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Leak Marking Scheme for Construction Quality Testing of Geomembrane liners in Landfills

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ABSTRACT: Landfill is the major method of solid waste disposal in developing countries. To protect soil and groundwater from contamination, anti-seepage systems have to be installed in landfills. However, during the construction of anti-seepage system, many factors can result in holes in geomembrane liners. For the purpose of improving construction quality, the construction company needs to find the leaks in geomembrane liners and analyze the damage causes according to the positions after construction. The electrical method can effectively test the integrity of geomembrane liners. In this paper, we combine the electrical method with the wireless location technology and bring forth a leak marking scheme. The working flow of the scheme is as follows: place two acoustic transceivers on two vertexes s of the detection area; after detecting the leaks with the electrical method, calculate the leaks' relative coordinates in the detection area through acoustic ranging and, then, mark positions of leaks in the landfill. At last, we design acoustic signals for ranging, analyze their performance on anti-interference, and design the leak marking algorithm.

Key words: Construction quality, Leak marking, Geomembrane liner, Landfill, Electrical method

INTRODUCTION

It is an important issue for the world to dispose of solid waste safely and properly. With the rapid economic development and acceleration of urbanization, the effective management of solid waste is especially meaningful for developing countries as the production of urban solid waste increases dramatically (Al-Maaded, Madi, Kahraman, Hodzic, & Ozerkan, 2012; Ambade, Sharma, Dass, & Sharma, 2013; Soomro, Uqaili, & Aziz, 2012; He, 2012). Major methods to dispose of solid waste include incineration, composting, and landfill, etc. (Tchobanoglous & Kreith, 2002). Among them, landfill has become the most common method in the world, particularly in developing countries due to its advantages of easy operation, low cost, large disposing capacity, and no need for waste classification, etc. (Bagchi, 2004).

Solid wastes usually contain large amounts of toxic and hazardous substances, and improper disposal will easily result in surrounding soil and groundwater polluted (Nagarajan, Thirumalaisamy, & Lakshumanan, 2012). This calls for the installation of anti-seepage system in the landfills. Take China for example, firstly, the bottom soil in the landfill is compacted as the foundation anti-seepage layer, then a synthetic geomembrane liner with a thickness no less than 0.5 mm is laid above, finally, a pebble drainage layer is laid on the geomembrane liner (Chen, Geng, & Fujita, 2010).

Geomembrane liners are the most crucial part of the whole anti-seepage system (Laner, Crest, Scharff, Morris, & Barlaz, 2012). The landfill usually covers an area of ten thousand square meters and geomembrane liners are sheets with limited size. So, heat welding splicing of geomembrane liners has to be operated in site to form an integral leachate barrier covering the whole bottom of the landfill (Laine & Darilek, 1999). The whole geomembrane liner barrier should be intact after heat welding. However, improper operations will easily cause welding seams during the process of heat welding. Besides, holes may also appear when laying leachate drainage pipes and pebble on the geomembrane liner (Binley & Daily, 2003). For developing countries like China, the late start in

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construction of standard landfills and imperfect construction technology and management cause even more severe phenomena of broken geomembrane liners during the construction of anti-seepage system. Therefore, the construction company should adopt some measures to find the leaks in geomembrane liners in time to repair and analyze breakage causes according to positions of leaks after the completion of construction in order to gradually improve their construction quality. Moreover, for some severe leaks, though repaired, they may break again in the operation of landfills. Thus, operators of landfills also need to be aware of the leak positions and monitor these positions with focus during the landfill operation.

The electrical method has been proved practicable in construction quality testing of geomembrane liners (White & Barker, 1997). In this paper, we combine the electrical leakage detection method with the wireless localization technology and propose a leak marking scheme. According to this scheme, two acoustic transceivers are set on two vertexes of the detection area, and we use acoustic as the signal media, calculate relative coordinates of leaks in the detection area through acoustic ranging, then the leak positions are marked. The rest of the paper first introduces the principle of electrical leakage detection method, and then designs the leak marking scheme and acoustic signal. The anti-noise performance of acoustic signals is also analyzed. Finally, we present the marking algorithm.

MATERIALS & METHODS

The basic structure of anti-seepage system in landfills is presented in Fig. 1. From top to bottom, there are three layers: the pebble drainage layer, the geomembrane liner and the foundation layer (Zhang, Tan, & Gersberg, 2010).

