Applications

Divas Karimanzira* and Thomas Rauschenbach

An intelligent management system for aquaponics

Ein intelligentes Managementsystem für die Aquaponik

Abstract: Population rise, climate change, soil degradation, water scarcity, and food security require efficient and sustainable food production. Aquaponics is a highly efficient way of farming and is becoming increasingly popular. However, large scale aquaponics still lack stability, standardization and proof of economical profitability. The EU-INAPRO project helps to overcome these limitations by introducing digitization, enhanced technology, and developing standardized modular scalable solutions and demonstrating the viability of large aquaponics. INAPRO is based on an innovation a double water recirculation system (DRAPS), one for fish, and the other one for crops. In DRAPS, optimum conditions can be set up individually for fish and crops to increase productivity of both. Moreover, the integration of digital technologies and data management in the aquaculture production and processing systems will enable full traceability and transparency in the processes, increasing consumers' trust in aquaculture products. In this paper, the innovations and the digitization approach will be introduced and explained and the key benefits of the system will be emphasized.

Keywords: aquaponics, intelligent management, zero-positive diagnostics, artificial intelligence

Zusammenfassung: Bevölkerungszunahme, Klimawandel, Bodendegradation, Wasserknappheit und Ernährungssicherheit erfordern effiziente und nachhaltige Nahrungsmittelproduktion. Aquaponik ist eine hocheffiziente Art der Landwirtschaft und wird immer beliebter. Allerdings mangelt es der industriellen Aquaponik immer noch an Stabilität, Standardisierung und Nachweis der wirtschaftlichen Rentabilität. Das EU-INAPRO-Projekt hilft diese Einschränkungen zu überwinden durch die Einführung von Digitalisierung und verbesserter Technolo-

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gie, die Entwicklung standardisierter modular skalierbarer Lösungen und die Demonstration von Rentabilität der großen Aquaponiksysteme. INAPRO basiert auf einer Innovation - eines doppelten Wasserrückführungssystems (DRAPS), eines für Fisch und das andere für Pflanzen. In DRAPS können optimale Bedingungen für Fische und Nutzpflanzen individuell eingestellt werden, um die Produktivität von beiden zu erhöhen. Darüber hinaus werden durch die Integration digitaler Technologien und ein Daten Management in der Aquakulturproduktion und -verarbeitung eine vollständige Rückverfolgbarkeit und Transparenz ermöglicht, um das Vertrauen der Verbraucher in die Aquaponikprodukte zu stärken. In diesem Papier werden die Innovationen und der Digitalisierungsansatz vorgestellt und erläutert und die wichtigsten Vorteile des Systems hervorgehoben.

Schlagwörter: Aquaponik, Intelligentes Management, Null-Positiv-Diagnostik, Künstliche Intelligenz

1 Introduction

Recently, the demand for producing agricultural products that are as environmentally friendly and resource-saving as they are highly efficient is increasing due to food price increases, water scarcity, crop production for biodiesel, increased toxicity due to heavy metals, excessive use of fertilizers as well as global climate change, and overfishing. This paper will focus on sustainability solutions based on closed-loop farming and management. Aquaponics (Fig. 1a) allows a drastic reduction of water use, increased density of the products per unit area, reduce the impacts of climate change as well as the application of biocontrol for plant protection. Nevertheless, there are several questions about the viability of aquaponics that need to be answered.

