A Fish Activity Monitoring System for Early Detection of Water Contamination

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Keywords

Fish activity monitoring system, motion analysis, tracking and counting, and computer vision method.

Introduction

The use of living organisms or enzymatic reactions as toxicity indicators is gaining prominence in the application of drinking water security [1]. Relevant prior arts can be referred to the works by [2]-[6]. By monitoring adverse biological effects on test organisms, end users are able to confirm the presence of toxins in the water supply prior to performing further analysis of determining the exact nature of threat. The key advantages of monitoring adverse biological effects are its rapid response and ability to be used at critical locations, such as at downstream of a water distribution system, before the biological process in a waste-water treatment plant, etc.

Throughout the years, the Public Utilities Board (PUB), Singapore's national water agency, has used fish to monitor the toxicity of the water in the entire water loop, from collection to treatment and distribution of the treated water. These fish monitoring systems are deployed at source water intakes, within the waterworks and at key control points such as along trunk mains and service reservoirs. CCTV with telemetry link to 24/7 Operation Centres were employed to remotely monitor the well-being of fishes in the tanks. Recently, more advanced Fish Biosensors were deployed which monitors the breathing pattern of the fishes using electrical signals [7]. These systems are not only capable of monitoring the fish automatically but also alerting operators at the 24/7 centres whenever the fish is agitated by any toxicity present in the water. These Fish Biosensors systems are more elaborate to setup and expensive to install and maintain. Institute for Infocomm Research and PUB has thus come together in this current project to develop a system using image profiling to monitor the activity of the fish in conventional fish tanks for detecting water contamination.

We name the system: Fish Activity Monitoring System (FAMS). The proposed system performs real time image processing of a group of fishes and counts the numbers of active and non-active fishes, where these fishes are exposed to water from selected sources. It is a computer vision based solution, in which cameras are used to provide 24/7 visual monitoring. Software algorithm based on background modelling and subtraction [8],[9] are developed to perform automated segmentation of fishes. Since our problem deals with counting a group of fishes within a confined area, occlusion which results from some fish hiding behind others from the camera's view has posed a challenge. To address such a challenge, a splitting method to resolve overlapping in the view based on fish shape model is developed. Criteria are imposed to ensure the estimation of fish count achieves a close approximate to the actual count. To analyze fish activity, attributes that describe movement of fish, such as motion trajectory, velocity and direction of movement are extracted. Based on these attributes, an alert notifying scheme is designed and tested based on realistic experiments with an addition of the contaminant to the water.

Typically, a water supply network will have various critical control points such as surface water reservoirs, waterworks, pumping stations and service reservoirs located in a wide geographical area. To cater for the setting in an actual water supply network, a network communication module is also developed to allow two-ways communication between the server at the control centre and the individual monitoring unit at the remote site. This project has been motivated by the needs of PUB's water supply network. The proposed FAMS aims to enhance the security measure of drinking water by providing 24/7 monitoring and triggering alarm when detecting anomalies in fish activity.

The proposed FAMS unit

Hardware design of FAMS

The hardware design of the proposed FAMS unit houses a fish tank, cameras and other necessary components that give constant light and controlled test environment as presented in Figure 1. The mid-section of the apparatus houses a fish tank in which a partition unit is placed within. The partition is shaped like a pyramid with its top portion removed to optimize the observation view by ensuring no blind spot within viewing area of the top-view camera. A certain number of fish to be monitored are placed within this pyramid-shape partition. There are ventilation holes on this partition to allow water to pass through. A light box is placed at the lower section to illuminate the viewing area.

Besides the first camera, a second camera is positioned on the side of the fish tank so as to capture the region below the water surface. This provides a view of fish staying or floating near water surface. In addition, a speaker is placed touching fish tank as an option to disturb any less active fish as a confirmation before alert is being triggered. The entire set up is then enclosed to ensure no external light penetrating into the box.

This proposed apparatus is designed such that it is standalone and independent of external lighting conditions. It thus provides a constant environment for the monitoring task.