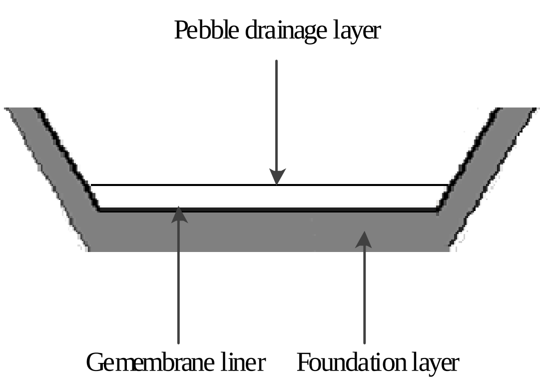

Fig. 1. Basic structure of anti-seepage system in landfills

The electrical method takes advantage of the insulating property of the material of geomembrane liners (high-density polyethylene) to find holes (Daniel, 1993). The working principle is as follows: a metal electrode is buried in the pebble layer and another is in soil outside the landfill, the two electrodes are respectively connected to the positive and negative poles of the direct-current power supply. If the geomembrane liner is intact, there will be only tiny electric current (approximately zero) flowing through the geomembrane liner and the induced electric potential in the pebble layer and in the foundation layer will be evenly distributed. When the geomembrane liner is broken, the leaks will provide passages for the electric current. Owing to the higher current density near the leaks than other parts, the distribution of induced electric potential above and below the geomembrane liner will not be even, then, the leaks can be found based on the electric potential distribution (Darilek & Parra, 1989). During the detection, we can water the landfill to enhance the electrical conductivity of the pebble layer.

The collection of induced electric potential data can be realized by two methods: the electrode grid method and the dipole method (Hix, 1998). The electrode grid method requires some detection electrodes to be buried in the foundation layer in advance, which is mainly used for real-time detection during the operation of landfills. The dipole method adopts a pair of metal electrodes with fixed spacing moving on the surface of the pebble layer. The induced electric potential distribution in the landfill is described by the electric potential difference between the two metal electrodes. When the dipole detection device passes over a leak, the electric potential distribution is illustrated in Fig. 2.

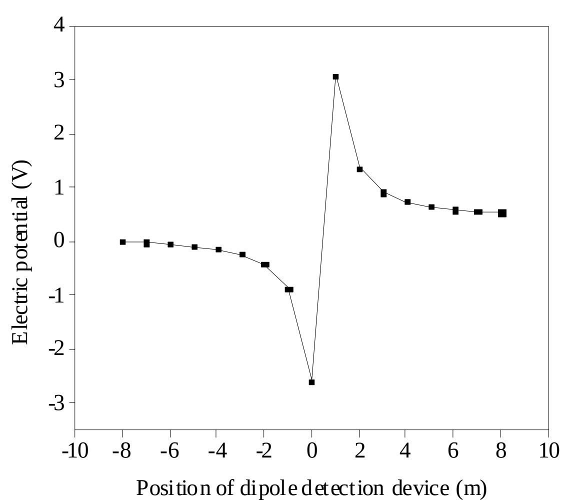

Fig. 2. Potential distribution near the leak

As we can see, when the dipole detection device passes over a leak, the electric potential difference between two electrodes becomes obvious anomaly, thus, the leak is found. This method operates easily and is the major method adopted in the construction quality testing of anti-seepage system.

In this section, we will discuss a method to mark positions of detected leaks in the landfill. So far, GPS is the most widely used outdoor positioning technology, which utilizes trigonometric function ranging to realize positioning (Ta, 2011). The straight-line distance between the user and the satellite is obtained by multiplying the travelling time and the propagation speed of the radio signal launched by the satellite to the user. Furthermore, we can calculate the user's position according to the distance relationship between the user and several satellites. However, civilian GPS positioning technology is coarse-grained. The positioning error is up to several meters or even over ten meters, which can meet the demand of navigation, but will result in large errors in leak marking. Because a landfill usually covers an area over ten thousand square meters, we can divide the landfill into several sections and carry out the leakage detection one by one. Inspired by the positioning principle of GPS, we proposed the leak marking scheme as shown in Fig. 3.

