Using A Security Monitoring Tool To Improve Operation of the Water Distribution System

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ABSTRACT

Since 9/11, numerous communities have installed multi-parameter monitoring stations as early warning systems for potential water security threats. These continuous on-line systems have recorded large streams of data relevant to water quality in the distribution systems. In this study, data streams from a number of communities are analyzed for pertinent information as to the health and operation of the distribution system. Changes in water quality are correlated with known causes attributable to day-to-day operational and also anomalous events. Information concerning what if any action was taken to ameliorate the problem will also be linked to the data for the identified events. This sort of information is critical in understanding and improving the operation of our distribution systems. We will need to consider databases such as this before we determine the best course of action to ensure our water supplies meet acceptable levels of quality and safety from source to tap.

Keywords: water security, dual use, operations, distribution system, water quality

1 INTRODUCTION

Spurred by the desire for technologies that can detect intentional water contamination, on-line monitoring in the drinking water distribution system has made large strides in recent years Numerous communities have deployed such systems to protect against intentional attack. For the past several years, scientists at Hach Homeland Security Technologies (HST) have been actively engaged in the development and testing of an early warning system for detecting water quality problems including those related to an intentional incident. This paper gives a brief summary of how the developed system operates and presents results form some of the recent field-deployment efforts that have been undertaken demonstrating the dual use nature of these systems.

2 METHODOLOGY

The Hach HST approach was to utilize a sensor suite of commonly available water quality sensors linked together in an intelligent network. The logic behind this approach is that these are tried and true technologies that have been extensively deployed in the water supply industry for a number of years and have proven to be stable in such situations. One of the difficulties encountered when designing such a device is that the normal fluctuations in these parameters found within the water can be quite pronounced. The secret to success, in a situation such as this, is to have a robust and workable baseline estimator. Several methods of baseline estimation were investigated. Finally, a proprietary, patented, non-classical method was derived and found to be effective.

In the system as it is designed, signals from 5 separate orthogonal measurements of water quality (pH, Conductivity, Turbidity, Chlorine Residual, TOC) are processed from a 5-paramater measure into a single scalar trigger signal in an event monitor computer system that contains the algorithms. The signal then goes through a baseline estimator. A deviation of the signal from the established baseline is then derived. Then a gain matrix is applied that weights the various parameters based on experimental data for a wide variety of possible threat agents. The magnitude of the deviation signal is then compared to a preset threshold level. If the signal exceeds the threshold, the trigger is activated.

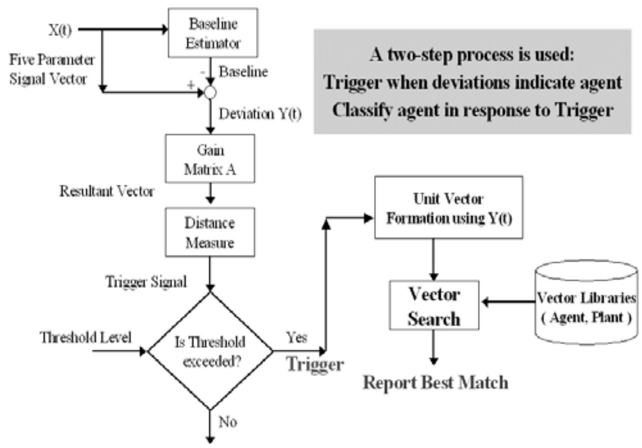

Figure. 1. The use of intelligent algorithms with standard bulk parameter monitoring equipment allows for a robust system that is capable of triggering on and classifying a wide diversity of threat agents including unknown events

The deviation vector that is derived from the trigger algorithm is then used for further classification of the cause of the trigger. The direction of the deviation vector relates to the agents characteristics. Seeing that this is the case, laboratory agent data can be used to build a threat agent library of deviation vectors. This system can be used to classify what caused the trigger event. This system can also be very useful in developing a learning-based system for classifying normal operational events that may be significant enough in magnitude to activate the trigger. The events learned on-site are referred to as the plant library.

