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Improving Detection of Events at Water Treatment Works: A UK Case Study

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Abstract: This study presents improvements to the event detection capabilities of the existing, threshold-based detection system used by United Utilities in one of their Water Treatment Works. These improvements were achieved by using new threshold and persistence values identified by performing a sensitivity type analysis. The findings from this study show that, although an overall increase in the true detection rate and decrease in the number of false alarms were achieved, the high number of false alarms remains an issue.

Keywords: Confusion matrices; Event recognition; Online monitoring; Water treatment works.

1 Introduction

Online water quality monitoring technologies for Water Treatment Works (WTW) operation have made significant progress in recent years [1]. Producing water in the required quality and quantity by operating their facilities in an effective and efficient way is a challenging task for water utilities. For this reason WTWs are already heavily monitored and automated. Although a number of fault detection and isolation techniques have been developed [2-4] only a few of these have found their implementation in software platforms and many have not proven their ability to detect measurement or equipment failures [5]. Near real-time applications used to date, such as Canary from the Environmental Protection Agency (EPA) or GuardianBlue (Hach Lange) still suffer from a range of shortcomings such as insufficient detection capability or too many false alarms [6]. Moreover, the Water Quality Event Detection System Challenge report published by the EPA highlighted that a change in the configuration settings of the tested systems has a great impact on their performance, whereat reconfigurations to reduce false alarm rates lead generally to a decrease of the detection sensitivity [7]. This is not surprising as quick response to failure events (performance) and robustness are two conflictive goals. Event detection systems are frequently robust to a minor degree or sensitive to high frequency influences followed by a higher level of false alarms [2]. New and more efficient technologies need to be developed to address this issue. The focus of further research is set on innovative, cost-effective and wherever possible predictive near real-time event recognition systems.

The objective of this work is to investigate possible improvements to the existing, threshold-based WTWs event detection system used by United Utilities (one of the largest water and wastewater companies in the UK). This is done by using sensitivity analysis to evaluate and formulate new detection thresholds. These findings will be used later on for the development of a new event detection system.

2 Wybersley Case Study

The study focuses on the Wybersley WTW operated by United Utilities. This WTW is situated to the north of High Lane Village in Stockport Metropolitan Borough and supplies around 200,000 domestic and industrial customers with 73.5 Ml/d maximum output of drinking water. Raw water is abstracted from different water sources and enters the WTW at the inlet chamber, where it is mixed with supernatant recycled flow from dirty backwash water and afterwards split into two separate streams (stream A and B). After dosing for coagulation and pH adjustment water of each stream is treated by Dissolved Air Flotation (DAF), first stage filtration and second stage filtration processes. After filtration, treated water enters the water holding tanks at the outlet works where both streams are combined and presented for the final disinfection procedure.

Wybersley WTW is heavily automated and multiple water quality parameters such as pH, turbidity, iron, chlorine, manganese, conductivity and colour are monitored by online sensors at different treatment stages. To ensure the required drinking water quality the WTW uses alarms generated by the existing event detection system. The system applies pre-defined thresholds to the monitored signals and carries out default actions (alarm/no alarm) in case of limit violation. Every 5 minutes, each water quality sensor signal is checked against the defined low and/or high thresholds. In addition to the limits a "time dead-band", i.e. persistence is used by the system. Persistence defines the time a signal has to be above/below a threshold before the execution of the default action. The same persistence is applied for the different thresholds that are set on a signal.

Historical data for 56 water quality and flow sensors over several calendar years and at a 5 minute resolution was collected. Initial data screening resulted in 28 water quality signals selected as relevant for the analysis shown here. The selected water quality parameters include pH, turbidity, iron, colour and chlorine at different treatment stages. The data was split into datasets for re-calibration of existing detection thresholds (time period from 01.01.2012 until 30.06.2015) and follow-on validation on unseen data (time period from 01.07.2015 until 30.06.2016).

3 Methodology

A number of historical events were identified first at the Wybersley WTW and classified as either major or minor events. Major (or "zero-flow") events were defined as events that have caused an interruption of the production flow and have led regularly to an unplanned shutdown of the WTW. Minor events were identified by simultaneous deviation of more than one signal from normal operating process conditions. During the analysed time period, 8 zero-flow events were identified. To identify minor events, normal WTW operating conditions were analysed on the basis of common statistical indicators for minimum, maximum, mean and range of the used signals. Bivariate correlations between parameters were then calculated via Pearson's correlation coefficient to derive possible related deviations of multiple signals from normal during events. Significant abnormal conditions were identified by visual inspection of the graphed signals. In case of simultaneous deviations of more than one signal the occurrence of a minor event was assumed, whereas deviations of single signals from normal were classified as a sensor fault. With this methodology 252 possible process events, hereinafter referred to as minor events, and 52 sensor/telemetry faults were identified during the analysed time period.

Once the events were identified, the existing United Utilities' Wybersley WTW detection system was simulated over the entire time period analysed. For each signal, confusion matrices with true/false positives/negatives were generated and the corresponding true detection and false alarm rates were calculated. The detection rates of single signals of a treatment stage were averaged to display detection statistics for the respective treatment stage. In the same way the detection statistics for the overall system were calculated as averaged detection rates of all used parameters. All this was done separately for major and minor events.

A sensitivity analysis using the one-parameter-at-a-time approach [8] was performed on the current event detection system to investigate possible improvements. The plausible ranges of high/low thresholds for the 28 water quality signals analysed were identified first. Within these ranges, new thresholds were created using 0.05 unit steps and with changing values for persistence from 0 to 12 time steps applied to the system. This way a total of up to 7,540 sensitivity tests were conducted for each of the 28 water quality signals resulting in estimated corresponding true and false positive detection rates. The optimal new thresholds and persistence value combination for each signal was then derived by selecting the combination with the maximum value of the ratio of true to false positives.

