Real Time Monitoring and Alert in Excavation Works using Machine-to-Machine Technologies

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Abstract: In high-density cities with tunnel networks and adjacent construction works, these sites require Real Time Monitoring and Alert systems when their movements exceed their allowable limits. Experiences have shown that in the Nicoll Highway Collapse in Singapore, where lives were lost with huge financial consequences, the traditional automated systems used were not effective in preventing site failures due to their inherent real time system design limitations. By introducing the other technologies into the existing sensor and logger system, Automated Real Time Monitoring and Alert system using Machine-to Machine (M2M) can provide a reliable and consistent data with a higher system uptime with less manual maintenance effort in an Ubiquitous environment. New innovative M2M technologies of Wire-less communications, Internet and Smart Supervisory systems are used to fully automate the entire information flow chain from sensor up to the end user. This will enable the system to send the right data to the right person to make the right decision for corrective actions to be undertaken. The paper will discuss the M2M system approach and the challenges in implementing an outdoor fully automated Real Time Monitoring and Alert system.

Keywords: Real Time Monitoring, Ubiquitous, M2M, GPRS, SMS

1. Introduction

Data loggers are used for collecting real time data from construction sites. The Geotechnical and Structural designers require the data for analyzing the behavior of the construction sequence and system. Normally the data is processed in days as these data are used for the verification of the design. By sharing this precious data with the construction works, and by making the data available in Real Time, the movements of these sensors can now be made into an Automated Real time Monitoring and Alert system. The site staff now can make real time judgment during the excavation process where reaction time is very short for remedial action.

In situations where data loggers are used for real time data collection, but not for real time monitoring and alert [1], the data loggers measure the sensor data and store them the data logger's memory at predefined intervals. This data is then retrieved every 12 or 24 hours automatically through the wire-less data communication Global System for Mobile communication (GSM) means. After the data is processed and analyzed, then SMS alert messages are sent out to warn users that the sensors have exceeded their alarm limits. This system design cannot achieve the alert response time of minutes from the change in sensor readings to the mobile phones Short Message Service (SMS) alert as the time delay is limited by the time when the data is processed after being uploaded from the data loggers. Experienced reported in the Nicoll Highway incident [2] shows that the dial up GSM data line system can cause data transfer delays due to unavailable point to point data connections availability due to its inherent switch circuit design constraint of GSM technology.