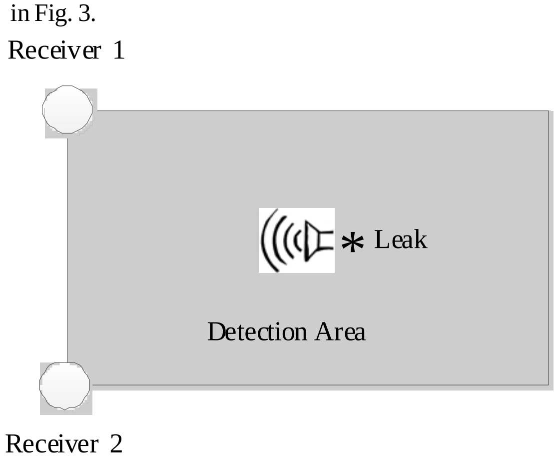

Fig. 3. Scheme illustration of leak marking

When detecting a certain section, we put two acoustic signal transceivers on two vertexes of this area, conduct ranging measurements between the leak detected and acoustic transceivers by means of acoustic, then, calculate the relative coordinates of leaks in the detection area based on the distance relationship among the three to mark positions of leaks. Detailed procedures will be further discussed in section 3.

In the leak marking scheme above, the most crucial part is to measure the distance between acoustic transceivers and leaks. Among the existing technologies, the most widely used one is ranging through the multiplication of the transmission time and the propagation speed of signals. Signal sources for the ranging measurement are mainly two types: RF and acoustic. Compared to RF, acoustic has a lower frequency, which can greatly reduce the hardware equipment costs and complexity. Moreover, the propagation speed of acoustic is slow (340 m/s, in the air), thus producing ranging accuracy at the centimeter level which is fine-grained ranging (Parkinson & Spilker, 1996). As a result, we choose acoustic as ranging signal source.

The principle of acoustic ranging is that the distance is gotten by multiplying the travelling time and its propagation speed. However, acoustic signals are prone to be interfered by all kinds of ambient noise during the transmission, which influences the receiver's detection of the signal's arrival time and then influences the calculation of transmission time and finally the ranging accuracy. Therefore, the anti-noise performance is the primary concern of signal source design. In this scheme, we adopt 5 kHz sine wave as the basic acoustic signal. Inspired by the CMDA technology in mobile communication (Stüber, 2011), we utilize the m-sequence pseudo-random code to conduct the binary phase shift keying (BPSK) modulation to improve the anti-noise performance of the signal source (Torrieri, 2011). As the m-sequence pseudo-random code possesses similar statistical properties with the white Gauss noise, signals after modulation can effectively resist channel fading, ambient noise interference, and multipath effect and so on (Viterbi, 1995).

At the acoustic receiving end, we utilize the excellent autocorrelation property of the m-sequence pseudo-random code to make the autocorrelation calculation of the acoustic signal (Girod & Estrin, 2001), then, we can accurately detect the arrival time of the signal. Employing 511 bits of m-sequence pseudo-random code to modulate the 5 kHz sine wave, detection results of the arrival time of the signal are presented in Fig. 4. From Fig. 4, we can observe that the autocorrelation function value accurately in dicated the arrival time of the signal.

To test the interference immunity of the modulated acoustic signal, we adopt 511 bits of m-sequence pseudo-random code to modulate the 5 kHz sine wave and add 3dB white Gauss noise, then make autocorrelation calculation of the acoustic signal and decide its arrival time. The results are illustrated in Fig. 5.

The results show that under the influence of 3dB white Gauss noise, the receiving end can still accurately