4 Results and Discussion

The statistics obtained for the existing event detection system are presented in Table 1. As it can be seen form this table, the existing event detection system was able to detect 55% of the major events which seems to be a reasonable number compared to the results presented in the EPA Challenge [7] where an averaged true detection rate of 62% for all the five tested event detection systems was shown. The average true detection rates are 37% and 55% for major events and for the validation and calibration time periods, respectively. The average true detection rates are 15% and 24% for minor events and for the calibration and validation time periods, respectively. The significantly higher true detection rate for major events was expected since these events should be easier to detect than the minor ones.

Table 1. Detection Statistics of United Utilities' Wybersley WTW Event Detection System

Treatmant Stage	Major Events				Minor Events			
	Calibration		Validation		Calibration		Validation	
	True Positive Rate (of total events)	False Positive Rate (of total alarms)	True Positive Rate (of total events)	False Positive Rate (of total alarms)	True Positive Rate (of total events)	False Positive Rate (of total alarms)	True Positive Rate (of total events)	False Positive Rate (of total alarms)
Inlet Works	45%	98%	33%	91%	17%	53%	9%	34%
Flocculation & Flotation	60%	96%	58%	90%	18%	49%	8%	80%
1st Stage Filtration	30%	99%	33%	96%	22%	63%	16%	49%
2nd Stage Filtration	72%	95%	30%	95%	31%	56%	17%	49%
Outlet Works	50%	97%	42%	92%	17%	38%	21%	64%
Avearge Overall System	**55%**	**97%**	**37%**	**93%**	**24%**	**55%**	**15%**	**54%**

The table also shows a significant number of false alarms generated by the existing detection system. The false alarm rates for both major and minor events are in the range of 54-97%, i.e. approx. 0.4 false alarms/parameter/day (given the total number of false alarms is 16,932) which is considered high. In general, these results are also in line with the findings of the EPA challenge [7], where it was shown that the event detection performance of the five tested detection systems greatly varied and the high number of false alarms was identified as one of the main problems.

By using the optimised thresholds and persistence values identified after carrying out the sensitivity analysis described above (values not shown here to save space), the detection statistics showed a notable increase. This is shown in Figures 1-4. The true detections increased by 6% and 7% for major events and by 1% and 2% for minor events on the calibration and validation data sets, respectively. Also, with regard to the false positives, better performance is achieved with the new thresholds and persistence values. Having said this, the improvements measured by percentage reduction of false alarms (new vs old) are rather minor (given their large number) with decrease of up to 3% and 8% for major and minor events, respectively.

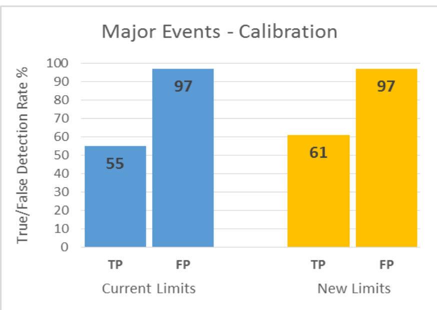

Figure 1: Comparison of Detection Rates for Major Events – Calibration

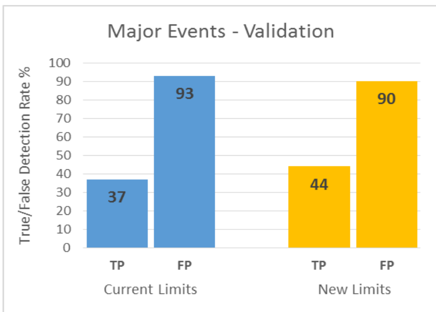

Figure 2: Comparison of Detection Rates for Major Events - Validation

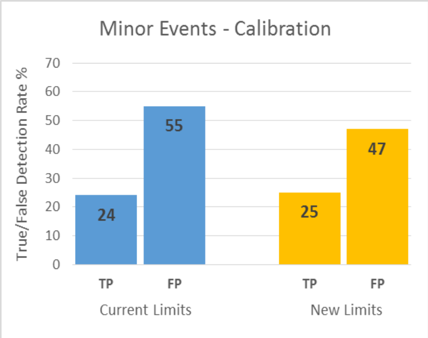

Figure 3: Comparison of Detection Rates for Minor Events – Calibration

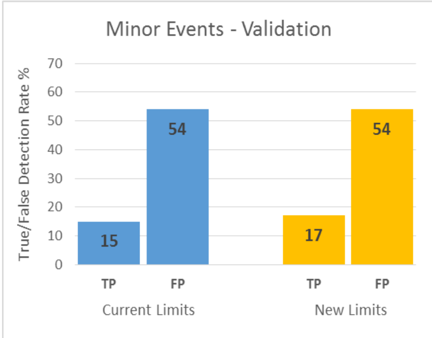

Figure 4: Comparison of Detection Rates for Minor Events - Validation

The minor reduction of false alarms was achieved because further modifications to detection thresholds (which are likely to reduce the false alarms) also increase the likelihood of missing the events [9].

5 Conclusions

The current event detection system used at Wybersley WTW has decent true detection ability, but suffers from a high rate of false alarms. Application of new threshold and persistence values to the current detection system showed an overall increase of the true detection rate up to 7% and decrease in the number of false alarms up to 8%. Although these improvements were achieved, the high number of false alarms remains an issue. To address this, a new event detection methodology will be developed based on rules that include suitable relations across multiple water quality signals.

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