An intelligent control system acquires the greenhouse climate data (temperature, light intensity, etc.), hydroponics information, and the growth status of the products from real-time analysis of images of fish and crops to make an informed decision about control strategies. Digitalization,
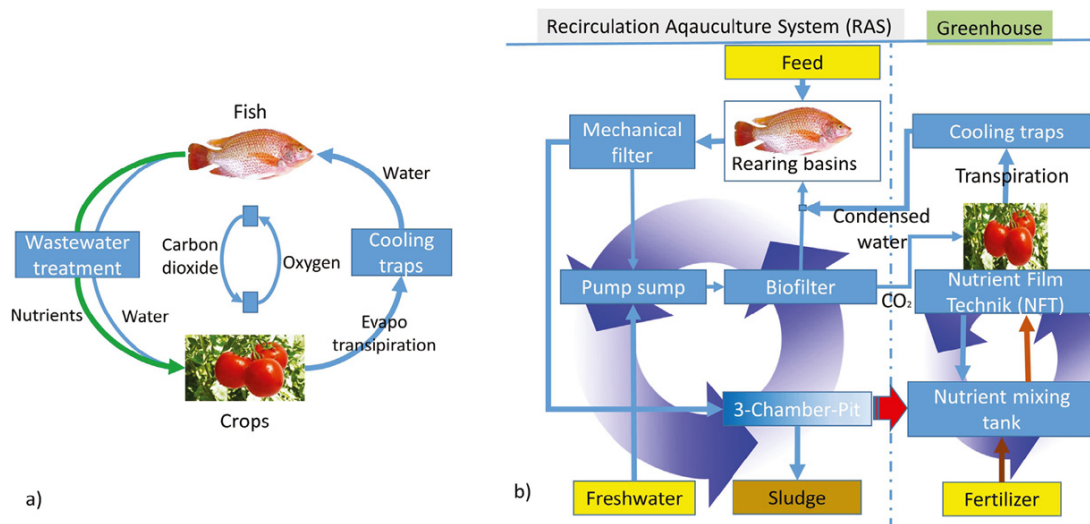
Figure 1: a) Classical aquaponics, plants utilizing fish nutrients in one cycle. b) DRAPS – Conditions for both cycles can be controlled individually.

monitoring, and control of agricultural processes offer numerous starting points for resolving the conflict of goals between economical viability and ecology. A more comprehensive understanding of cause-effect relationships in the ecosphere can be built, optimized workflows based on comprehensive data can increase productivity while achieving sustainability.

It is obvious that the classical automation pyramid with its strict information flows upwards from devices to the enterprise via levels of control is outdated and does not suffice to intelligently and efficiently manage the complete system due to the following reasons: project facilities are distributed (Spain, Germany, Belgium, and China), we aim to improve productivity through learning from other sites, one installer and service provider sits in German, different data sources and stakeholders are involved in the value chain (farmers to consumers). In the INAPRO project, technological innovations such as DRAPS were developed [4, 3]. The technology was implemented in several demonstration sites e. g., in Spain and China. A model-based control and the management system for water, energy, and nutrients was developed based on classical automation pyramid [3]. The modeling approach allowed the optimization of all details in the design, construction, integration, and operation of the system, proving the technical and economic viability of INAPRO. This extension to a cloud-based platform will contain such diverse information (farm data, predictive data,operating procedures, etc.) to provide data to stakeholders and consumers.

2 Methodology

In order to be able to understand the reason of the enhancement with IoT, we will first describe the INAPRO concept, followed by the management system based on the classical automation pyramid and then the enhancement architecture.

The EU-INAPRO aquaponics design is based on the Double Recirculation (DR), where the Recirculation Aquaculture System (RAS) and the horticulture are separated as shown in Fig. 1b) compared to the classical aquaponics definition in Fig. 1a). In DRAPS, the optimum conditions can be set up individually for both units. This gives the possibility to increase the productivity of both sectors without generating adverse interactions between the them.

In Fig. 1b), the filtered, nitrate-rich fish water is transferred to the horticulture and buffered by the nutrient mixing tank. In contrast to conventional aquaponics, the amount of transferred water is automatically adjusted to the plant's actual water requirements. The nutrient solution not taken up by the plants is recollected and reconditioned in the nutrient mixing tank and then pumped to the plants again. Evaporated water in the greenhouse is regained via cooling traps, stored and returned into the fish tanks. The CO_2 exhaled by the fish is directed to the plants.