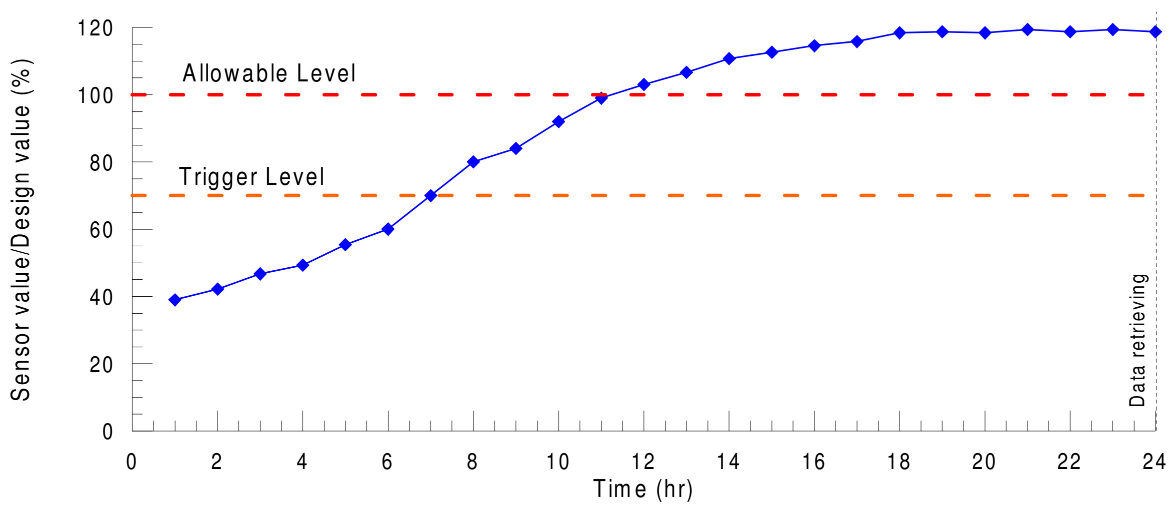


Fig 1 Time history plot of a critical monitoring event

Figure 1 shows an example of sensor reading for a critical monitoring event. The sensor is measured every hour and the stored data is uploaded to a computer for processing and analysis at 2400 hours everyday. The computer will send out Short Message Service (SMS) alerts if the recorded data was found to exceed the preset trigger level. This system is a continuous data logging system but not a real time monitoring and alert system. As an illustration, when the sensor level exceeds the trigger limit at 0700 hours, no alert would send out. The sensor level increases progressive thereafter and reaches the allowable level at 1100 hours. The data is uploaded at 2400 hours and subsequently only then alert is sent out via SMS or email. Based on the above example, if an SMS alert is send out in real time within minutes after the reading exceeded the trigger level, 17 hours of precious time could have

been used to mitigate the problem and possibly prevent deterioration of the situation. However if an email is used for alert, then the delay could be longer as this important alert information depends on fixed communication access of PC and Internet as compared to the mobile phone, which gives the user an Ubiquitous environment.
If the system is required to alert users at the shortest lead time possible when the sensors exceed their limits, so that action could be taken in time, then real time monitoring and alert within minutes is important [2,4]. This paper explains the challenges in the design and operation of the Real Time Monitoring and Alert system

2. Real Time Monitoring and Alert system

Figure 2 shows the Real Time Monitoring and Alert system described by Ng and Tan [6] using Machine to Machine (M2M) technologies. In this system, a wire-less General Packet Radio Service (GPRS) modem is used to transmit the data from the data logger to the central server. GPRS is used as an always-connected data communication system. In this design, the monitoring and alert response time is in minutes.

The GPRS speed is 32,000 bps as compared to the GSM data speed of 9,600 bps, hence making it suitable for wire-less real time monitoring and alert systems. The cost for using GPRS network depends on the amount of data transfer and not on the connection time, hence the data logger can always be connected to the central server. Data can be transmitted between the logger and server immediately when the last channel of sensor is measured. Hence, there is no connection time delay as experienced in the GSM system. The GSM line is connected on demand whilst the GPRS is always connected on-line to the central server. The information can then be access by multiple users through the Internet. Through the use of IT and Internet technologies in instrumentation and monitoring, engineers and decision makers could operate in the Ubiquitous environment and access to the real time data from their desktops, notebooks or pocket PC anytime and anywhere in the world [5,9,6].

