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Real-time monitoring of water quality using temporal trajectory of live fish

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ABSTRACT

This paper proposes a real-time water quality monitoring scheme, which is based on judging time-series motion trajectories of live fish acquired by a CCD camera. The proposed scheme includes a floating-grid method to extract patterns in the motion trajectories and a neural network mechanism to quickly determine the frequency of pattern changes in these trajectories. To validate the proposed methods, several experiments were conducted by changing pH values of the water that houses live fish. The experimental results showed that the proposed methods could effectively differentiate motion trajectories of the fish in an efficient manner. The proposed scheme could be employed as a precautionary warning system for aquatic farms, drinking water treatment plants, and other related industries.

1. Introduction

Water quality is an important factor in aquatic farms, drinking water treatment plants and other related industries since contaminated water not only claims losses of aquatic products, but also leads to severe threats on human health. Generally, water sources of aquatic farms or drinking water treatment plants are mainly acquired from natural sources such as rivers, lakes, reservoirs and groundwater. Contamination of these sources could include sudden mountain soil downpours caused by typhoons or earthquakes, and waste dumping by human beings. The latter might even contain some noxious chemical substances, which could dramatically deteriorate the water quality. Although certain procedures are conventionally employed for purifying the source water, the outcome could still fall under the acceptable level of quality when heavy pollution is suddenly present. Under such a situation, the cost for the purification facilities of these industries will greatly increase; even worse, some of the facilities might not be operational for months because some pollutant residuals require time to be neutralized. For example, the multi-thousand aquatic farms with varied scales in Taiwan claim losses of hundreds of million dollars each year in the typhoon season. This is mainly because most of the farmers could not be informed timely when the water source is being deteriorated. Therefore, a precautionary system that sends out instantaneous warnings upon the source water is being contaminated becomes very desirable.

To send out timely warnings of bad water quality from a precautionary system is somewhat complicated because determining whether a particular substance exists in the water is often time-consuming because it requires a sequence of lab tests. As there are a great number of unknown substances that could jeopardize the water quality, it becomes virtually impossible to implement such a system. We observe that some ornamental fish are very sensitive to their surrounding water environment. The sensitivity could be visualized by connecting time-related locations of the fish in a sequential manner, also referred to as temporal trajectory, which could vary to some extent, e.g., sudden changes of speed or direction, as abnormalities are present in the water. With the advent of digital imaging technologies, the temporal trajectory can be recorded in real-time by CCD cameras. These real-time recordings are then compared with a database containing trajectories of the same fish in normal water for determining whether the current movement has been “seen” before, using a discrete trajectory representation and an efficient matching scheme proposed in this paper. In short, our implementation for the precautionary system is based on discriminating motion trajectories of live fish in real-time.

Temporal trajectories of moving objects have been profoundly utilized in analyzing behaviors or extracting semantic contents of the target objects in the past decade. For example, Yacoob and Black (1999) presented a model formation to distinguish each motion by generating eight motion trajectory parameters to represent the activity, and the parameters were obtained from the five body languages when people walk. Ricquebourg and Bouthemy in 2000 described a video-surveillance application by analyzing human motion in an image sequence, which could track the apparent con-

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tours of a moving articulated structure. Bobick and Davis (2001) developed a view-based approach in recognizing human movement using temporal templates, which was tested on aerobics exercises. Shan, Wei, and Tan (2004) proposed a mean shift embedded particle filter for tracking human hand, and the hand gestures were recognized by a two-layer classifier based on temporal based trajectories of the hand. Min and Kasturi (2004) utilized Hidden Markov Chain to implement human activity recognition based on motion trajectories generated from body parts, such as hand, feet and joints. Kang, Hwang, and Li (2006) extracted the trajectories of 22 players and a ball in a soccer game, and developed a model for expressing the performance of the players based on the trajectory relationships among the 22 players and the ball in a quantitative way. Hu et al. (2006) proposed a system that could automatically learn motion patterns based on statistical methods to detect abnormalities and predicts behaviors of a crowed traffic intersection scene. Nara and Torrens (2007) utilized trajectories acquired by Global Positioning System for analyzing pedestrian egress behaviors and efficiency in a crowed environment. These applications were all devoted to recognizing actions of moving objects in 3D space based on their 2D trajectories acquired from a proper viewpoint.