The new intelligent management platform for the aquaponics system is illustrated in Fig. 2. All information will be collected in a central database. Models will be applied and simulated data will be displayed on stakeholder-specific websites or in a mobile app. The consumer can en-
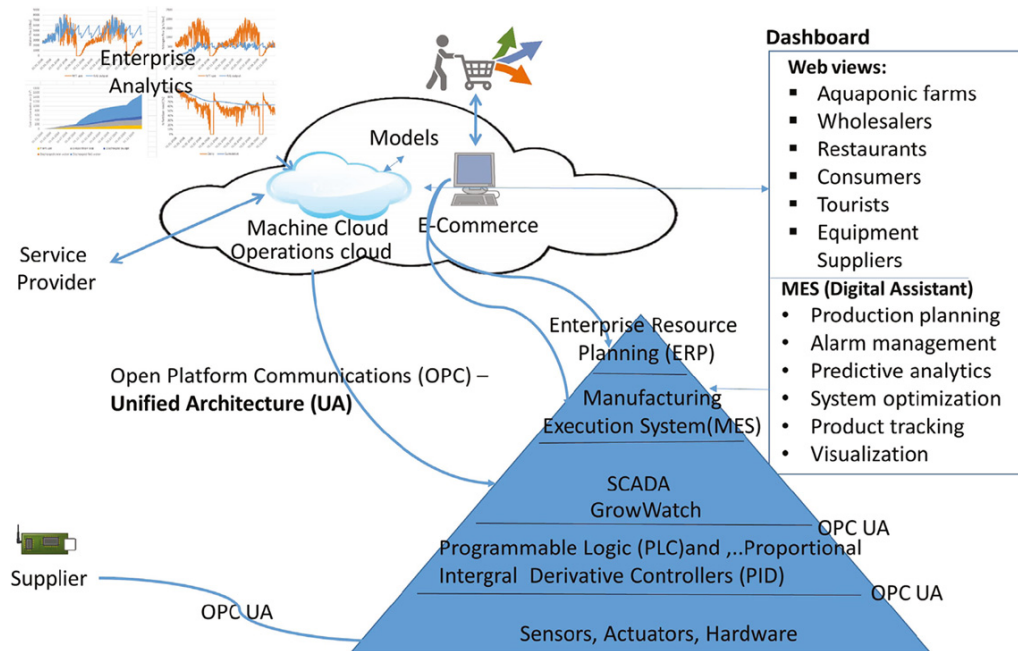
Figure 2: IoT-Cloud-based platform for the aquaponic systems with a resolved automation pyramid and using OPC-UA standards for communication. Farmers, consumers and suppliers get customized views.

ter the tracking code, and relevant growth data will be displayed. A fish farm owner can view online sensor data, actual and modeled growth curves and compare data with other fish farms.

The platform collects data from all system components (fish tanks, bio and mechanical filters, greenhouse, hydroponics, fish and plants) on size, water quality, feeding patterns, etc. Combined with other data, the algorithms provide recommendations such as feeding regime, optimal harvest dates, detection of anomalies /faults occurring in the system, fertirrigation etc. It will connect all demonstration aquaponics farms and end-users by a web interface. In this way farm conditions can be tracked and displayed online and utilized to robustify the prediction models. Different farms can learn from one another. In this way the project will provide more transparency on the rearing of fish and environmental conditions and better exchange of good practices among different geographical regions. Therefore, encapsulated in the IoT-enhanced management system are besides other components, an optimization module, and a diagnostics system. The diagnostics system will be described in the following section. For the optimization system, we refer to our previous publication [2].

2.1 Monitoring, diagnostics and remote service

Due to the fact that aquaponics system processes are quite complex and usually staff at the farms lack professional knowledge, a monitoring, diagnostics, and remote service assistance system as illustrated in Fig. 3 is required. In the DRAPS system, data is monitored at different locations to maintain proper water chemistry and physics. Obviously, in an IoT-based aquaponics [7], faults can occur **anywhere along the line** from the facility itself, software, up to the communication system. Therefore, we developed a **Digital Sentinel,** which constantly watches the whole chain for anomalies. Due to limited space in this paper, we focus on the faults which can happen at the facility. The system takes sensors, actuators, fish and plant growth information, and their tolerance bands and calculates remotely the system status and recommendations for action. Instead of a human measuring the fish or plant growth up and again, photos from IoT-Cameras in combination with deep learning estimators can be used to estimate remotely the fish and plant growth in real-time. We implemented a Convolutional Neural Network (CNN) for estimating the growth parameters (Leaf Area Index (LAI) and the plant height) from optical camera images.