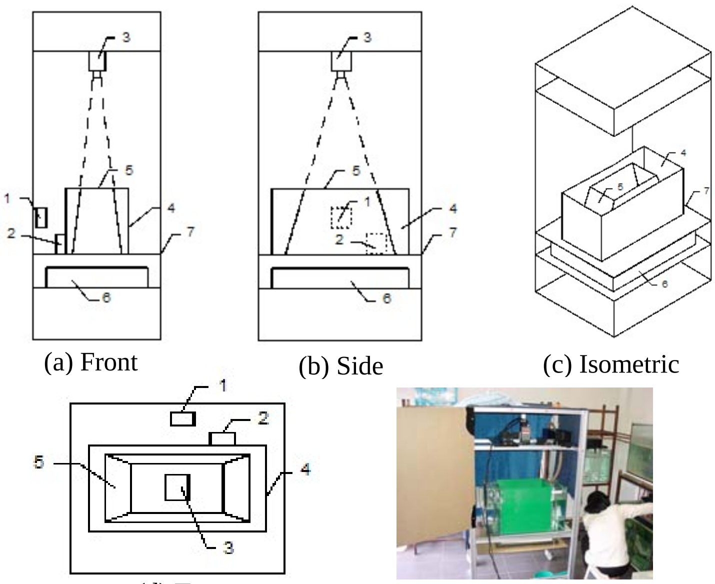


Figure 1. The proposed fish activity monitoring apparatus. It houses fish tank, cameras and other necessary components that gives constant light and controlled test environment.
(Legends: 1 - front camera, 2 – speaker, 3 – top camera, 4 – fish tank, 5 –partition, 6 – light box)

Software architecture of FAMS

Figure 2 gives an overview of the software architecture of the proposed FAMS. Our FAMS algorithm reads live video footages and decomposes the video into a series of images. The first processing module of our algorithm involves segmenting fish from background based on statistical modelling of the background and followed by background subtraction step. This is to achieve fish detection from the background with result in the form of a binary silhouette map containing the foreground. After the detection step, the next step involves labelling the detected fish into separate entities by assigning a unique ID to each fish. At the same time, this allows the counting to be done. When addressing a crowded scenario where silhouettes of close foreground targets overlap and results in a large contiguous blob, our system performs a splitting step to resolve overlapping based on fish shape model. After this, tracking is performed to have a same target being followed temporally, while keeping the same ID for the same target. Multiple attributes such as motion trajectory, velocity, direction of movement, etc., are extracted once a target is successfully tracked. Our system performs the analysis based on fish motion activity for every instance, and triggers an alarm immediately once the anomaly in fish activity is detected.

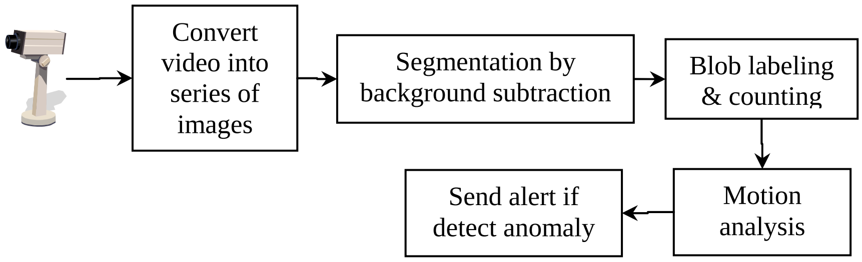


Figure 2. Software architecture of FAMS

Automated fish segmentation

The detection of fish from the image background is achieved by statistical modelling of the image background and background subtraction steps [8],[9]. Fish which is the foreground in our context is detected by identifying image pixels with relatively large deviation from background statistics. Segmentation is done by firstly computing statistical model of background scene. Then, changes at every instance in the background are computed by comparing every current frame with respect to the background models. In the similarity measure w.r.t. the background, normalized Mahalanobis distance is computed at every pixel. Our system will recognize a region as a foreground object if the region is sufficiently dissimilar from the modelled background. A binary map is then formed comprising background and foreground respectively, in which regions corresponding to foreground targets are known as motion blobs.

One technical consideration of this module is to ensure consistent and robust detection of fish over long operation hour. We have carried out long hour evaluation of the system to ensure consistent detection performance can be achieved. Figure 3 shows promising results of one of the tests.

