DEVELOPMENT AND DEPLOYMENT OF A REAL-TIME REMOTE CONTINUOUS MONITORING SYSTEM FOR MANHOLES

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ABSTRACT

A new system for the detection of septic sewer overflows (SSOs) and unauthorized intrusions of manholes has been developed jointly with public water agencies in San Diego County, California. The goal of the project is to provide detection of SSOs early enough to deploy personnel to provide preventative action. The system has been in operation since May of 2005 and has detected and, with field staff intervention, prevented several SSOs. In addition the system has detected unauthorized intrusions which resulted in effective response by water district staff. The system is also intended to be economical enough to be affordable for wide deployment. The deployment and results of multiple field installations are described in detail.

KEYWORDS

Sewer, monitoring, real-time, continuous, manholes, collection system, septic sewer overflow, SSO, prevention, detection, rapid.

INTRODUCTION

Sanitary sewer overflows (SSOs) and combined sewer overflows (CSOs) are a longstanding and continuing problem for collection system operators. The USEPA estimates that there are at least 40,000 SSOs in the United States each year\(^1\) and that 946 communities with CSO systems experience releases of 850 billion gallons of untreated waste water and storm water annually.\(^2\) SSOs and CSOs cause significant environmental damage, increase health risk, are expensive to clean-up and often result in regulatory fines for collection system operators.

Methods for decreasing the incidence and severity of SSOs typically fall into two categories: increased maintenance and early detection through remote monitoring.
Increased maintenance, while effective, has the obvious disadvantage of higher costs and labor, and early detection through remote monitoring has generally been capital intensive, required significant on-site labor and expense for installation and suffers from sensor reliability problems in the challenging manhole environment.

Several factors are combining to put increased pressure on collection sewer operators and treatment plant operators to improve performance and decrease the frequency and severity of spills. Increasing population and growth is putting strain on aging infrastructure, particularly on collection systems that were built decades ago with older technology and limited capacity. Water and wastewater customers are expecting more from the industry in the age of rapidly changing technology and the Internet. Regulatory requirements are becoming more stringent, for example the recently adopted California General Wastewater Discharge Requirements for Wastewater Collection Agencies requires increased reporting, and demonstrated plans for all California wastewater agencies to reduce SSOS. Finally, general strain on fresh potable water supplies has put an increased emphasis on use of reclaimed/recycled water. As the use of reclaimed water becomes more widespread, the importance of protecting the source of this water—wastewater—becomes more important. Monitoring of collection systems for unauthorized dumping and noxious chemicals will become more important in order to provide a more consistent and safe source product for reclaimed water supplies.

**OBJECTIVE**

The overall objective of this project is to design and develop a technical and user-friendly tool that could be used to reduce or eliminate many SSOS and CSOS through better and more pervasive monitoring of manholes. Current alarms for spills and overflows are primarily phone calls by customers or residents that observe the spills long after the damage has already been done and too late for prevention or early mitigation.

The specific goal of the SmartCover™ Collection Monitoring System is to integrate state-of-the-art sensor and communications technologies into a remote continuous real-time manhole monitoring system specifically designed to meet the industry’s requirements of low cost, small size, simple installation and maintenance, and high reliability. The SmartCover system is intended to create an automated low burden system that serves two basic purposes:

1. Provides continuous monitoring that establishes a detailed record of manhole conditions over long periods of time; and

2. Rapidly alerts field response personnel using wireless field devices such as cell phones and pagers to (a) exceptional water level conditions in a manhole prior to a sewage spill and (b) that a manhole has been entered without authorization.
METHODOLOGY

Previous attempts at developing an effective remote monitoring system for manholes have had limited success due to a variety of reasons, including cost, installation logistics, battery life, communications, reliability, and size. In order for systems to be widely used, they need to be: simple and fast to install; low enough cost to enable widespread deployment in more than just a few locations; avoid false alarms; minimize maintenance burden; and provide reliable and dependable information.

