Faster Investigation of Shear Modulus of Soil through Wireless Networking

Zamri Chik[1] & S.M. Taohidul Islam[2]

ABSTRACT

This paper reveals the faster investigation of shear modulus of near surface soil with wireless networking system as a determination of soil properties in geotechnical investigations. Characterizing of surface soil behavior subjected to a specific loading condition is a primary goal in geotechnical engineering. The soil properties such as the shear modulus and material damping ratio is important to determine the response of soil characteristics. Spectral analysis techniques of Rayleigh-type surface waves can be utilized for characterizing the shallow subsurface through the multichannel analysis of surface wave method (MASW). In this paper, the new idea is established to embed wireless networking with characterizing near surface soil behavior using surface wave method. Wireless networking devices and microcontroller handles the data acquisition, signal processing, control, and communication for obtaining shear wave velocity and shear modulus of surface soil. The performance of newly developed surface wave method is estimated as faster and robust with arrangement of wireless networking system in soil investigations. The importance of our research is to establish the reliable, faster and cost-effective system for near surface soil characterizations with wireless interfacing in geotechnical site investigations.

Keywords: Surface wave method; Shear wave velocity; wireless networking; near surface soil.

I. INTRODUCTION

In Geotechnical Engineering, the estimation of shear-wave velocity as well as shear modulus is in fact interpreted as a direct indicator of near-surface soil stiffness profile. Seismic surface wave method is gaining popularity in geotechnical engineering practice for determining shear-wave velocity of soil profile. The main advantage of surface wave method is essentially related to its non-destructive and non-invasive nature of soil characterization that is revealed as robust and cost-effective method. One of the familiar seismic method for determining the shear wave velocity is the spectral analysis of surface waves (SASW) method in surface soil investigations. Park and others [3,12,13] have shown that multi-channel analysis of surface waves (MASW) represents an improvement over SASW, overcoming the few but significant limitations of the SASW method. MASW method was developed with the implementation of 2-D Fourier transformation for the seismic signals of multiple receivers [5,11,12].

[1]Department of Civil and Structural Engineering
[2]Department of Electrical and Electronics Engineering, PSTU & PhD Fellow
Universiti Kebangsaan Malaysia, Bangi 43600, Selangor, Malaysia
Corresponding author. Tel.: +60166912790; fax: +60(3) 8921 6147
E-mail address: staohidul@yahoo.com, irzamri@yahoo.com
Manuscript received at 9 March 2011 & revised at 13 April 2011

MASW method is also convenient to be used in a shallow marine environment [4] and pavement feasibility test [9,10]. This method also shows better performance to evaluate stiffness of water-bottom sediments, to determine a sinkhole impact area, collapse and subsidence feature, to represent near surface anomalies [8], to map bedrock surface [6,7].

Advances in MASW method allow high confidence, non-invasive delineation of horizontal and vertical variations in near-surface soil properties. Nevertheless, data collecting of shear wave velocity detected and handled properly that may cause time consuming in the results for surface wave analysis.

Usually, seismic signal received by geophone have been acquired with microcontroller or laptop to obtain shear wave velocity through processing of phase velocity in surface wave method. In MASW method, RAS24 device is used to obtain time domain seismic signal from geophone in laptop for surface wave analysis. Data acquisition in microcomputer with wired system in soil site investigations is also tedious and time consuming for seismic signal investigations.

In addition, very limited work has been done so far on the technologies to get soil characteristics data wirelessly from field to the remote server. A consistent wireless networking system is embedded with the surface soil characterizations in this paper where real time data of seismic signal and other soil properties are sensed and relayed to a central repository [14].The advancement in surface wave analysis is very significant due to the cost of deployment and rapidness with running of a feasible precision in geotechnical framework. Emerging wireless technologies [1] with soil characterizations of near surface soil are very consistent for the low power needs in civil and environmental engineering.

National Instruments (NI) wireless modules are used in this work to demonstrate better performance in networking system. NI wireless sensor networking (WSN) Ethernet gateway module offers boosted outcome in wireless networking and retains the low current to make this module ideally suited for battery operated end devices with the lowest power in this system. NI wireless networking system are more reliable for wide spread deployment in the form of a mesh network and offers robust communication through redundant propagation paths. This networking system allows faster deployment and installation of various types of device because many of these networks provide self-organizing, self-configuring, self-diagnosing and self-healing capabilities to the data transmitting nodes. The aim of this research is to obtain robust, cost-effective, faster and reliable outcomes in near surface soil characterizations with wireless networking for determination of shear wave velocity and shear modulus in geo-environmental engineering.