The core of the system is a Long-Term-Short-Memory (LSTM) neural network [1] for anomaly detection and
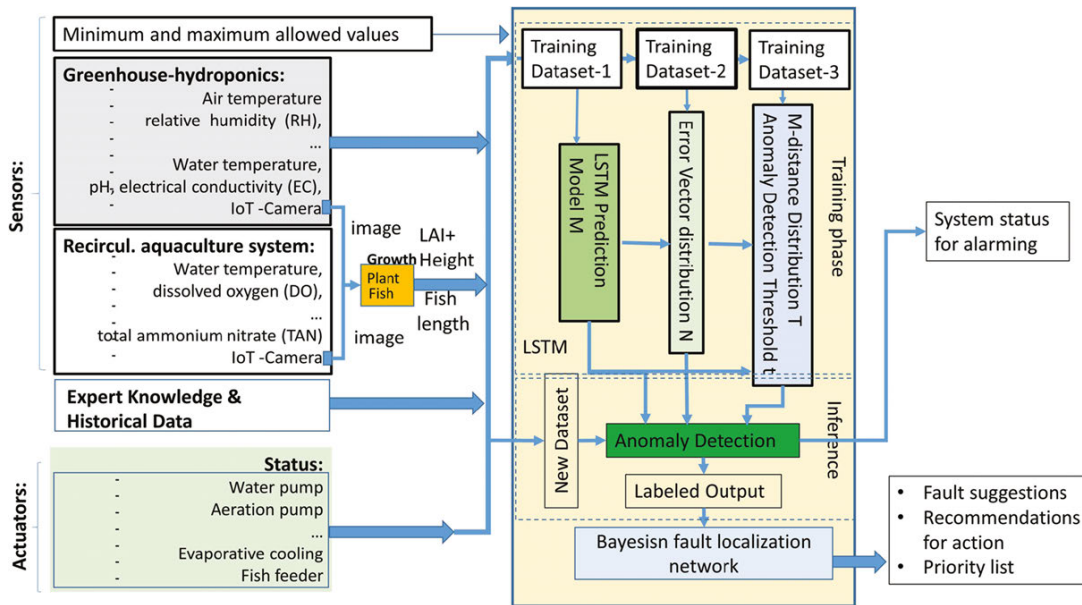
Figure 3: A monitoring and diagnostics system, with inputs to the LSTM-BN system. Outputs are alarms, fault locations and recommended actions.

symptom generation, and a Bayesian Network (BN) for fault localization (see Fig. 3). The LSTM can predict future time point values based on past observations. It is a zero-positive machine learning system [5]. Therefore, it is trained on values from normal operation regimes (does not require anomalous training samples). This is of practical significance, because anomalous samples are difficult to collect and varying. For the training, the dataset from the normal regime is divided into three portions. The LSTM is trained on the first dataset to get a model M. Following this, the Model M is used to the second portion of the dataset. Error vectors are computed and fit into a multivariate normal distribution N. Further, the Model M is applied to make predictions and compute error vectors for the third portion of the dataset. Then Mahalanobis distances are calculated and fit into a truncated normal distribution T. Finally, the inverse cumulative distribution function of T at a user-specified percentile is evaluated to be used as the anomaly detection threshold τ. For the inference, the system is applied to a new dataset to make predictions. Error vectors and M-distances between these error vectors and the center of N are computed and finally, the time-series values whose M-distances exceed the threshold τ are considered as anomalies. τ is determined by the following procedure. For the validation set the anomaly score is calculated using logarithmic spaced threshold values set in the anomaly score range. The best τ is the threshold that maximizes the F_β-score, where the F_β-score is defined as the weighted harmonic mean of

precision and recall. For training, the *BN* requires expert knowledge and historical data of symptoms and faults relationships. For inference, it takes the values calculated by the LSTM model as symptoms.

The recommendations for action are sorted automatically according to the importance of the parameters and reaction times required by the failures. In aquaponics, issues with water, electrical power, dissolved oxygen i. e., aeration system and oxygen system require very fast response in minutes. Moderate response time –hours are required by issues of temperature, pH, ammonia, etc.

