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River Bedload Monitoring Using a Radar System

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Abstract:

Bedload measurement is vital for the monitoring rivers and streams to prevent natural disasters and to assess land use changes. Various techniques have been developed to monitor river bedload such as acoustic, optical, and pressure difference technologies. Acoustic technology (geophone) has been widely used to measure gravel bedload; however this system has some problems related to noise due to water flow and the precision of measurement is low at lower flux discharges for short intervals. In this paper, we report the use of ground penetrating radar technology for the first time to monitor sand and gravel bedload movement. We performed laboratory experiments at Kyoto Prefecture University, Matsumura Lab., using the 1 GHz Ground Penetrating Radar (GPR) calibrated with manual sediment samples. The radar data and the manual measurements agree in terms of radar signal amplitude and the density of sand and gravel.

1. Introduction:

Measurement of sand and gravel transport is a challenging and difficult job as the direct measurement is not always possible and precision is also low. There has been a large amount of research and investigation on the use of acoustic sensors [Laronne et al., 2006; Gray et al., 2005] for bedload measurement during recent decades. However, research on application of the high frequency electromagnetic wave device called GPR (Ground Penetrating Radar) has not yet been reported for bedload measurement. GPR has been a promising and emerging technology for underground and underwater characterization and investigation, such as groundwater investigation, soil mapping, water saturation measurement, void detection, water pipe, gas pipe and electric cable, duct detection and river depth mapping [3]. We developed for the GPR with special type of pipe antenna, which can be submersed for monitoring bedload.

Principles of Radar

The principle of radar lies in the transmission of a narrow pulse width signal inside the water medium and the receiving of an echo signal from the target in the water. Here, electromagnetic waves from the transmitting antenna are transmitted in the water and the echo signal from the sediment is received by the receiving antenna. Since the dielectric constants of water and sand differ considerably, reflections occur when there are changes in the dielectric constant of a sediment and water mixture. In this experiment, we used impulse radar, which transmits the electromagnetic wave at 1.0 GHz (1.0 ns pulse width), and estimates the delay time of the reflected signal. When the low frequency band is used, signal attenuation is lower and the detection range is higher, but resolution is degraded. In contrast, when the high frequency band is used, signal attenuation is higher, the detection range is lower, but the resolution is improved.

3. Experiment

The preliminary experiment was conducted at the Matsumura Lab, Kyoto Prefecture University. The experimental equipment consists of an impulse radar (pulse width 1.0 ns), a dipole antenna, a data logger (A/D Converter, DSP board, FPGA), a signal processing unit, a water channel made of iron bars and glass, and sand and gravel of varying diameter (Fig.1, 2). The dimensions of the flume are: 15 m long, 38 cm wide, and 35 cm high.

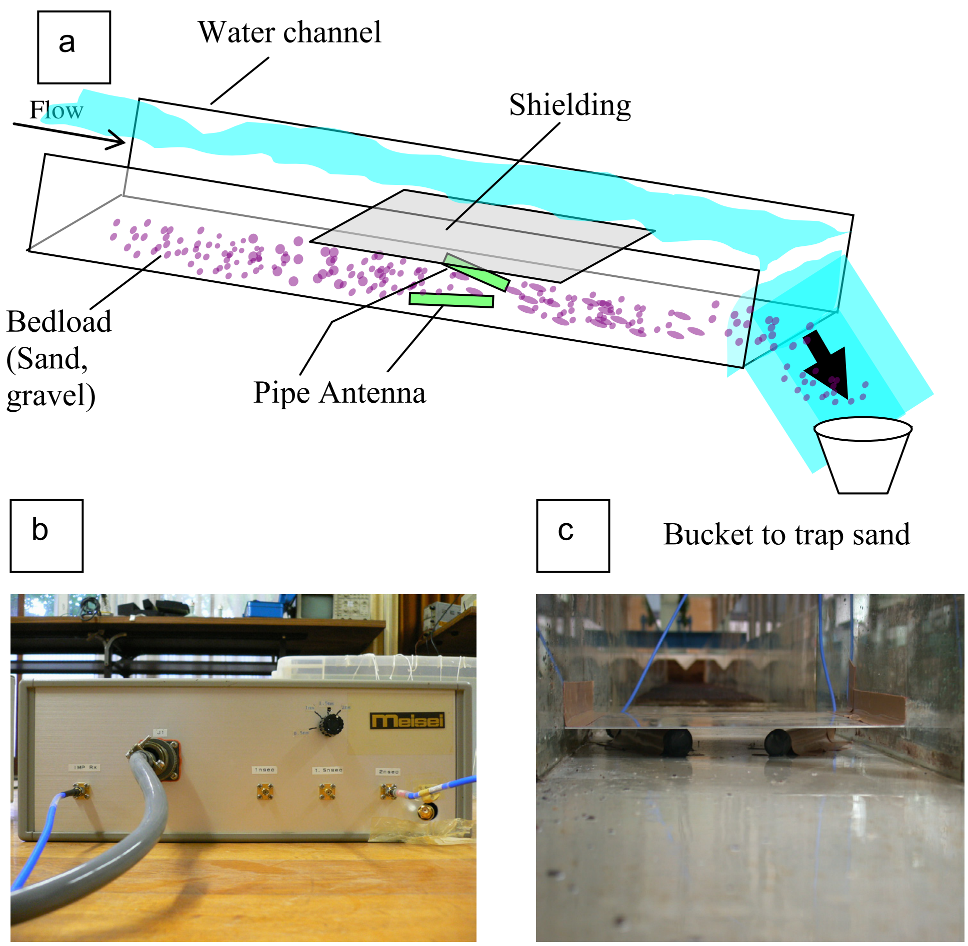

Figure 1. (a) Experimental setup for bedload measurement; (b) Impulse radar; (c) radar antenna in the flume.