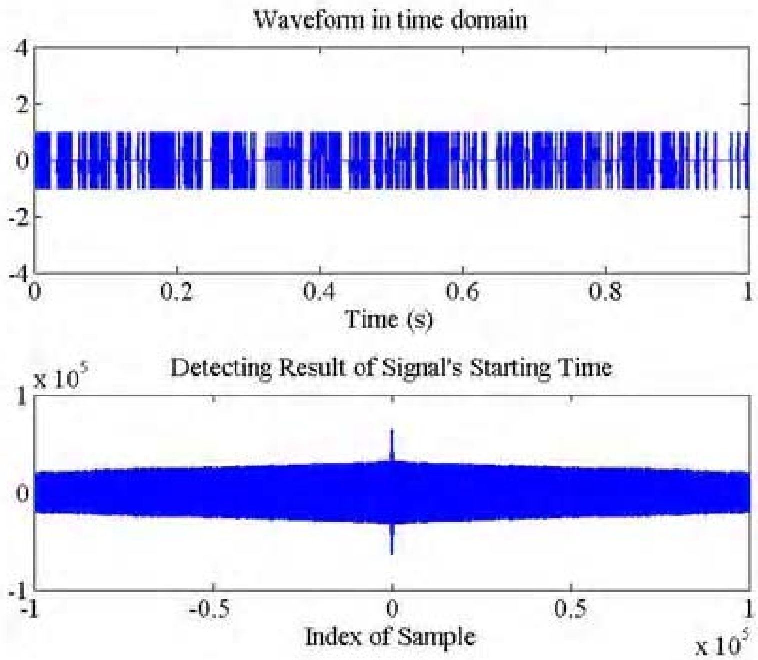

Fig. 4. Diagram of acoustic signal arrival time detection

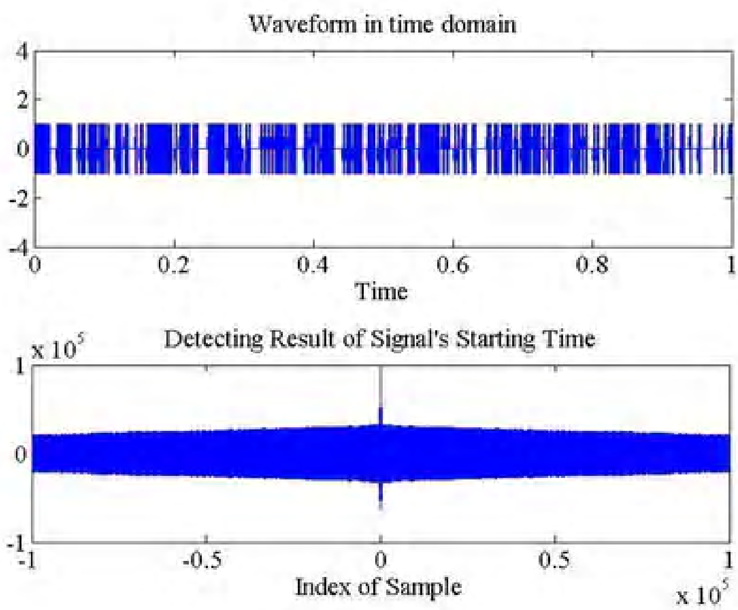

Fig. 5. Detection results of the arrival time of acoustic signal with additive white Gauss noise

detect the acoustic signal's arrival time through the autocorrelation calculation.

RESULTS & DISCUSSION

Suppose that the distance relationship between acoustic transceivers and the leak is shown in Fig. 6, two acoustic transceivers are represented by A and B, and the leak position is represented by C. The distance a between A and B is known. Take the position of the acoustic transceiver A as the coordinate reference point (0, 0). The leak position is expressed by (*x*, *y*). Inspired by the BeepBeep acoustic positioning technology (Peng, Shen, & Zhang, 2012), the leak marking scheme goes as follows: suppose the propagation speed of acoustic is v, C sends an acoustic signal at the time $t_{0,}$ A and B receive the signal at the time t_{A1} and t_{B1} respectively. After a certain interval, A sends another acoustic signal at the time t_1,

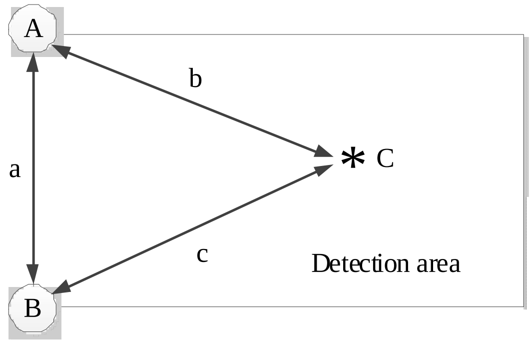

Fig. 6. Distance relationship between the acoustic transceivers and the leak

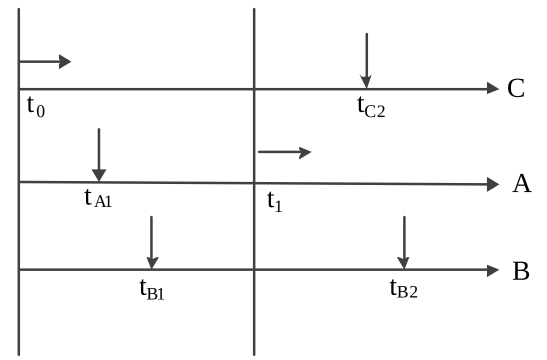

Fig. 7. Sending and receiving points of acoustic signals

B and C receive the signal at the time t_{B2} and t_{C2} respectively. The relations among all the points are shown in Fig. 7.