ISBN: 978-988-19251-4-5
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

II. METHODOLOGY

The research study on the surface wave analysis is conducted at University Kebangsaan Malaysia with the cooperation of Ministry of Science, Technology and Innovation of Malaysia. The simulation of faster networking system through NI WSN Ethernet gateway is carried on using Lab-VIEW Software at University Kebangsaan Malaysia (UKM) in Bangi, Selangor, Malaysia. The study of wireless networking system with soil site investigations is done and the analysis is performed using MATLAB 7.8 in Geotechnical Laboratory, Faculty of Engineering and Built Environment, University Kebangsaan Malaysia (UKM).

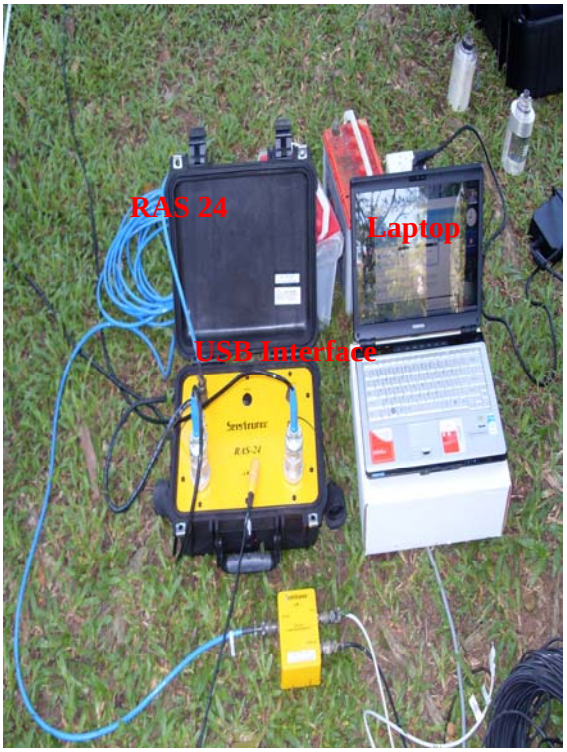

FIGURE 1 Recording of seismic signal data collection

Figure 1 shows the instruments used for seismic signal data acquisition in laptop including device of RAS 24, Seistronix and Analog to digital (A/D) converter and power supply for surface wave analysis. The time domain seismic signal is converted to frequency domain signal through our developed software, GEO-SW@T. The frequency versus phase velocity is obtained after dispersion analysis in surface wave analysis of geotechnical investigations. The shear wave velocity of near surface soil is determined at the inversion analysis of seismic method. The time domain seismic data is transmitted to the microcomputer through wireless networking for faster soil site investigations. The specifications of NI wireless networking device used for rapid soil site investigations are shown in Table1.

TABLE 1 Specifications of wireless networking device in soil characterizations

Devices	Model Specifications	Functions
Analog Input Node	NI WSN-3202, 4-Ch, 16-bit, ±10V	International w/ 4 DIO channels. Provides selectable input ranges and external sensor power up to 12V, 20mA.
Desktop Power Supply	2-Position Screw Terminals	12 VDC, 1.25A
WSN Ethernet Gateway	NI WSN-9791	9-30V powered - International Version, 9-30V DC powered, Industrial temperature and shock & vibe ratings. Outdoor range up to 1000m with line of sight
Universal Power Input	PS-5 Power Supply, 24 VDC,	Easy way to distribute power from one power supply to up to 8 devices with replaceable blade fuses.

The system includes a microcontroller and database options as storage device to save collected data and process consistently as expert electronics device. The time domain seismic signal is modulated with defined carrier signal through 4-Phase Shift Keying (PSK) method in wireless networking. The modulated signal is passed through a filter to reduce the noise in signal transmission through Additive White Gaussian Noise (AWGN) channel. Figure 2 shows the block diagram of the data processing for modulation and demodulation technique through wireless networking.

