Simulation of Agent-Based Negative Selection Model (ABNSM) for Reservoir Water Level Monitoring

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Abstract. Reservoir water level monitoring is an important process during heavy or light rainfall to determine the volume of reserved water. Mistakes in data recording by the dam operator can lead to disasters. Data from different gauging stations are collected to determine whether to release water in the dam or not. The decision to release water is critical because it can affect the volume of water left in the dam for both drought and flood seasons. Constant water level monitoring is difficult because of the changes in water level. To overcome this issue, intelligent agent-based architecture is proposed for reservoir water level monitoring by imitating the artificial immune system. This paper presents the agent technology where agents communicate with each other concurrently by sending online data from different gauging stations to the main reservoir. One of the techniques in the artificial immune system is known as negative selection and this technique has been chosen as a water level monitoring model.

1. Introduction
A dam is a physical structure that is built to prevent or limit water flow. It can also be built for forcing the river to generate electricity, for human activities and agricultural uses, as well as to control flooding in downstream ecosystems. This means that the amount of water being poured out of the dam will be controlled depending on the current requirements. A reservoir, on the other hand, is a natural or an artificial lake that is designed to store water and to suppress floods. It can also provide water for human activities, such as irrigation, drinking and cooking, as well as for industrial and aquaculture uses. Moreover, the reservoir can also act as a defence mechanism against flood and as a water source during a drought. [1] stated that reservoirs can be classified into two types, namely as a single and multipurpose reservoir systems. A multipurpose reservoir system is more complex than a single reservoir system and is classified based on its purposes and functions.

Flood is one of the sudden disasters that can endanger human lives and properties. In Malaysia, the flood response operation involves multiple agencies working together under a Flood Management Committee for each district, such as the District Office, Fire and Rescue Department, Royal Malaysia Police, Social Welfare Department, Drainage and Irrigation Department, Health Department, and Public Works Department [2]. Making the right decision for reservoir operation is crucial to prevent excess water (floods) and to mitigate water shortage (droughts). These problems can disrupt the quality of lives and the economic growth of a country, resulting in severe damages and loss of...
properties, and occasionally, the loss of human lives. Therefore, early warning systems for water level monitoring are an attractive solution for flood management.

The decision to open the reservoir gates is usually made by the dam engineer by analysing rainfall and water level measurements. Nonetheless, the dam engineer might not have the appropriate measurements because of errors by new officers and inexperienced staffs. When officers are transferred to a new place, they would bring their expertise as well. Newly appointed engineers who take over their position would need to learn the basics to become an expert, which takes a long time. There are various factors towards becoming an expert, such as education, training, and knowledge that could affect their ability to make viable decisions in an emergency.

Today, many computational applications based on human biological processes have been developed for emergency decision making, such as neural network, data mining, and artificial immune system. Negative selection algorithm (NSA) is one of the methods found in the Artificial Immune System (AIS), which was adopted from human immune process. AIS is widely used in anomaly detection [3], data mining [4], computer security [5], network security [6], and other applications of AIS [7].

NSA is also applied in various complex areas, such as for monitoring and decision making in emergency situations. The ability of T-cells to distinguish self and non-self will encourage researchers to expand the use of this algorithm in more complex computer applications. Table 1 shows the different applications of NSA following improvements to the technique over time.

| Author | Technique | Application |
|--------|-----------|-------------|
| [8]    | Self-adaptive NSA | Anomaly detection |
| [9]    | Real-value NSA | Fault detection |
| [10]   | Modified Real Value NSA | Fault diagnosis |
| [11]   | New detector model and matching rule model | Spam detection |
| [12]   | Mobile Agent-based AIS | Machine condition monitoring |
| [13]   | Immune Optimisation Based Real-Valued NSA (IO-RNSA) | Anomaly detection |
| [14]   | Novel negative selection algorithm (NNSA) | Recognising problems |
| [15]   | NS-based Decision Support System | Monitors and controls public bus transportation systems |
| [16]   | Extension negative selection algorithm (ENSA) | Comparison between ENSA with RNSA and V-Detector algorithm. |
| [17]   | Improved NSA Based On Subspace Density Seeking (SDS-RNSA) | Anomaly detection |
| [18]   | NSA | Chemical process |

Researchers are currently working to combine AIS techniques with other techniques to enhance their capabilities, known as a hybrid technique. Existing hybrid techniques may include combinations of AIS and genetic algorithms [19, 20], fuzzy and AIS [21], AIS and swarm intelligence (SI) [22], AIS and artificial neural network [23], and AIS and mobile agent [24]. The NSA has been improved over time to address the weaknesses in the conventional algorithm. The similarities between the immune system and the intelligent agent have spurred efforts to combine these two techniques for water level monitoring applications.