Then the distance between A and C can be expressed as:

$$b = \frac{1}{2} \cdot v \cdot [(t_{C2} - t_0) - (t_1 - t_{A1})]$$

According to Fig. 7, all the points are related as follows:

$$t_{B1} = t_0 + \frac{c}{v} \quad (1)$$

$$t_{B2} = t_1 + \frac{a}{v}$$

$$t_{C2} = t_1 + \frac{b}{v} \quad (2)$$

Based on relations above, the distance between B and C can be represented by the following equation: (3)

$$c = a - b + v \cdot [(t_{C2} - t_0) - (t_{B2} - t_{B1})] \quad (4)$$

From equation (1) and (5), we can calculate the distances b and c between the two acoustic transceivers and the leak. We draw two circles with the radius of b and c, taking A and B as the centers respectively. The leak lies in the intersection point of the two circles in the detection area. Thus, we can calculate the coordinate of the leak relative to the acoustic transceiver A. According to the leak marking scheme above, the designed algorithm is shown below.

Algorithm 1: Calculate the position of the leak

Data: t_0, t_1, t_{A1}, t_{B1}, t_{B1}, t_{C2}, a

Result: (x, y) /*the position of leak/

$$b = \frac{1}{2} \cdot v \cdot [(t_{C2} - t_0) - (t_1 - t_{A1})]$$

/*calculate the distance between A and leak/

$$c = a - b + v \cdot [(t_{C2} - t_{C1}) - (t_{B2} - t_{B1})]$$

/*calculate the distance between B and leak

$$x = (b^2 - c^2 + a^2) / (2 * a)$$

$$y = \sqrt{b^2 - x^2}$$

return (x, y).

For instance, suppose that the distance between A and B is known as 10 m. The distance between A and C is 9 m and that between B and C is 11m gotten by the acoustic ranging. Then based on this algorithm, we can get the leak's coordinate, which is (3.0, 8.5) relative to A.

Errors of this scheme are mainly influenced by the accuracy of acoustic ranging. Since acoustic signals we adopt have good anti-noise interference performance, the receiving end can accurately detect the arrival time of the signal; therefore, ranging errors are mainly influenced by signal sampling rate when receiving the acoustic signal. For example, for the sample rate of 48 kHz, the theoretic ranging accuracy resolution is 0.7 cm. In practical applications, influenced by various factors, ranging errors can still be constrained within several centimeters (Yang *et al.*, 2012), and this accuracy can meet the requirements of practical project.

CONCLUSION

The electrical method is currently the most effective testing technology of the construction quality of geomembrane liners. We combine the electrical method with the wireless positioning technology, and propose a leak marking scheme for the construction quality testing of geomembrane liners in landfills. In this scheme, we put two acoustic transceivers on two vertexes of the detection area. After detecting the leak through the electrical method, we obtain the distances between the two transceivers and the leak through acoustic ranging. Then we calculate the coordinate of the leak relative to the transceiver and mark the position of the leak. Given acoustic signals will be interfered by all kinds of ambient noise during propagation, which will influence the receiving end's detection of the signal's arrival time, further influence the ranging accuracy and finally the positioning accuracy of the leak, we propose using the m-sequence pseudo-random code to carry out the binary phase shift keying modulation of 5 kHz sine wave to yield the acoustic signal. Because the m-sequence pseudo-random code possesses the similar property with the white Gauss noise, it can effectively resist the influence of ambient noise and multipath effect, etc. So, the receiving end can accurately detect the signal's arrival time. This scheme provides the positions of leaks in geomembrane liners for the construction company to analyze the breakage causes. Their construction quality of anti-seepage system will gradually be improved.

It should be noted that to successfully employ this scheme, we need to make alterations to the dipole detecting device and add acoustic sending and collecting module. Furthermore, we should be able to transmit the time information between acoustic transceivers and the dipole detecting device through wireless means.