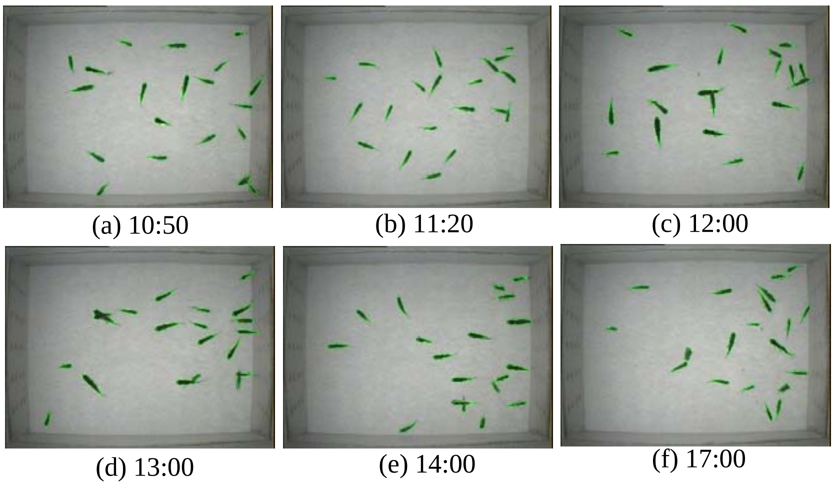


Figure 3. Shows consistent segmentation results over a long hour of operation.

Fish counting

Segmentation task from previous section produces a binary map comprising background and foreground (fish). Connected components labelling is performed in this module to group detected foreground pixels into components based on pixel connectivity for object counting purpose. Pixels from a same blob are to be given a same label, where each blob is then given a unique ID.

When addressing a crowded scenario, silhouette mask of close foreground targets may overlap to result a large contiguous blob with foreground targets become inseparable. To have more accurate count of the number of fish in occlusion, our system involves a splitting step to resolve overlapping based on fish shape model. Denote a contiguous blob in frame-*t* as M^t, which is the union of silhouette maps belonging to a group of close foreground targets. Let also γ_i^t be the parameters vector characterizing an ellipse-shape model for foreground-*i*. The problem involves a process to identify a set of $\Gamma = \{\gamma_i^t\}$ such that this splits a contiguous blob into smaller ellipses. Equivalently, we formulate the problem to maximize a posteriori given by:

$$\Gamma^{t*} = \arg\max_{\Gamma} P\left(M^t \mid \Gamma^t\right) P\left(\Gamma^t \mid \Gamma^{t-1}\right)$$

To measure the goodness of fitting $\{\gamma_i^t\}$ to M^t, the aim here is to find a solution such that $\{\gamma_i^t\}$ in the image lattice space gives: i) a good coverage that includes as many considered foreground pixels but fewer background pixels and ii) there will be minimum overlapping between any two ellipse-shape models to ensure the visibility of each ellipse. Figure 4 shows detailed steps taken in the blob splitting process.

Analysis of fish activity and alert triggering

In the monitoring process, once a fish is successfully tracked, multiple attributes such as spatial location of the centroid, body orientation and size are extracted. From the temporal sequence of these attributes, other attributes such as motion trajectory, velocity, the rate of orientation change, moving directions, regularity of motion are obtained as well. Tracking of each individual target is performed by associating current centroids to projected centroids established in the history. The projection of centroids is performed by means of Kalman filter or linear projection.

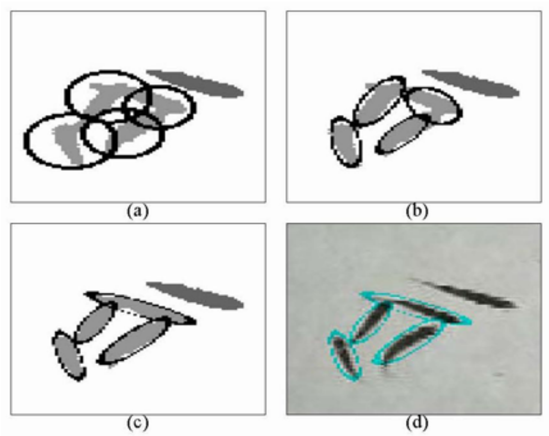


Figure 4. Steps taken in blob splitting process. (a) Clustering based on Euclidean distance that gives round-shape fitting; (b) Improved fitting by computing Mahalanobis distance and computing ellipse parameters $\{\gamma_i^t\}$; (c) Parameters of ellipses $\{\gamma_i^t\}$ are perturbed to give better fitting; (d) Final result of the blob