3 Results

The sample results of selected feature of the developed system will be presented and discussed in the following:

a) Monitoring, diagnostics and service: As required by the procedure described in section 2.1, three datasets were prepared form the 2 years data in the ratio of 50 % dataset 1 to train the LSTM to get a model M, 30 % dataset 2 used to compute error vectors with model M and fit into a multi-variate normal distribution N, and 20 % dataset 3 where the model M is applied for testing the predictions. The LSTM with (input dimension (No. of sensors+ No. of actuators), a dropout layer with dropout rate of 0.2, Hidden layer with 100 neurons, another dropout layer of rate 0.6, a dense layer and relu) was defined and the key hyperpa-
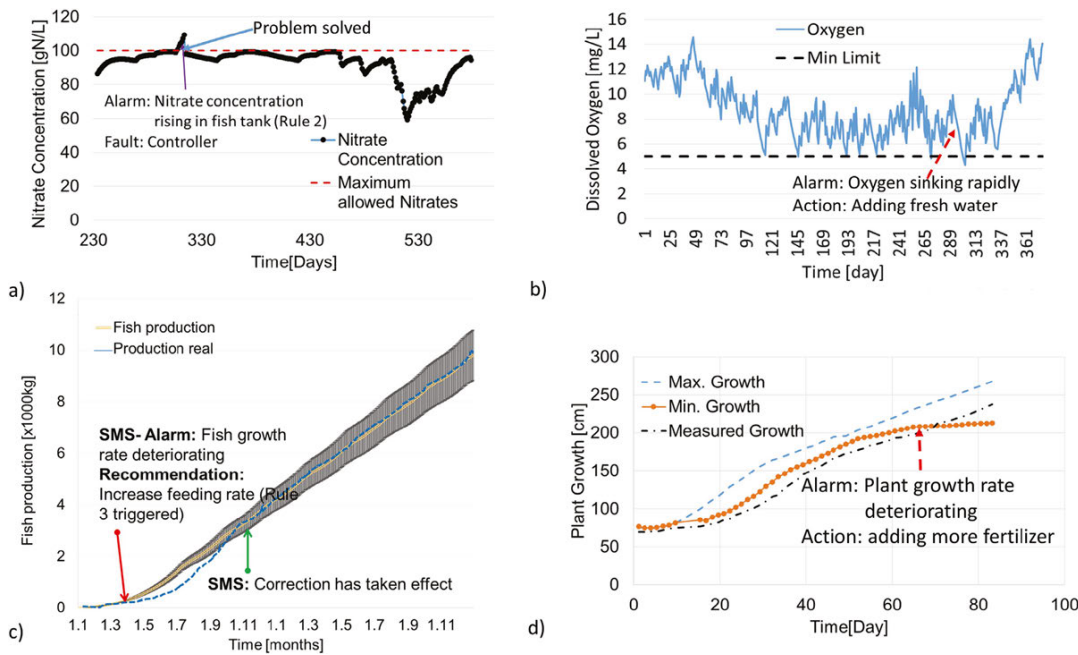
Figure 4: Short-term monitoring a) Nitrate and b) DO, LSTM caught anomaly and BN found the fault. Long-term: b) Retarded fish and d) plant growth detected, actions taken to increase feeding and fertilizer supply, respectively.

rameters (batch size = 1, learning rate = 0.7 and number of epochs = 50) were tuned while checking the performance of the system. For example, for the dissolved oxygen, the network achieved a training MAE of 0.006 and a test MAE of 0.002. For all the sensors and actuators, the LSTM model had an average recall rate of 0.87, precision rate of 0.533 and F_β-score of 0.0825.