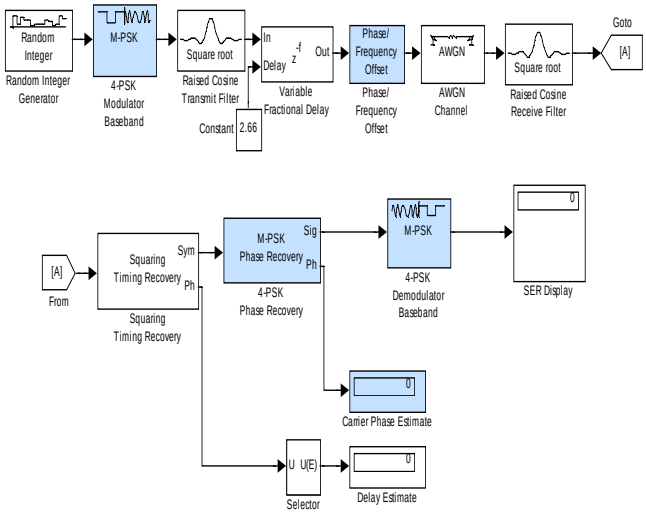

FIGURE 2 Modulation and demodulation technique in wireless networking

ISBN: 978-988-19251-4-5
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

The signal is transmitted with a frequency range to get faster seismic data in soil site investigations. The filter reduces the noisy outcomes with collected electrical signal according to the frequency of the signal and supplied it to the microcontroller. The microcontroller handles the data acquisition, signal processing, calibration, control and communication and the RF terminal handles the data transmission and reception. This modulated seismic signal is then transmitted to the computer through the antenna of RF transceiver interfaced to the microcontroller. Wireless Networking [15] with Mesh topology is configured to be able to react on external influences and noises with robustness using filtering technique. Robust wireless mesh topology also includes NI WSN Ethernet Gateway, Lab-VIEW software used in our research work

III. RESULT AND DISCUSSION

Soil characterizations of near surface soil with wireless networking system are developed in this research work. Recent advancement in electronics and wireless networking technologies have improved the ability to collect, process, and transfer real data to manifest subsurface soil properties of in geotechnical engineering [14]. To maximize the effectiveness of obtaining shear wave velocity through surface wave analysis, wireless networking system is embedded in this system for geotechnical characterizations.

The NI instruments for wireless networking offers boosted outcome in wireless networking system for soil compaction monitoring. WSN Ethernet Gateway retains the low power needs to make this module ideally suited for battery operated end devices with the lowest transmit current. Based on the Analog Input Node and WSN Ethernet Gateway solution utilizes the robust mesh topology and it has been designed for fast integration into any device without the need for RF experience and expertise.

The NI WSN makes the networking system consistent with the specifications of 9-30V powered - International Version, 9-30V DC powered, Industrial temperature including shock and vibe ratings. The system also reveals the performance of optional board-to-board or board-to-cable connector, antenna options, microcontroller with non-intrusive debug interface (SIF), 128k flash and 5kbytes of SRAM, optional software support for hardware I2C and SPI.

In the soil site investigations, time domain seismic signal is recorded with the geophone or accelerometer in technique of surface wave analysis. The seismic signal data is transferred through robust wireless networking and stored in computer for soil properties investigations. The surface wave of seismic signal is processed and soil properties are obtained in the inversion analysis of surface wave investigations. Table 2 shows the soil properties data corresponding to the different layer of near surface soil. As an example, layer 2 shows shear wave velocity as 230 m/s including the thickness of 8.0 m, damping ratio of 0.05 and Poisson's ratio 0.45 for surface soil profile whereas layer 3 reveals shear wave velocity as 478 m/s for the layer thickness of 2.0 m.

TABLE 2 Investigations of soil properties of near surface soil

	Shear wave velocity (m/s)	Thickness(m)	Damping ratio	Poisson's ratio
Layer 1	150	6.0	0.05	0.45
Layer 2	230	8.0	0.05	0.45
Layer 3	478	2.0	0.05	0.45
Layer 4	680	4.0	0.05	0.45
Half-space	800	∞	0.05	0.45

The inversion analysis demonstrates the depth versus shear wave velocity profile in geotechnical properties exploration [2]. The absolute outcome of updated inversion technique is fitted as Figure 3 which is also resulted in the window of the developed GEO-SW@T software as the 1- D inversion option. The measurement of shear wave velocity is thus justified confidently up to 40 meter depth.

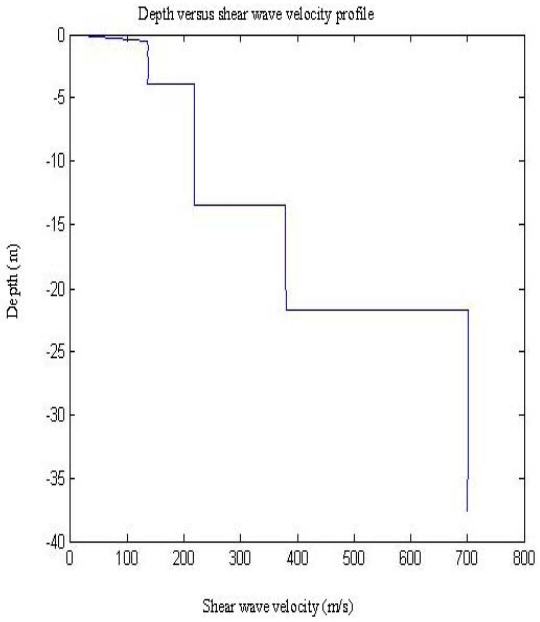

FIGURE 3 1-D depth versus shear wave velocity profiles from GEO-SW@T

Usually, seismic data has been taken from soil site to obtain the comprehensive information for analysis with computer software which is labor intensive, and expensive for soil investigations. Including wireless networking with soil characterizations in our research work is also faster and cost-effective system for commercial and technological solutions with few test verifications in surface soil investigation. The use of microcontroller and NI WSN devices are cooperative to save the power by transmitting the data only when needed and going to sleep mode rest of the time. The filtering technique in this system is competent to reduce the noise

ISBN: 978-988-19251-4-5
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

of seismic signal collected through WSN sensor in soil monitoring technique.