The SmartCover System was designed and developed with these concerns under consideration using the most recent technologies in order to: reduce the size of the system; prolong battery life; provide reliable communications; and minimize false alarms. The system is fully self-contained and consists of the following components:

- Electronics package containing: two-way digital radio modem; PC board with power supply, computer, communications interfaces; and acceleration sensors.
- Power package containing sufficient primary battery power for one year of operation.
- An ultrasonic level sensor specifically designed for the sewer environment.
- A mount for the SmartCover unit to mount directly onto a manhole cover or hatch.
- Antenna and antenna mount for mounting the RF antenna onto the exterior of a manhole or hatch.
- Two-way wireless communications.
- A User-interface consisting of a secure user-specific web site.

The SmartCover as mounted on a manhole cover is shown in Figure 1. The manhole shown in Figure 1 is a standard SBF-1310 24-inch manhole widely used in Southern California.
All components are ruggedized to deter decay in the difficult and corrosive manhole environment.

The SmartCover system operates as a remote continuous monitoring and alarm system. Alarms are generated under two main conditions. First, the manhole is moved or tilted during an unauthorized intrusion into the hole. This action will generate an alarm. Second, a level threshold may be set for the ultrasonic sensor that represents a water level that requires attention: either an unusual surcharge or a level that indicates that a spill is imminent. Alarms are sent by the unit through the wireless communications to two locations: a hand-held wireless device such as a cell phone, pager, or PDA as well as to the secure web site operated by the user. These alarms are typically received in less than a minute after the alarm condition has been detected.

Under normal circumstances, alarms are not generated, and the SmartCover system operates as a monitoring or logging system. At set intervals, the SmartCover unit will send a history of the temperature, level, battery voltage and radio signal strength back to the User secure web site, and this information is stored in a database that is accessible by the User through any Internet access through a password-protected portal.
STATUS

The SmartCover™ has been in development since February 2005, and has been through three generations of evolution to refine and improve the performance of the system. Test and prototype systems were placed in six manholes at various places in north San Diego County between May 2005 and October 2005. A production version of the SmartCover became available in November 2005 and has been installed at a wide variety of sites in Southern California, including manholes, siphons, and lift stations.

The SmartCover attaches directly to the manhole cover (see Figure 1), greatly simplifying and reducing costs of the installation process, and providing a way to install the system in a maintenance yard to be later transported to the manhole site for rapid and easy installation in the manhole. This system provides five continuous monitoring measurements in the manhole and on the manhole cover, the first two directly related to preventing or mitigating SSOs and CSOs, the second three related to self-monitoring of the SmartCover:

1. The level of the water in the manhole above the shelf is monitored using an ultrasonic sensor;
2. Acceleration sensors detect in less than one second if the manhole cover has been tilted or accelerated in an unauthorized intrusion into the manhole;
3. The temperature of the manhole cover is measured as a diagnostic measurement;
4. The battery voltage is measured as to alert for low battery voltage and call for a replacement battery. Battery life for the SmartCover™ is expected to exceed a year;
5. The radio signal strength is measured and reported.

RESULTS

The SmartCover real-time remote monitoring system has been in continuous operation in the San Diego county area since May of 2005, and has been successful in measuring surcharges at problem sites, preventing spills, and detecting unauthorized intrusions.

Surcharge Measurement – Summer 2005
During the period of July through August 2005, a SmartCover unit was installed at a Fallbrook Public Utility District (FPUD) location near a stream crossing. See Figure 2. This location has two influent lines and has had surcharges previously. The goal of this installation was to continuously log the levels in this manhole over a period of a few months in order to ascertain the frequency and severity of surcharges while at the same time testing the viability of the SmartCover system in a challenging environment.
Figure 2. Photograph of location of SmartCover field testing, summer of 2005, Fallbrook, CA. Location of installed Unit is less than 100 yards from flowing stream. This location is known to have generated surcharges and is monitored continuously to measure height and duration of surcharges.