If no match is found, the event is classified as an unknown and can be named if an investigation determines its cause. This is very significant because no profile for a given event need be present in the libraries for the system to trigger. This gives the system the unique ability to trigger on unknown threats and events. Also, the existence of the plant library with its heuristic ability to learn plant events results in a substantial and rapid decrease in unknown alarms over time and offers a tool for system optimization. The developed system has been subjected to strenuous testing in both laboratory and field scenarios.

3 RESULTS

Prior to development of this system, very few utilities carried out data collection in the distribution system other than periodic grab samples. Since the initiation of this program over, 500,000 hours of real time data has been collected across a wide variety of different distribution systems exhibiting different water matrix profiles revealing many interesting attributes of these distribution systems. The following are a few examples of incidents that have been recorded during these real world deployments. These incidents help to demonstrate the systems ability to learn and to become a useful tool not just for security but also for every day operational improvements.

3.1 Grab Sample Versus On-line Case Study

In this situation, the local water utility had in place an extensive system of water monitoring through grab samples. All indications were that the water quality was good. After installation of several water monitoring panels in the distribution system they found that the turbidity spiked to levels as high as 20 NTU during the night and early morning hours when typically no grab samples would have been collected. They also found extremely high variability in chlorine levels during these time periods.

A series of changes to their treatment plant operations and distribution system procedures allowed the system to regain control of the water quality in the distribution system. They were able to lower the turbidity spikes to around 1.5 NTU at night and maintain more consistency in chlorine residual levels resulting in better water quality and consistency for the end consumers.

3.2 Main Break Events

In this situation the system had only just been installed a few days previously. Hach HST personnel were informed that the instruments were behaving abnormally and were giving strange readings. An investigation of the sensors found no problems. A short time later a major main ruptured in a catastrophic mode. The system was able to detect the perturbation in water quality parameters that were precursors to the main break and trigger upon them. Unfortunately, the system was newly installed and the event was not recognized until too late.

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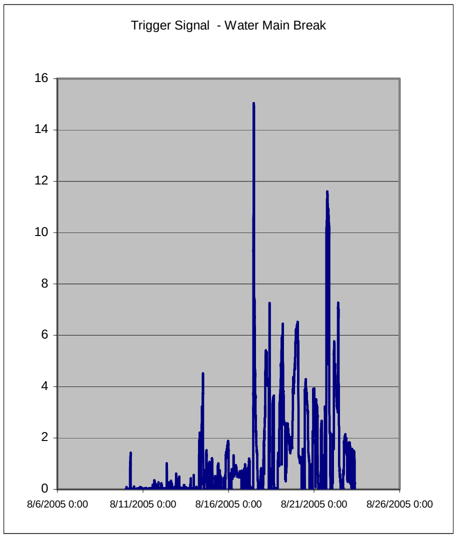

Fig 2. Trigger signal for main break event.

3.3 Effect of Variable Demand

In this deployment, daily events influencing turbidity, chlorine, pH and conductivity are not completely understood but are suspected to be caused by water demand fluctuations in the area. This may indicate a need for more routine flushing of the area's pipes and the instillation of a chlorine booster station.

3.4 Ammonia Overfeed Events

On March 26th, 2007; maintenance was performed at the plant supplying water to the distribution system being monitored. After the maintenance was completed, the plant was restarted and the system that feeds ammonia to create monochloramine as a residual disinfectant overfed the chemical. The person in charge of the on-line monitors immediately noticed the increase in pH and notified plant operations. Operations reported a problem with ammonia feed pumps. The problem was temporarily fixed, but a slug of ammonia was sent into the distribution system. Several customers called, complaining about an ammonia smell and taste coming from the tap. The exact amount of ammonia released was unknown, but was believed to be less than 10 ppm. The facility continued operations but temporarily switched to free chlorine as a disinfectant until July 2nd.

On October 3rd, the same treatment plant experienced a brief ammonia overfeed. In this case, a pump was turned on and not switched off at the proper interval. There was a drop in chlorine and a decrease in pH.

Between August 22 and August 23, 2007, three similar events occurred. Increases in turbidity pH and possibly TOC with drops in chlorine caused triggers. These changes resemble the large ammonia event that occurred in March. The operator believes that these could be ammonia feed events, but could not confirm it or find the fault.