2. Overview of reservoir water level monitoring
The Timah Tasoh Dam is located at the junction of two major rivers, namely the Timah River and the Tasoh River. The geographical coordinates of the dam are 6°34′U, 100°14′T. The nearest town is Kangar, about 17 km south of the dam. The Timah Tasoh Dam is an important component of the water resource management system in the northern part of Peninsular Malaysia.
Reservoirs are physical structures that are naturally created or artificially developed for the purpose of impounding and regulating water. There are four main components in a reservoir, namely, upstream, reservoir catchment, spillway gate, and downstream. Reservoirs are developed for a specific purpose, but they can also be multipurpose. Therefore, to ensure that the reservoir is in good condition, it is important to monitor the process regularly.

Reservoir water level monitoring is a process of continuously observing the water level to ensure that the reservoir maintains a high water volume during less rainfall and has enough space for incoming heavy rainfall. Proper handling of water level monitoring is critical because it is highly ambiguous, dynamic, time pressured into making decisions, as well as involves multiple players and experienced decision-makers. The reservoir, when functioning as a flood mitigation mechanism, requires fast and accurate decision in determining water release.

In the reservoir operation, decision making is one of critical process and need some experienced officer. During the heavy raining season or less rainfall season, reservoir operator has to determine whether to maintain the water level or to release the water. The decision making for release the water is very crucial because the wrong decision will impacts the human life. During flood season, early water release decision should be established to prepare the reservoir for incoming in-flow. While during drought season, reservoir water level should be maintained in order to sustain the supply and other usages. To maintain the water level, best action should be taken by the efficient monitoring system.

Thus, major functions of reservoir operations are monitored and managed by qualified and experienced reservoir operators. The conceptual model of a reservoir system is presented in Figure 2.
Figure 2 shows the main components of the reservoir system. The reservoir water level is closely related to the amount of rainfall distribution in the upstream and reservoir catchments. These rainfall data are obtained through the telemetric system at these stations. These data are recorded hourly by the dam operator into the operation log book. At the spillway gate, data for the number of gates opened, the size of opening, and the opening duration are also recorded manually.

Monitoring water level is important because any changes in reservoir water level may also affect the storage that influences the decision to release water [1, 2]. Therefore, this decision is not easily made. Detailed studies need to be conducted to avoid any possible adverse events. Among the possible disasters are floods, damaged dams or inadequate water supply during the drought seasons. Several approaches are used in water level monitoring operation, as listed in Table 2.

Table 2 Applications of water level operation with different techniques

| Author | Computational Algorithm | Technique | Domain |
|--------|-------------------------|-----------|--------|
| [25]   | Fuzzy Logic             | Fuzzy inference system | Forecasting water level (WL) |
| [26]   | Neural Network          | Regression analysis | Relationship between rainfall and Timah Tasoh reservoir water level |
| [27]   | Artificial Neural Network | Feed forward backpropagation | Forecasting of reservoir WL |
| [28]   | Artificial Neural Network | Feed Forward distributed time delay | Forecasting reservoir WL |
| [29]   | Artificial Neural Network | Bayesian regularisation backpropagation training algorithm is employed for optimising the network | Forecasting reservoir WL |
| [30]   | Immune system           | Multi-objective immune algorithm | Reservoir flood control operation |
| [31]   | Neural Network          | Propagation algorithm and sliding window 2 | Forecasting reservoir WL |
| [32]   | Artificial Neural Network | Sliding window technique | Forecasting reservoir WL |
The human immune system is a good inspiration for developing a new method that could address various computational problems. The immune system, through the use of B-cells and T-cells, can launch an attack against invading antigens and destroy them from the system. The immune system has the capability to retain information on the antigens for future use. This process is known as the secondary immune response that can be triggered to eliminate infection. This study will concentrate on agents and their characteristics in order to develop a model of the Artificial Immune System by adopting the intelligent agent approach. The intelligent agent system has similar features with the immune system and can be used to provide a new scope for applying immune system methodologies. An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors.

The AIS have appeared as a new computational approach for the Computational Intelligence community, inspired by biological immune phenomena and biological medical theories [43]. The AIS technique has been applied to a wide range of applications. AIS is an adaptive system that was inspired by theoretical immunology and observed immune functions, principles, and models, which are applied for problem solving [44].