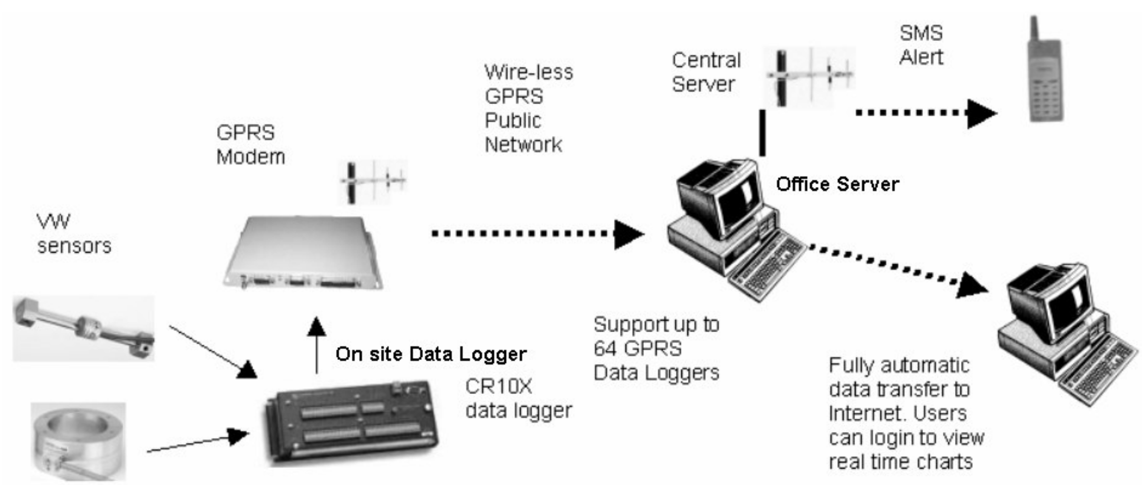


Fig 2 Data Logger with wire-less GPRS

3. The Challenges of Real Time Monitoring and Alert system

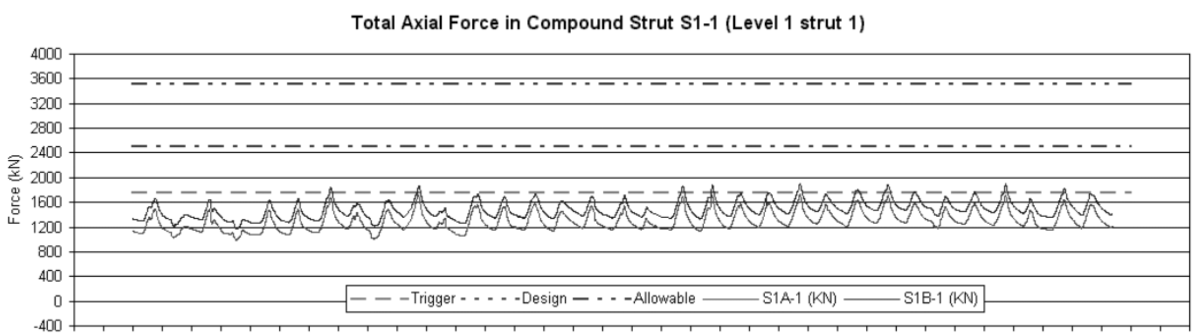
With Real Time Monitoring, the sensor data streams into the central server system at a high data rate. Traditional manual monitoring and alert system will experience user information overload as any manual EXCEL spreadsheet system used. The computer system will slow down and manually the user cannot cope up with the high data rate [2]. Hence a fully automated information flow system is a solution to overcome such a challenge.

In a Real Time Monitoring site for temporary works, the Real Time Monitoring and Alert system monitors 92 Vibrating Wire Strain Gage (VW SG) and 4 Load Cells readings every 10 minutes. Two VW SGs monitor a strut with its individual temperature sensor and the Load Cell has 4 VW SGs and 1 Temperature sensor. Hence there is a total of 92 VW+ 92T + 4 x 4 VWSG + 4 T = 1,840 sensor readings per 10 minute measurement cycle. The data rate is then 1840x 6 x 24 = 264,960 data points per day.

At this type of dynamic data rate, any sensor noise or intermittent failure will cause unnecessary alerts. There is a need for a Monitoring System Design strategy to overcome false alert and prevent user overload.

As the sensors and electronics are used in outdoor environment, noise is a perpetual problem causing false SMS alerts on the lower limits.

Field results of Fig 3 from a site show that the VWSG readings for strut at Level 1 strut 1 have very clean readings while for those strut at Level 1 Strut 4 shows noisy VWSG readings. By compressing the time, these strut force readings have now been interpreted as a waveform for signal analysis where the rules of digital waveform signal processing comes into play. Traditionally when the user takes only a few reading per day, such time series information is not analyzed.



