the data

set is split into two sections (70% of the time series is used for training and the rest of 30% used for testing the performance in predicting one-step ahead values). An example of the ANFIS model (FIS and Neural Network) is depicted in Figure 5 showing the topology used in order to predict temperature intervals for the internal temperature of the aquatic products based on the aforementioned times as they have been discussed in sections 1 and 2. The most popular ANFIS model module which has been developed and used widely is the ANFIS-ToolBox by MATLAB, however there are some restrictions using it especially on the number of variables (time-series). More specifically if the number of inputs exceed five, the computational time and rule numbers will increase, so ANFIS will not be able to model output with respect to inputs. In this study, the number of yield quality inputs is four, including all the temperature, humidity, and time intervals between stations.

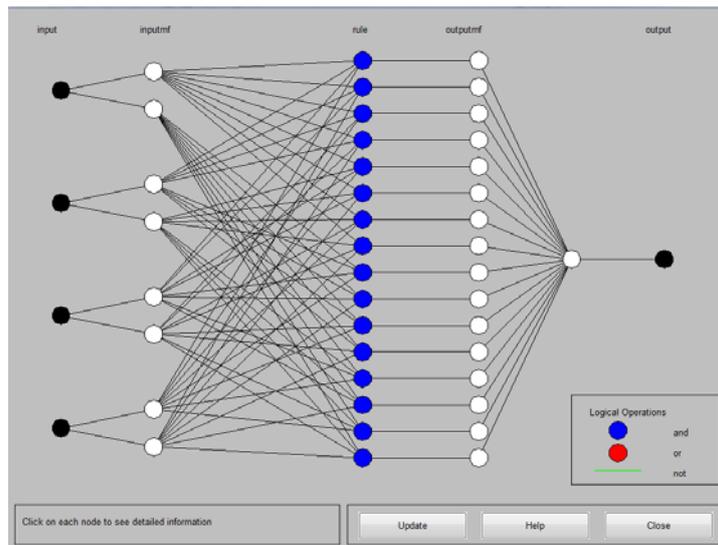


Figure 5. The topology of ANFIS model to predict internal temperatures of the aquatic product packages

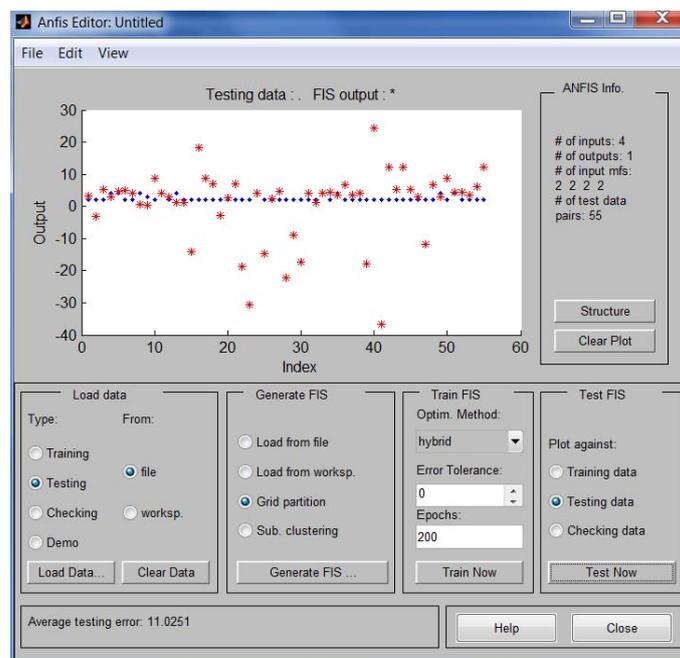


Figure 6. The ANFIS Editor and the appearance of the training and testing data

To find the most effective architecture of ANFIS model, we experimented with various modifications in order to increase the accuracy of the network and decrease the errors and the RMSE. These modifications refer to altering the number of membership functions, the types of the membership functions (interchange between triangular, trapezoidal, bell-shaped, Gaussian and sigmoid), modifying the types of output membership functions (constant or linear), trying between various optimization methods (such as hybrid or back propagation) and finally experimenting with the number of epochs needed to train the network while avoiding overfitting and under fitting (Naderloo et al. 2012).