Level data generated by the SmartCover at this location are shown in Figure 3. There are several interesting aspects of these data. The distance is shown “inverted”, that is, with the street level at the top of the graph and the bottom of the manhole at the bottom of the graph. This manhole was a relatively shallow hole, only about 45 inches deep. The baseline distance is the distance from the unit to the bottom of the manhole, that is, when water was running below the level of the channel, the nominal level measurement showed 45” from the sensor to the base of the manhole. Dates are shown along the x-axis of the graph, with midnight indicated by the vertical lines. Surcharges occurred nearly every day, and while the time was not always identical, the majority of the surcharges occurred in the afternoon and early evening, suggesting higher usage upstream from this manhole during these periods. The surcharges were small – a couple of inches – or significantly larger, seven to 18 inches in height. Typically the surcharge events lasted a couple of hours or more, but eventually levels returned to the baseline level of the bottom of the manhole.
Figure 3. History of levels at the site in Fallbrook, CA shown in Figure 2 over a period of three weeks during the summer of 2005. Baseline depth of the manhole is 45” and surcharges were observed that lasted several hours, and varied from a few inches in height to more than 15” in height. In no case, did the surcharges get close to street level.

Spill Prevention – June 2006
On June 21, 2006, the SmartCover unit was installed at a location referred to as the “Buena Street Siphon” in the City of Oceanside that had a history of previous surcharges and overflows. If a spill occurs at this location, it could remain undetected for long periods, because (a) the site is on an easement; and (b) an overflow weir below the manhole cover allows surcharges to drain into a canyon that is generally out of sight and difficult to access. The installation is shown in Figure 4.
The baseline distance between the ultrasonic sensor and the nominal water level is about 32 inches. At roughly eight inches above this level, corresponding to the exit pipe being completely filled, water is within about 10 inches of the weir. The alarm threshold level was set at this level, corresponding to 25 inches below the sensor. A complete history of this site is during the week of June 21 is shown in Figure 5.

Hourly measurements taken at this site are shown. The first indication that there may be a problem at this site occurred on Saturday, June 24. For two hours, a surcharge occurred, but this surcharge did not trigger an alarm, since it reached only 26 inches below the sensor, one inch below the trigger. However, on Sunday, June 25, the water level at roughly the same time of day surcharged again, this time exceeding the pre-set limit of 25 inches. This triggered an alarm, and City personnel responded to the site within 20 minutes, opening the manhole, and observing the surcharge as it was taking place. A combination truck was immediately dispatched to this site, and a significant amount of grease was removed downstream from this location. There were no subsequent problems at this site subsequent to the maintenance and removal of the grease from the pipe.

A screen shot from the City of Oceanside secure web site is shown in Figure 6, showing the exact time of the alarm, and the acknowledgement of this alarm by one of the authors (M. Patnode).
Figure 5. Continuous level measurements taken at City of Oceanside site during the week of June 21, 2006. Threshold alarm level is shown by the red line.
Intrusion Detections – February and March 2006

SmartCover units are installed at various locations throughout the FPUD service area, including rural and urbanized sites. In February, 2006, during a routine maintenance visit to one of the SmartCover sites in a rural area, an open manhole was discovered. The site as it was found is shown in Figure 7. Unfortunately, this particular site was not instrumented, and therefore was not able to alarm upon the unauthorized intrusion.

The SmartCover installation was one manhole downstream from this site, and there was another manhole downstream from the SmartCover site that was historically at the risk of surcharge. This manhole configuration is shown in Figure 8.
Referring to Figure 8 above, Manhole A was the manhole attacked by intruders sometime around February 22; Manhole B was instrumented with a SmartCover™; and Manhole C was downstream from both manholes. At the time of the discovery of the intrusion, Manhole C was inspected and sticks and other detritus likely thrown into Manhole A at the time of the attack were found at the base of Manhole C.

A review of the level history of Manhole B in Figure 8 revealed some interesting results. Figure 9a shows the level history of Manhole B for a period of about three weeks prior to the discovery of the intrusion. The level is constant 44 inches, indicating a measurement of just the base of the manhole, with no surcharging occurring.