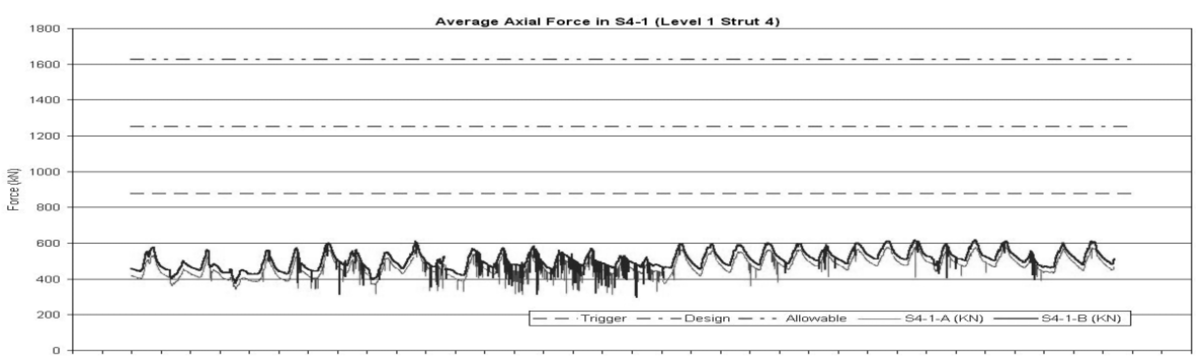


Fig 3 Strut forces time series readings over days

At every 10 minutes, the sensor readings stream in continuous. If there is a trigger event as shown in Fig 4. The system will send SMS alerts, but that point which exceed the trigger value might be a true reading or a false trigger caused by noise. After the trigger and if the next measurement cycle exceeds the trigger limit, then the site engineers take it with more attention. However if the next cycle, the sensor readings drop, then it is classified as a false trigger. Various smart alert algorithms can be used but however the choice is always by the end users.

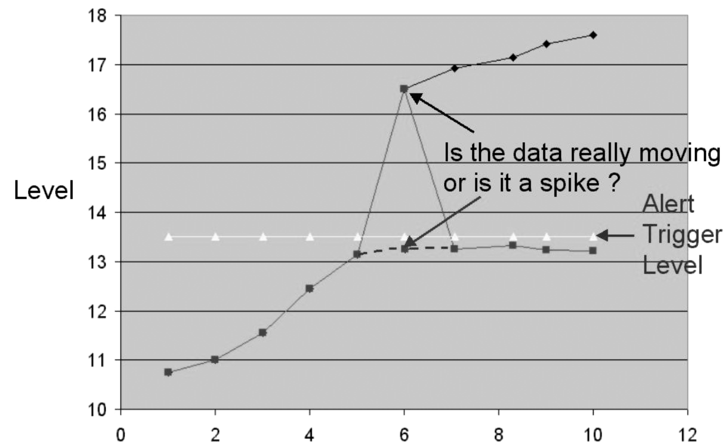


Fig 4 Triggering of Alert

3. Sources of electrical noise in readings

Noise plays a major part in the Real Time system, as any noise is pick up by the system can cause false alerts. In outdoors, these electronics components will experience voltage surges from main cables, electrical leakage and lightning voltage surges [7,8]. These can cause readings errors, computer freezes or even damage. On site when the sensor measure the data, the sensor wire travels along the site and unwanted electrical signals will interfere with the sensor wires. Unfortunately by a simple averaging technique commonly used in data loggers, the readings can have a high signal to noise ratio and still gives a readings without warning the user about the signal to noise ratio. Fig 5 shows a sensor reading of 1.1 taken from a Data logger, without knowing the signal to noise ratio, this 1.1 value can cause false alert when the actual sensor output reading is low but the noise content is high.