The similarities between an agent and the immune system have prompted this study to explore AIS modelling based on the agent approach, and to seek ways to integrate agents into AIS application. [45] reported that the distinct similarities between the agents and the immune system are because of their distributed or decentralised systems. Both have multiple autonomous entities, as well as individual and global goals. These systems learn from their experience and they are adaptable to the changes in the environment and act accordingly. They can communicate, coordinate, and pass knowledge within their
system to make intelligent decisions. Therefore, the immune system and the intelligent agent architecture are derivable.

3. Proposed system

This study proposes a model of an early warning system for water level monitoring, as an attractive solution for flood management. Figure 3 shows the proposed architecture for reservoir water level monitoring.

![Proposed Architecture](image)

Figure 3. Proposed Architecture

Upstream stations will record and collect rainfall data over time. This record will be reviewed every 5 seconds. Then, the collected data will be sent to the reservoir station. At this station, the data will automatically display the rainfall status of each upstream station. This process makes it easier for operators to record and subsequently, notify the relevant parties about their current status at the reservoir station.

The main objective of this system is to share data online and in parallel between the components of the monitoring reservoir system. The upstream station will record the amount of rainfall and send it to the reservoir station. Online data sharing is implemented using intelligent agents located at their stations. The advantages of this developed system are as follows:

I. Data is captured by the online system;
II. Data will be updated if any changes occur;
III. The record will be reviewed every 5 seconds; and
IV. The monitoring process is done automatically by the negative selection model.

Figures 4(a) and 4(b) show the manual and automatic monitoring process in this developed system, respectively.

4. Prototype

The main process in this prototype is divided into 2 main tasks, namely, water level monitoring and rainfall monitoring based on previous operator experiences. This prototype will receive the rainfall data from the gauging station using the online system. Intelligent agents located at each station will release information at the reservoir for further processing. This data will be processed for water level monitoring purposes by taking into account changes in the water level. This system will display changes to the water level immediately. Views on the reservoir can also show the amount of rainfall at other stations. This data will be processed using the negative selection method and through communication between agents to ensure proper water level monitoring in the reservoir system management. The intelligent agent will be on alert mode for 24 hours to monitor any changes on water level. Communication between agents in this prototype has made this system successful. Figure 4 shows the difference between the manual and online processes at the reservoir.
Figure 4. General monitoring: a) manual process; and b) online process using ABNSM

Several agents will be involved, including the upstream agent, reservoir agent, WL Agent, RF agent, NSA agent, and alert agent, as shown in Figure 5. These agents communicate with each other, as shown in Figure 6.

Figure 5. Location of agents in ABNSM
Figure 5 shows where each agent is located within the developed system. These agents will only act based on the assigned roles, and will communicate and transmit the data required by other agents periodically. NSA agents will show action in the event of an emergency resulting from a change in data. There are 6 agents available, namely, the reservoir agent, upstream agent, RF agent, WL agent, NSA agent, and alert agent, as shown in Figure 6.

The agent located at the upstream station will send rainfall information to the agent at the reservoir. The reservoir agent will process the submitted rainfall data and will now update the site for any associated rainfall station. The reservoir agent will also update water level data and will then send the information to the negative selection model to process the data. The results from the negative selection model will be communicated with the alert agent to recommend the next action. The process that occurs within the agent alert will be sent to the reservoir agent for storage. RF agents and WL agents will monitor changes in rainfall and water levels. Figure 7, Figure 8, and Figure 9 show examples of a water level monitoring system.

![Diagram of agent communication process](image)

**Figure 6.** Communication process for each agent

![Example of gauging station page](image)

**Figure 7.** Gauging station page

![Example of reservoir page](image)

**Figure 8.** Reservoir page

![Example of negative selection model page](image)

**Figure 9.** Negative selection model page
This system was developed using web-based language from retrieved data. All related processes are parallel through the online system using the web-based language.

Conclusion
The Agent-based Negative Selection Model was designed to assist dam operators or the flood management committee in monitoring dam water levels. This system enables the collected data to be accessed online, parallel with collected rainfall data at related gauging stations. This model can be used as an alternative for faster information analysis that a dam operator can use to make early decisions for reservoir water release management. This study could be enhanced by using mobile application as an alert message for dam engineer or group of decision maker to monitor any changes situation automatically.

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