On the other hand, Figure 9b shows details of the recorded levels of 24 hours after midnight on February 20 show that a surcharge occurred at Manhole B (see Figure 8) at 6AM and 7AM of that day. Given the facts that foreign detritus was discovered in Manhole C, downstream from Manhole B, and that an intrusion was discovered on February 22, it is highly suggestive that the event actually occurred sometime during or before the early morning of February 20. Apparently the foreign materials caught in
Manhole C caused a small surcharge that was recorded by the SmartCover in Manhole B during the morning of February 20. Since the level alarm threshold was set at 35 inches, 10 inches above the base of the manhole, this surcharge was not detected in real-time, it was only noted in data review after the fact.

On March 24, 2006 at 8:03AM, an intrusion alarm was detected at another FPUD location behind a commercial area in downtown Fallbrook. FPUD staff responded to the alarm, and arrived at the SmartCover site about five minutes after receiving the intrusion alarm. A person was seen lowering the manhole and leaving the site as the FPUD staff member arrived on the site, and this person was stopped and questioned. The FPUD secure web alarm is shown in Figure 10.

![Figure 10. Web site screen shot of alarm that was produced by unauthorized intrusion on March 24, 2006 at 8:03:27AM. The alarm was received and FPUD personnel responded and apprehended the intruder.](image)

DISCUSSION AND CONCLUSIONS

The results reported in the previous section represent various means that the SmartCover has been used to improve collection system operations.

In the case of surcharge detection, the SmartCover was able to detect, log, and transmit level data that revealed surcharges that appeared to be diurnal and which self-corrected over a few hours. However, this data could help operators either determine that usage upstream was unusual or could help detect a downstream blockage before a spill occurred.

In the siphon application where a spill was prevented by a combination of surcharge detection by the SmartCover and rapid response by City personnel, several lessons were learned from the use of real-time remote continuous monitoring. First, since this was a critical and sensitive site, this site was previously checked by City personnel daily to look at water levels in order to pre-empt an overflow into the nearby canyon. The level data from this site – as well as the surcharge data discussed earlier in Fallbrook – point to
surcharges that are transient. If field personnel are not monitoring the site at the exact
time that a surcharge is occurring, then the problem may be missed. Real-time
continuous remote monitoring not only provides a continuous measurement of water
level, it also alarms upon the exceeding of a threshold, and can also provide a “health
check” of the specific site that is being monitored as well as locations immediately
downstream. This capability can provide much earlier warning of a spill that was due to
slow blockages due to grease, roots or other obstructions in collection systems.

The ability to detect intrusions remotely has a variety of uses, as shown in the two
eamples. In the first case, an intrusion was detected, albeit delayed, through inspection
of the level data provided by the SmartCover system. In retrospect, the level alarm may
be been set lower and closer to the base of the manhole, since there was a constant level
measurement over long periods with no natural changes in level due to water level. In
any case, many manholes can be protected by a single unit, since a surcharge caused by a
“natural” or intentional blockage can be detected several manholes upstream from a
blockage prior to the blocked manhole spilling. In the second case, as long as the
response is available and fast, illegal dumping can be detected quickly enough either stop
the dumping from occurring or catching the dumping as it is taking place.

The SmartCover™ Collection Monitoring System has undergone field tests at six
manhole sites for more than six months prior to going into production in late 2005. Data
collected include water level (below or above the shelf, depending upon the location of
the sensor), intrusion times, temperature, radio signal strength, and battery voltage. The
system works reliably in a manhole environment and provides real-time continuous
information about the status of the manhole. The SmartCover™ system has potential for
wide deployment at a large number of manholes in a collection system because the
installation and maintenance has been seen to be low. By continuously monitoring
levels and intrusions, this type of system could provide early warning of SSO and CSO
events and prevent spills from occurring or provide timely information to system
operators to minimize damage from a spill.

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