In the anomaly detection, the optimal results from the models are continuously in comparison with the real measured data as shown in the Fig. 4 for the water quality and plant and fish growth, respectively. Alarms and corrective measures are triggered as can be seen in the Figures a-d. In Fig. 4a) were limiting factors issues in this case a controller outage was found as the fault and an SMS – Critical alert controller defect was sent, and in Fig. 4c), the fish growth was predicted to be slower than expected.

b) IoT enhanced Manufacturing Execution System (MES): One important feature of the INAPRO aquaponics system is to minimize fresh water less than 3 %, energy and nutrient supplies [3]. This can only be achieved by appropriate design of the fish and crop mixture, considering the fish to crop ratio, when to sow the crops etc. and to monitor the system to see whether or not, it performing as designed. Therefore, the MES has a view to show the system with all the material flow (water, energy and nutrients) and also how the system will be performing for a given prediction horizon. Knowing the future developments of the sys-

tem, the operator can taking corrective measures to make sure that the system is behaving as required. The MES is responsible for 1) cost and yield monitoring, product tracking on a user-friendly dashboard, 2) enables production without human intervention and maintain accountable and controlled production flow 3) visualizing quality, costs (energy, food, water, heating, etc) and productivity in comparison to market prices 4) Assists users in feed and nutrient calculation and other planning issues and 6) log farm activities.

4 Key benefits

The modularity, scalability and viability of the of the INAPRO system has been proven in many demonstration sites, e. g., in Germany with 573 m^2 greenhouse produces 24 tonnes of African catfish and 11 tonnes of tomatoes and another large scale site in China of 2100 m^2 of greenhouse produces 30 tonnes of fish and 360 tonnes of vegetables. All the sites have been running at <3 % freshwater input. The resulting benefits of the system are 1) improved productivity. DRAPS provides optimized conditions for both fish and plants 2) Costs and resources savings. Efficient double use of water and energy, model-based optimization, reducing sewage and the amount of fertilizer used. The reduction of fish water emission saves costs for fresh-

water and wastewater treatment and protects the environment and regaining evaporated water 3) Reduction of freshwater consumption. Compared to conventional (RAS) which requires a daily water input representing 10 % of the total amount of water circulating [4, 6], INAPRO cuts this rate to 1–3 %. The freshwater demand is minimized by a secondary clarification step in the RAS circuit and using evaporated water from the plant section which is regained via cooling traps 4) Automated system management. Production conditions are adjusted automatically model-based on the analysis of different sensors and historical data 5) Competitive advantages. High-value products for consumers who are concerned about the environmental impact. Transparency through product tracing, achieving higher retail prices.

5 Conclusions

An example of cognitive farming in the form of an aquaponics system has been presented. It is based on the double recirculation technology, which enables the creation of optimal conditions for both fish and plants. Fish and plant health and welfare are ensured with the help of smart sensors monitoring water quality and biological parameters of the fish and plants in the fish tanks, before and after the filters, for monitoring fertilizers before and after the plant storage tank. Cameras are installed to measure fish and plant growth. The management system does not follow the outdated classical automation pyramid with its bottom-up, layer to layer structure. It looks at the digitalization of the whole value chain from production to customers. This will enable full traceability and transparency in the processes, increasing consumers' trust in aquaponics products.

References

1. Loic B., Van Loi C. and James M. Collective anomaly detection based on long short term memory recurrent neural network, 2017.
2. D. Karimanzira, K. Keesman and W. Kloas. Efficient and economical way of operating a recirculation aquaculture system in an aquaponics farm. *Aquaculture Economics & Management*, 21: 1–18, 12 2016.
3. D. Karimanzira and T. Rauschenbach. Enhancing aquaponics management with iot-based predictive analytics for efficient information utilization. *Information Processing in Agriculture*, 6, 09 2019.
4. W. Kloas, R. Gross and D. Baganz. A new concept for aquaponic systems to improve sustainability, increase productivity, and reduce environmental impacts. *Aquaculture Environment Interactions*, 7, 01 2015.
5. Tae J. L., Justin G. and Nesime T. Greenhouse: A zero-positive machine learning system for time-series anomaly detection, 2018.
6. D. Lastiri, C. Geelen and H. Cappon. Model-based management strategy for resource efficient design and operation of an aquaponic system. *Aquacultural Engineering*, 83, 07 2018.
7. Chien Lee and Yu-Jen Wang. Development of a cloud-based iot monitoring system for fish metabolism and activity in aquaponics. *Aquacultural Engineering*, 102067, 03 2020.

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