3.5 Possible Chlorine Feed Event

On April 3rd, 2007 there was a turbidity and pH increase and a decrease in chlorine and conductivity. The operator suspects that there was a problem with the chlorine feed at the plant. However this cannot be confirmed. The plant was using free chlorine at the time which rules out the possibility of an ammonia feed problem.

3.6 Caustic Overfeed Event

The plant uses caustic feed to control water pH. The system experienced a trigger that when investigated was identified as an operational problem that resulted in the feed of excess caustic.

The reason behind this was that the vendor from which the casuistic was being purchased had delivered the wrong concentration of the solution. No one had checked to see if the concentration was correct before feeding in the material. New procedures were put in place to verify incoming raw materials. The Event Monitor learned this Plant Event and can identify a recurrence of the event in the future if there is another failure in the system and it is repeated.

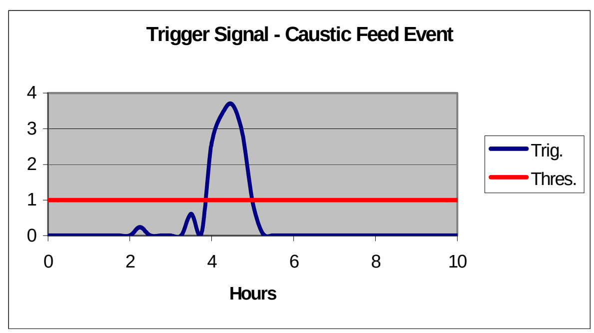

Fig. 3 Trigger signal for caustic overfeed event.

3.7 Fluoride Overfeed

In this scenario, the water utility was forced to revert to the utilization of an older water treatment plant while maintenance was being done to the new plant. A pump responsible for dosing fluoride into the treated water malfunctioned causing the dose to increase over time. In this case the monitor not only alarmed but also classified the likely cause of the problem to be a fluoride overfeed as that fingerprint was in the agent library. This allowed a rapid response before consumers were exposed to potentially dangerous levels of fluoride.

4 CONCLUSION

Extensive laboratory and pipe loop testing that has been detailed in previous papers (Kroll & King 2006, Kroll 2007) indicate that these types of monitoring systems appear to be a good choice for detecting water quality excursions that could be linked to water security events. The deployment incidents detailed in this paper further confirm this and also demonstrate the applicability of utilizing these everyday parameters by linking them with advanced algorithms. The field deployment studies not only demonstrate robustness in the field and the ability to recognize a wide variety of events, but these studies also demonstrate such system's ability to learn. Both operational events such as turbidity spikes as well as potentially serious problems such as the caustic and fluoride overfeeds were easily detected and responded to in a timely manner. It is foreseeable that these devices will become much more than a system that is capable of detecting security related events. They could easily become a critical tool for improving everyday operations.

For example, through many years of experience, the best old hands at treatment plant operations have developed "a sense" for knowing something in the treatment system is amiss. It can be a smell, color, clarity (or lack there of), sound or just tingling in the nape of the neck. One gains this sense only by extensive experience in a particular facility. These senses do not exist in distribution systems because there has typically been little measurement done upon which to gain these "senses" and, therefore; "Bulk Parameter Monitoring in the Distribution System with Interpretive Algorithms" has the potential to become the artificial "sense" able to quickly "learn" the quirks of the distribution system and have those quirks labeled by those with extensive experience so that less experienced employees have the benefit of that knowledge without having to wait to gain the needed experience. A good phrase to describe this knowledge base would be "institutional intuition." (Kroll 2006)

With the aging of the work force and rapid employee turnover "institutional intuition" has the chance of quickly dying out. Above and beyond their obvious security benefits, algorithms could be a way to circumvent this loss of knowledge and to build a knowledge base where none as previously existed. As a result, the improved operation of the systems on an everyday basis will allow the provision of higher quality water to the end user on a more controlled basis. As in all processes, measurement is the cornerstone to process control and the supply of water through our distribution systems is a process that needs to be more rigorously controlled. While the cost of these systems is often difficult to justify strictly on a security risk basis, their dual use capability makes the case for their widespread deployment more tenable.