Since the majority of temporal trajectories are presented in a continuous form, i.e., streaming data, and their movements could vary with respect to time, e.g., direction, speed and acceleration, researchers have proposed methods to extract defined features from them or transform them to specific formats, prior to storing in a database, for further querying or indexing purposes in a convenient and efficient way. Chon, Agrawal, and El Abbadi (2001) described the space in time domain as a grid, which was utilized to model a trajectory of a moving object as a polyline. Lin, Keogh, and Chiu (2003) introduced a new symbolic representation of time-series allowing dimensionality reduction, and distance measures could lower bound corresponding distance measures defined on the original series based on the proposed representation. Chen, Ozsu, and Oria (2004) proposed a trajectory representation called movement pattern strings, which convert the trajectories into symbolic representations, and both movement direction and distance information are encoded in the strings. Bakalov, Hadjieleftheriou, Keogh, and Tsotras (2005) proposed an approach that represents an object trajectory as a sequence of symbols based on special lower-bounding distance between two strings, and a pruning heuristics for reducing the number of trajectory pairs that need to be examined. Zhang et al. (2006) employed a dynamic programming algorithm to split one trajectory to get the minimal total volume of segments from the splitting. These trajectory modeling or approximation approaches are generally associated with a querying or indexing mechanism in which matching or predicting a trajectory acquired in real-time could be achieved.

Querying or indexing a trajectory in a database is a key issue for applications based on temporal trajectories. Moving patterns of an object could be efficiently extracted or approximated through such a process if the trajectories are properly formatted in the database. Black and Jepson (1998) described a framework utilizing the CONDENSATION algorithm based on random sampling techniques to incrementally match the trajectory models to variant input data. A framework for handling temporal queries with inexact matches using relation similarity was proposed by Papadias, Mamoulis, and Delis (2001), in which multidimensional data and flexible query-answering could be achieved. Fablet and Bouthemy (2003) proposed an approach for motion characterization in image sequences, which relies on a probabilistic modeling of temporal and scale co-occurrence distributions of local motion-related measurements. Pelanis, Saltenis, and Jensen (2006) developed an indexing technique capable of capturing positions of moving objects at all points in time. The performance of a time-slice query is independent of the number of past position samples stored for an object using this technique. Hadjieleftherious, Kollios, Tsotras, and Gunopulos (2006) incorporated a number of algorithms and heuristics in combination with a multiple index structure to greatly improve query performance comparing with straight-forward approaches. Bashir, Khokhar, and Schonfeld (2007) presented classification algorithms for recognizing object activity using motion trajectory, in which trajectories were segmented at points where curvature changes and the segmented trajectories were represented by their principal component analysis coefficients. Hidden Markov Models with a data-driven design were utilized to capture the temporal relations and ordering between the segmented trajectories.

In this paper, our goal is to determine whether the swimming patterns of fish are apparently different from the normal ones. Classifying the swimming patterns according to some hazardous substances in the water is not only difficult but also unnecessary for the precautionary system. Therefore, our approach must firstly construct an archive containing normal swimming patterns for fish, which is accomplished by collecting the swimming patterns in an off-line mode for a period of time with unpolluted water. When the system is operating on-line, a series of patterns are continuously acquired and compared with the archive for checking their existence in the archive. Since the checking must be efficiently performed considering the size of the archive could be very large, we characterize the trajectories as string patterns using a moving-grid method, and subsequently employ a neural network mapping specializing in string handling and recollecting for meeting the efficiency need.

2. Water quality precautionary system

The proposed precautionary system includes two phases, i.e., the off-line and on-line ones. Each phase is composed of three steps of operation: (1) track and determine the current position coordinates of the fish, (2) convert the trajectory formed by the position coordinates into string representation and (3) submit the string pattern to the neural network mapping. The first two steps are the same for both the on-line and off-line phases, whereas the third step is different. For the off-line phase, the output error from the neural network mapping for an input string is disseminated to elements responsible for contributing to the error, while in the on-line phase the output error represents the status of the input string, i.e., included or not included in the normal-trajectory archive. Since the motion trajectories of fish are collected by a CCD camera, the fish is placed in a specially-designed glass container, where the thickness of the container is intentionally reduced to confine the movements of the fish along the third axis. To alleviate noises causes by human beings or some other disturbances, the container is placed in a isolated space with fixed lighting and stable water flow. Feedings are carried out on a daily basis by an automatic feeder. The layout diagram for the precautionary system is shown in Fig. 1.

2.1. Position tracking of the fish

Since fish are not rigid bodies and their movements are three-dimensional, they will appear as a cluster of grey pixels on images acquired by the CCD, given that the background is white. Yilmaz, Javed, and Shah (2006) pointed out that tracking objects can be complex if the objects are non-rigid or of articulated nature. Veenman, Reinders, and Backer (2001) utilized the centroid to represent an object's position on the image coordinates. In this paper, we also employ such a method to designate the fish's position. To determine the fish's whereabouts on the image, a full