IV. CONCLUSION

A robust wireless networking with near surface soil investigation system is developed with the aim of achieving a low cost, low power, reliable and faster outcomes in geotechnical engineering. To obtain the better performance in soil site investigations, the NI wireless module is embedded with surface wave analysis in the research work. The design, block diagram, and the performance through wireless monitoring system are obtained for obtaining shear wave velocity and shear modulus in geotechnical and geo-environmental engineering. Incorporating wireless networking with surface wave analysis is faster and cost-effective including a data storage system for transmitting the data to a computer, or another sensor in a network. There are many features like damping ration criteria, attenuation factor that still need further investigation in surface wave analysis. These features will be embedded with wireless networking system in the future modeling for soil characterization in near surface soil profile.

ACKNOWLEDGEMENTS

This research is sponsored by Research Project of Science Fund No. 01-01-02-SF0681 from Ministry of Science, Technology and Innovation of Malaysia.

REFERENCES

[1] Anurag, D. , Roy, S. & Bandyopadhyay, S. 2008. Agro-sense: precision agriculture using sensor-based Wireless mesh networks. *IEEE Xplore*, 2008 ITU.

[2] Islam, T., Chik Z. 2010. Advanced performance in geotechnical engineering using tomography analysis. *Environmental Earth Science*, Accepted at 10 August 2010, In Print.

[3] Ivanov, J., Park, C.B., Miller, R.D., & Xia, J. 2005. Analyzing and filtering surface-wave energy by muting shot gathers**.** *Journal of Environmental & Engineering Geophysics*, **10(3):**307-322.

[4] Kaufmann, R.D., Xia, J., Benson, R.C., Yuhr, L.B., Casto, D.W. & Park, C.B. 2005. Evaluation of MASW data acquired with a hydrophone streamer in a shallow marine environment**.** *Journal of Environmental & Engineering Geophysics*, **10(2):** 87-98.

[5] Lin, C.P. & Chang, T.S. 2004. Multi-station analysis of surface wave dispersion. Soil Dynamics and Earthquake Engineering, 24: 877–886.

[6] Miller, R.D., Xia, J., Park, C.B. & Ivanov, J. 2000. Shear wave velocity field from surface waves to detect anomalies in the subsurface. *Proceedings of the First International Conference on the Application of Geophysical Methodologies to Transportation Facilities and Infrastructure*, St. Louis, December 11-15.

[7] Miller, R.D., Xia, J., Park, C.B. & Ivanov, J. 2001. Shear wave velocity field to detect anomalies under asphalt. Proceedings of the 52nd Highway Geology Symposium, May 16, Baltimore, Maryland.

[8] Park, C.B., Miller, R.D. & Xia, J. 1999a. Detection of near-surface voids using surface waves. *SAGEEP 99*, Oakland, Calif., March 14-18, 281-286.

[9] Park, C.B., Ivanov, J., Miller, R.D., Xia, J. & Ryden, N. 2001a. Seismic investigation of pavements by MASW method—geophone approach. *Proceedings of the SAGEEP 2001*, Denver, Colorado, RBA-6.

[10] Park, C.B., Ivanov, J., Miller, R.D., Xia, J. & Ryden, N. 2001b. Multichannel analysis of surface waves (MASW) for pavement-feasibility test. *Proceedings of the 5th SEGJ International Symposium*, Tokyo, pp. 25-30.

[11] Park, C.B., Miller, R.D. & Xia, J. 1999b, Multi-channel analysis of surface waves. *Geophysics*, **64(3)**: 800-808.

[12] Park, C.B., Miller, R.D., Xia, J. & Ivanov, J. 2000.Multichannel seismic surface-wave methods for geotechnical applications. *Proceedings of the First International Conference on the Application of Geophysical Methodologies to Transportation Facilities and Infrastructure*, St. Louis, December 11-15.

[13] Penumadu, D. & Park, C.B. 2005. Multichannel analysis of surface wave (MASW) method for geotechnical site characterization. *Proceedings of the Geo-Frontiers conference*, Austin, Texas, January 23-26.

[14] Sabatier, J.M., Sokol, D.C. , Frederickson, C.K. , Rdmkensb, M.J.M. , Grissingerb, E.H. & Shipps, J.C. 1996. Probe microphone instrumentation for determining soil physical properties: testing in model porous materials, *Soil Technology* ,**8** :259-274.

[15] Tilak, S. 2005. Towards A Holistic Approach for Protocol Development in Sensor Networks. Thesis of PhD, Graduate School of Binghamton University State University of New York.