The first step in our approach for the creation of the DSS is the designing of the the neuro-fuzzy model which in the MATLAB toolbox is achieved by identifying the fuzzy input and output variables along with their membership functions. The combination between the number and the type of the membership functions assigned to the input variables is selected in order to provide the best set of outcomes that result the minimum RMSE. The MATLAB ANFIS editor offers different types of membership functions (MFs) including: triangular, trapezoidal, generalized bell (Gbell), Gaussian curve, Gaussian combination, difference between two sigmoid functions, and product of two sigmoid functions. Correspondingly all these MFs were evaluated and eventually trapezoidal MF has performed better in all of our cases. The hybrid learning method was applied because this algorithm uses back propagation for parameter associated with input MF and least square estimation for parameters associated with output MF (Mathworks, 2014). Finally 150 epochs was used to train the models.

4. Application of the Method, Challenges and Conclusions

To illustrate the effectiveness of the proposed monitoring and DSS system, a case study must be conducted on a specific cold supply chain that provides the set of time series data for the corresponding transportation paths. The data acquisition must be come from the pre-installed WSN and the monitoring server that overlooks the network.

There are a number of challenges to consider when adopting any/all of the systems outlined in this research work. It is important to highlight however, as with all solutions there exists no single “out of the box” solution due to the fact that the composition of product, transport route, method of transport and process efficiency varies greatly across products transported and also depends solely on the climate conditions of each country. For example, in the case of Greece most of the aquatic products are coming from the islands and especially during the winter time when the weather conditions do not allow the creation of a predefined transportation schedule. On the other hand during summer the opposite exists, i.e. there is greater flexibility in transporting goods but the heat minimizes the time intervals between the stages in the supply chain making a totally different transportation schedule. The developed DSS must take care of these unforeseen special cases and be able to adopt accordingly. In any case, the proposed system can provide consumers, transporters and sellers with a set of smart device tools that give prediction to the arrival times of aquatic products at the retailers’ locations. However, one major concern as to the number of people using these applications and the smart devices over all. Therefore it is important to convince people about the improved ability of the artificial intelligence methodologies to accurately predict the quality level of the products.

REFERENCES

1. Azeem M.F., Fuzzy Inference Systems: Theory and Practice, ISBN 978-953-51-0525-1, Publisher: InTech, Published: May 09, 2012 under CC BY 3.0 license, in subject Control Engineering, DOI: 10.5772/2341.
2. Adriaenssens, V., De Baets, B., Goethals, P.L.M, and N. De Pauw. 2004. Fuzzy rule-based models for decision support in ecosystem management. *The Science of Total Environment* 319, pp. 1-12.

3. Costa, C., Antonucci, F., Pallottino, F., Aguzzi, J., Sarria, D., and Menesatti, P., (2013). A review on Agri-food supply chain traceability by means of RFID technology. *Food and Bioprocess Technology*, vol. 6, no. 2, pp. 353–366.
4. Ec.europa.eu Transport Legislation on Freight and Logistics (2018). [Last accessed September 24th 2018]. URL: https://ec.europa.eu/transport/themes/its/road/application_areas/freight_and_logistics_en
5. Jang, J. S. R., Sun, C., & Mizutani, E. 1997. *Neuro-fuzzy and soft computing: A computational approach to learning and machine intelligence*. Upper Saddle River, NJ: Prentice-Hall International, Inc.
6. Kasabov, N., 1998. *Foundations of Neural Networks, Fuzzy Systems and Knowledge Engineering*. The MIT Press.
7. Kumari, L., Narsaiah, K., Grewal, M. K., & Anurag, R. K. (2015). Application of RFID in agri-food sector. *Trends in Food Science & Technology*, 43(2), pp. 144-161.
8. Laguerre, O., Hoang, H., & Flick, D. (2013). Experimental investigation and modelling in the food cold chain: Thermal and quality evolution. *Trends in Food Science & Technology*, 29, pp. 87-97.
9. Mathworks, Makers of MATLAB and Simulink toolbox, (2018), URL: www.mathworks.com Last accessed Sept. 25th 2018.
10. Naderloo L., Alimardani R., Omid M., Sarmadian F., Javadikia P., Torabi M.Y., *et al.*, Application of ANFIS to predict crop yield based on different energy input, *Measurement*, 45 (6) (2012), pp. 1406–1413.
11. Shi, J., Zhang, J., and Qu, X., (2011). Optimizing distribution strategy for perishable foods using RFID and sensor technologies. *Journal of Business and Industrial Marketing*, vol. 25, no. 8, pp. 596–606.
12. Todd, E. C. (2017). Foodborne disease and food control in the Gulf States. *Food Control*, Vol. 73, pp. 341-366.
13. Xbee, Wikipedia. (2018). URL: <https://en.wikipedia.org/wiki/XBee>. Last accessed September 24th 2018.
14. Zigbee, Wikipedia. (2018). URL: <https://en.wikipedia.org/wiki/Zigbee>. Last accessed September 24th 2018.