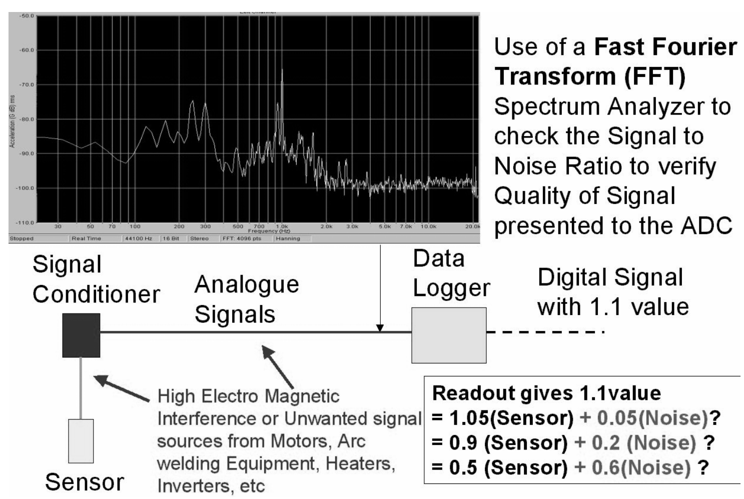


Fig 5 Noise sources causing reading errors

To help the user to trace the cause of this noise, the VW SG readings sometimes jump to high or a low SG readings even without any change in load. The cause of these reading fluctuations can be explained as high frequency noise or low frequency noise. A typical circuit of the VW SG readout circuit is shown in Fig 6. The VW SG output goes into an amplifier filter and the time taken to measure the number of cycles are recorded with a period counter circuit.

Fig 6 VW SG Period Counting Measurement circuit

For a simulation test, Geokon VW 4200 VW SGs were connected to a Geokon 403 Readout Box and a CR10X data logger. The noise source used for the experiment was a negative ionization generator for high frequency noise and a 50Hz demagnetizer. Fig 7 (a) waveform is injected into the circuit to get say 900Hz. By having a VW SG signal plus a high frequency burst caused by high voltage electric surge voltages due to by capacitive cross coupling, the period counter will count the same number of cycles in a short period, giving the readout box or data logger as a higher frequency reading. Fig 7 (b) shows the combination of the VW SG 900Hz plus the higher frequency noise burst. Fig 7 (c) shows the next waveform with magnetic 50Hz field overload, due to mains currents, the waveform gets overload at the peaks and dips of the 50Hz such that the counter gets saturated and cannot count the particular cycles in the 900Hz signal. The counter then will take a longer period to count the same number of cycles. This in turn is interpreted as a lower frequency VW SG reading.

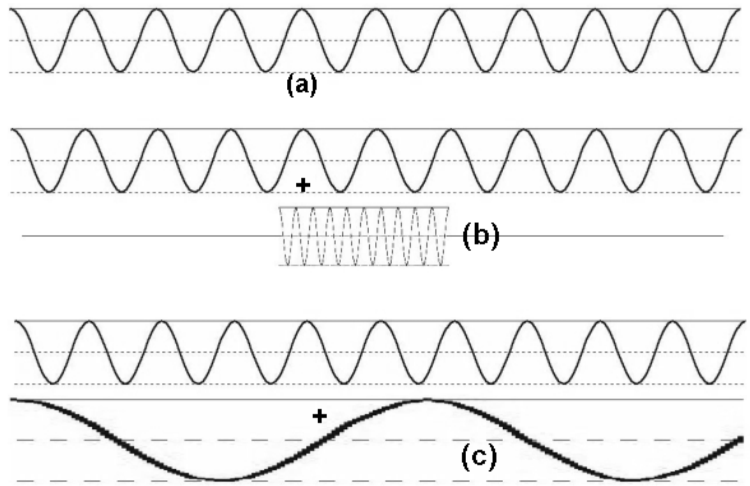


Fig 7 VW SG signals

As the application of electronics, signal processing and communication increases in the traditional civil engineering sector, the improvements of the automated instrumentation will require a multi-disciplines approach such as Structural, Geotechnical, Electronics, Communication and Computer Engineering expertise to collaborate as a team to overcome the new more complex Real Time Monitoring requirements to make the construction site a safer place to work.

4. Benefits of Real Time Monitoring system

The main advantage of the Real Time Monitoring and Alert system is obviously the Real Time alert where the site staff gets urgent data instantly when sensors exceed their limits. The other benefit is to provide the users and designers the actual on-site forces acting on the struts when construction work progresses as shown in Fig 8. This increases the productivity of the designer by having their verification of their design via the Internet instead of visiting the site which could be hours drive away. This brings the important data to the