To take into consideration where monitored targets may be at rest or asleep for certain period of time in a continuous monitoring process, the system needs to tolerate certain degree of inactiveness of the organisms in order to minimize false alarm rate. At every instance, our system computes the likelihoods of triggering yellow and red alerts. Alert will be sent to the control centre once the likelihood of triggering a yellow or a red alert exceeds a pre-determined threshold.

Network configuration and user interfaces

To cater for the setting where water reservoirs and control centre are at different geographical locations, a network communication module has been developed that allows two-ways communication between the server at the control centre and individual monitoring unit at the remote site. In the setup, service reservoirs at remote sites are connected to control centre via Singtel's MegaPop, which is a dedicated point-to-point connection as given in Figure 5.

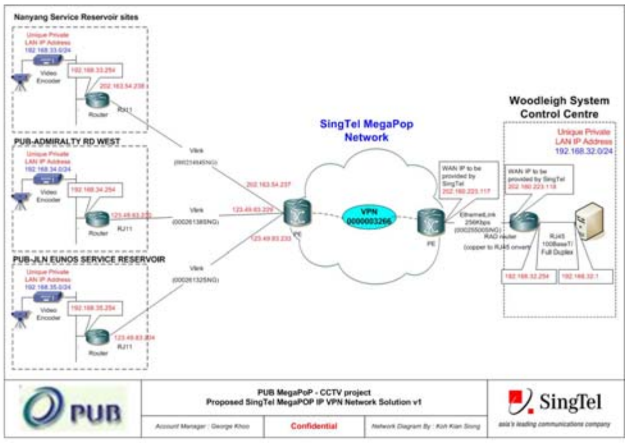


Figure 5. Singtel's MegaPop network configuration

Figure 6 shows the FAMS network software running at control centre. It comprises four display windows, which are: i) alert windows – the two display windows on the top row which are dedicated for displaying alert images. Images of the first alert will be displayed on the top left window and followed by displaying images of the second alert on the top right window. If there are three alerts arriving at almost the same time, the third alert will overwrite the first alert on top left window. However, images of the first alert can be play-backed by selecting the alert event on logging window to be viewed on the review window; ii) review window - it is meant for playback alert images received. This can be done by selecting alert events recorded in the Logging window and followed by pressing the Review button; iii) polling window - when there is no alert received, the FAMS network software will automatically poll images from different tanks at different service reservoirs in a round robin manner. The time gap between one polling and the next is currently set to be 30s, but which can be adjusted.

Figure 7 meanwhile presents the FAMS software that runs at service reservoir.

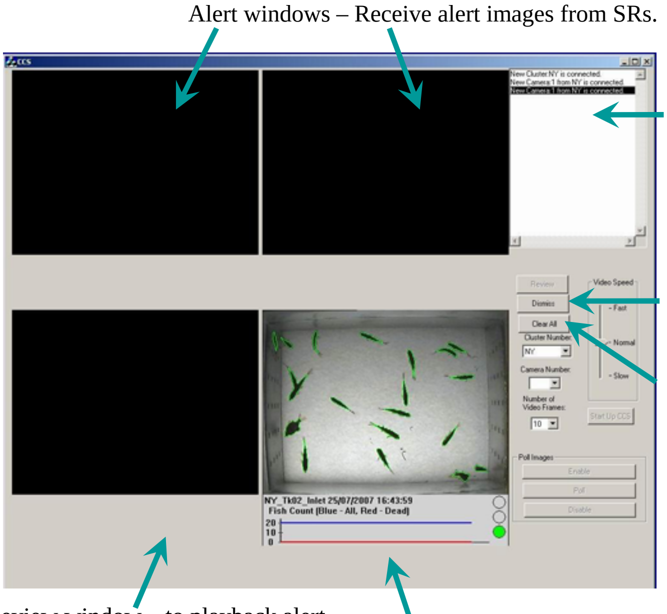


Figure 6. User interface of FAMS network software that runs at the control centre.