REFERENCES

Al-Maaded, M., Madi, N., Kahraman, R., Hodzic, A. and Ozerkan, N. (2012). An overview of solid waste management and plastic recycling in Qatar. Journal of Polymers and the Environment, **20 (1)**, 186-194.

Ambade, B. R., Sharma, S., Dass, A. and Sharma, Y. (2013). Municipal solid waste management in Jodhpur city, Rajasthan (India)-current status. International Journal of Environment and Waste Management, **11 (4)**, 430-440.

Soomro, S. A., Uqaili, M. A. and Aziz, S. (2012). Municipal Solid Waste Management: Options for Its Treatment and Energy Recovery. (In Mohammad A.U. and Khanji H. (Eds.), In Energy, Environment and Sustainable Development (pp. 245-252). New York: Springer.

Bagchi, A. (2004). Design of landfills and integrated solid waste management. New Jersey: Wiley.

Binley, A. and Daily, W. (2003). The performance of electrical methods for assessing the integrity of geomembrane liners in landfill caps and waste storage ponds. Journal of Environmental & Engineering Geophysics, **8(4)**, 227-237.

Chen, X., Geng, Y. and Fujita, T. (2010). An overview of municipal solid waste management in China. Waste management, **30 (4)**, 716-724.

Daniel, D. E. (1993). Landfills and impoundments Geotechnical Practice for Waste Disposal. New York: Springer.

Girod, L. and Estrin, D. (2001). Robust range estimation using acoustic and multimodal sensing. Paper presented at the Proceedings of the Intelligent Robots and Systems, USA.

He, P. J. (2012). Municipal solid waste in rural areas of developing country: Do we need special treatment mode? Waste management, **32 (7)**, 1289-1290.

Hix, K. (1998). Leak detection for landfill liners overview of tools for vadose zone monitoring. Diane Publishing, USA.
Darilek, G. T. and Parra, J. O. (1989). The electrical leak location method for geomembrane liners. Journal of Hazardous Materials, **21 (2)**, 177-187.

Laine, D. and Darilek, G. (1999). Performance-based specification of electrical leak location surveys for geomembrane liners. Paper presented at the Proceedings of the Geosynthetics' 99 Conference, USA.

Laner, D., Crest, M., Scharff, H., Morris, J. W. and Barlaz, M. A. (2012). A review of approaches for the long-term management of municipal solid waste landfills. Waste management, **32 (3)**, 498-512.

Nagarajan, R., Thirumalaisamy, S. and Lakshumanan, E. (2012). Impact of leachate on groundwater pollution due to non-engineered municipal solid waste landfill sites of erode city, Tamil Nadu, India. Iranian journal of environmental health science & engineering, **9 (1)**, 1-12.

Parkinson, B. W. and Spilker, J. J. (Eds.) (1996). Global Positioning System: Theory and Applications (volume One). Washington: American Institute of Aeronautics and Astronautics, Inc.

Peng, C., Shen, G. and Zhang, Y. (2012). BeepBeep: A high-accuracy acoustic-based system for ranging and localization using COTS devices. ACM Transactions on Embedded Computing Systems, **11 (1)**, 4-33.

Stüber, G. L. (2011). Principles of mobile communication. New York: Springer.

Ta, J. (2011). Global Positioning System. Dissertation, California State University Tchobanoglous, G. and Kreith, F. (2002). Handbook of solid waste management. New York: McGraw-Hill.

Torrieri, D. (2011). Principles of spread-spectrum communication systems. New York: Springer.

Viterbi, A. J. (1995). CDMA, principles of spread spectrum communication. New Jersey: Addison-Wesley Reading.

White, C. and Barker, R. (1997). Electrical leak detection system for landfill liners: a case history. Ground Water Monitoring & Remediation, **17 (3)**, 153-159.

Yang, J., Sidhom, S., Chandrasekaran, G., Vu, T., Liu, H., Cecan, N. and Martin, R. P. (2012). Sensing driver phone use with acoustic ranging through car speakers. IEEE Transactions on Mobile Computing, **11 (9)**, 1426-1440.

Zhang, D. Q., Tan, S. K. and Gersberg, R. M. (2010). Municipal solid waste management in China: Status, problems and challenges. Journal of Environmental Management, **91 (8)**, 1623-1633.