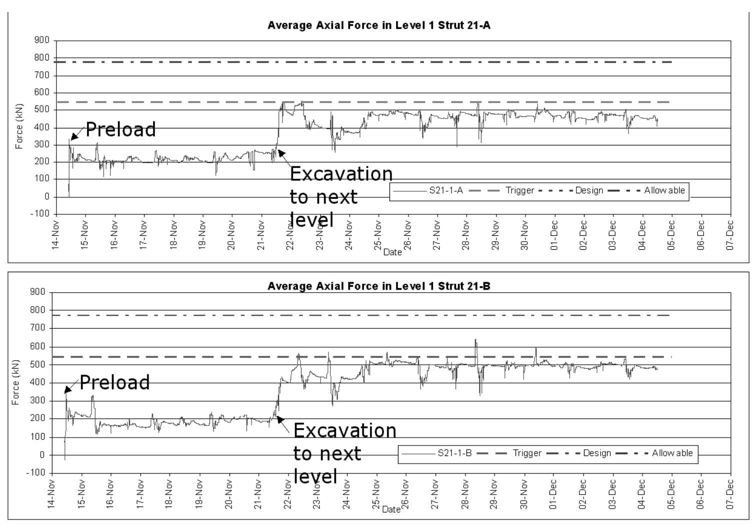


Fig 8 Real Time Strut Force

desktop of the designer via communication technologies.

In another Real Time monitoring system, the results help the bridge designers to verify their post –tension forces. The real time monitoring is done every 10 minutes so that the slower thermal effect does not take into account yet. The results show of the strain movements and discriminate temperature effect as the thermal effect takes hours to change the strain while the post tensioning process is done within minutes.

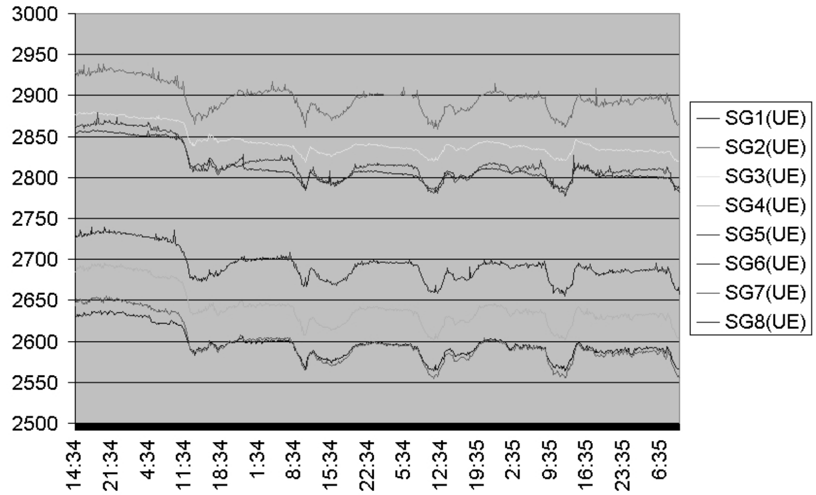


Fig 9 Real Time Force during post tensioning process

In this field test, 18 VW SGs and 1 Temperature sensors are mounted onto the bridge and recorded during the post tension process. The data is logged every 10 minutes and send back to a website for computation for sensor calibration into **με.** Real time is used so that the effect of strain changes during the post tensioning can be tracked continuously. The results show that the strain values do change with respect of the post tension timings. The temperature strain readings show a slower change over time.

5. Conclusions

Data Loggers have been used in monitoring systems for many years, especially for projects which required continuous monitoring. They are mainly used for design verification, monitoring, investigation works and research. Using M2M technologies of wireless communications, Infocomm Technologies and Internet, these monitoring systems have evolved into mission critical civil engineering applications where the information are needed in a matter of minutes rather than hours. When the sensor readings exceed their predefined limits, the system automatically sends SMS alerts to multiple users within minutes. This compression of the total delivery time, from the remote site sensor to the user mobile phones, is useful to inform site problems immediately for critical projects. It gives users more reaction time to organize, to investigate and to prevent collapses or failures rather than having data to confirm that the site had problems. With the wider acceptance of M2M technologies by the consumer sector, the relevant technologies have become easily accessible for wider deployment in the civil engineering sector. This forms a new cluster of mission critical monitoring and real time alert systems based upon the M2M technologies.

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