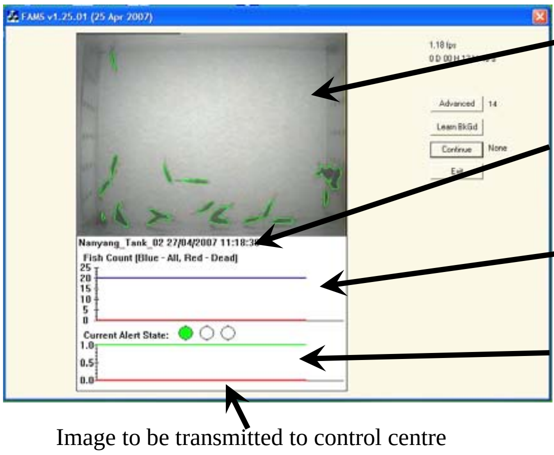


Figure 7. User interface of FAMS unit that runs at service reservior.

Experimental results

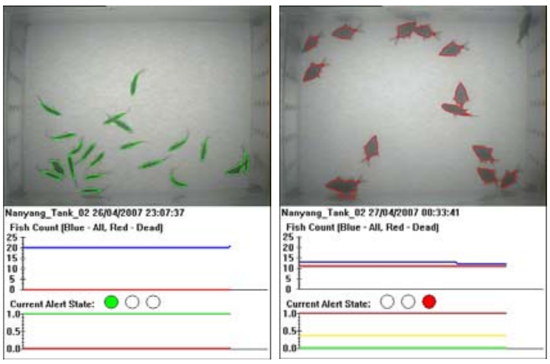
Table 1 illustrates one set of tests performed at PUB's water network. Three FAMS units had been installed at three different service reservoirs, named N1, W1 and E1, and these three FAMS units were linked via Singtel's Megapop network back to the serve at control centre. In the test, alerts triggered by the three FAMS units at remote sites were verified by checking the alerts received at the control centre, which are tabulated in Table 2. Results show that the developed FAMS system had performed to what it is expected by meeting the requirements of the test. In Figure 8, we present typical scenarios observed for normal and alert conditions.

Table 1. Test scenarios

	Test scenario
1	Keep 20 live fish in N1, W1 and E1.
2	Add reagent to lower pH in N1. W1 and E1 maintain 20 live fish each.
3	Add reagent to lower pH in W1 and E1 at almost the same time.
4	Replenish 20 live fish to three tanks. Add reagent to lower pH in N1, W1 and E1 at the same time.
5	Replenish 20 live fish to three tanks. Select E1 to remove dechlorination unit.

Table 2. Alerts received at control centre for tests given in Table 1

	N1	W1	E1
Test 1	No alert	No alert	No alert
Test 2	Yellow alert then Red alert	No alert	No alert
Test 3	Maintained red alert from Test 2	Yellow alert then Red alert	Yellow alert then Red alert
Test 4	Yellow alert then Red alert	Yellow alert then Red alert	Yellow alert then Red alert
Test 5	No alert	No alert	Yellow alert then Red alert



(a) Normal condition (b) Alert condition

Figure 8. Typical examples of a normal condition and an alert condition.

Conclusion and Future works

In this paper, we presented a water quality monitoring system, which is named as Fish Activity Monitoring System. In this work, three FAMS prototype units had been developed and integrated to the PUB's water network for evaluation in actual scenarios. Based on the test results, we conclude that the current FAMS has satisfied the requirements being a prototype system that can be placed in the PUB site for trial testing and for alerting the central monitoring station when an alarm occurs, and also for providing an image of the fish tank where the alarm occurs. From the experiments, we are also confident that the project is moving in the right direction towards meeting the project requirements and operational need. In addition, the developed prototype is ready to be further extended and scaled up for future deployment plan.

As a continuous effort to improve the system, our on-going research looks into the development of an early warning system with the capability of recognizing unique behavior of fish, when the fish senses danger caused by harmful level of toxin in the water. To achieve the objective, we will look into the analysis on group motion patterns like detection of circular/erratic group motion, detection of struggle activity to escape, measuring number of active fish versus number of non-active fish, etc.

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