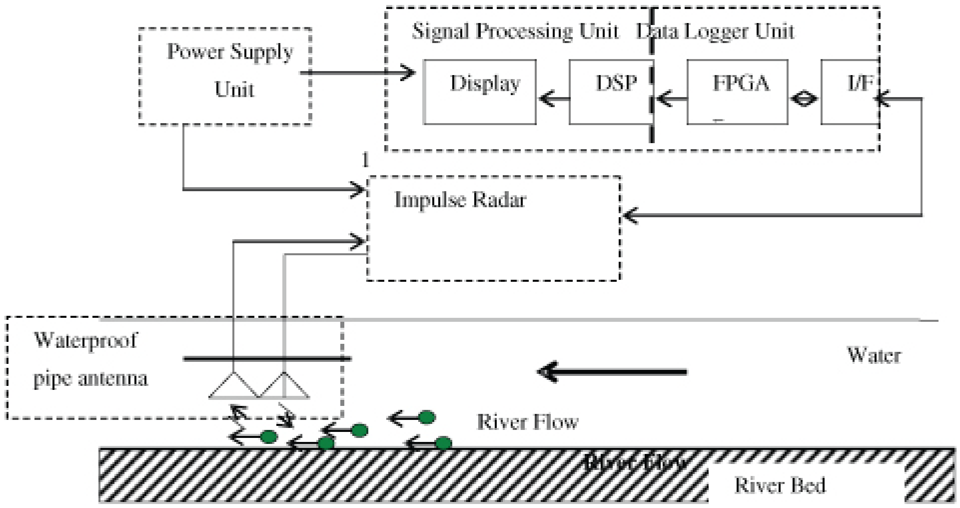

Figure 2. Block diagram of the bedload monitoring radar system.

4. Data Acquisition and Data Processing

Water was pumped into the experimental channel and sand and gravel of various diameters (0.8 mm, 2.0 mm, 4.75 mm, 6.0 mm, 9.0mm, 12.0 mm and 15.0 mm) were poured in the channel for data acquisition. The impulse radar specification and experiment setting are shown in Table 1. Different sets of data were acquired by the radar system using various sized sediment; the slope of the cannel was set to 1/50 (Table 2). We arranged the transmitting and receiving antennas in a V shape as shown in Fig.1 (c). In this case, the transmitting antenna transmits the signal and strikes the signal at the target; the receiving antenna receives the echo from the target. We processed this echo signal to get the information on sand transport rate, which is explained below.

Table 1. Specification of impulse radar

Pulse width	1 ns
Power	20 mW
Antenna Type	Dipole Antenna (Pipe antenna)
Antenna Separation	50 mm
Data Acquisition Frequency	10 Hz
Receiving Time Resolution	128 psec
Sampling Number	256

We collected manual sediment samples using a bucket to calibrate the radar data. We used a bucket to collect the sand and water for only one second for every set of experiments. We collected 18 liters of water plus sand because the flow of water in the channel was 18 liters per second. However, we could not ensure that the bucket had a 100% trapping efficiency, so we repeated each set of data acquisition 5 times and used the mean to minimize the error. The density of the sediment in percent is calculated by the following formula:

$$\text{sediment density} = \frac{100\,(\text{sediment volume})}{\text{volume of sediment} + \text{water}} \tag{1}$$

Table 2. Experimental Data

Slope	Water Discharge (1/s)	Sediment Diameter (mm)	Input sand volume (l)
1/50	18	0.80	1.0
		2.00	
		4.75	
		6.00	
		9.00	
		12	
		15	

Since the diameter of the sediment is very small and it is difficult to reconstruct a clear image of the sand, statistical methods have been used for data analysis. The standard deviation is used as a statistical parameter to analyze the experimental data. The square root of a set of N values is the sample standard deviation, which is expressed as:

$$S_N = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(x_i - \bar{x}\right)^2} \tag{2}$$

where x_i is each value of N number of values and $\bar{x}$ is average value.

In this experiment, data acquisition time was approximately 60 seconds. Standard deviation is taken in every second to thoroughly analyze the amplitude of the signal. In addition, we preprocessed the radar data by differential method to increase the signal to noise ratio (SNR).

5. Results and Discussions

The raw data for 4.8-mm diameter gravel at 1/50 slope is shown in Fig. 3 (a). The signal processing result using the standard deviation method is shown in Fig. 3 (b).

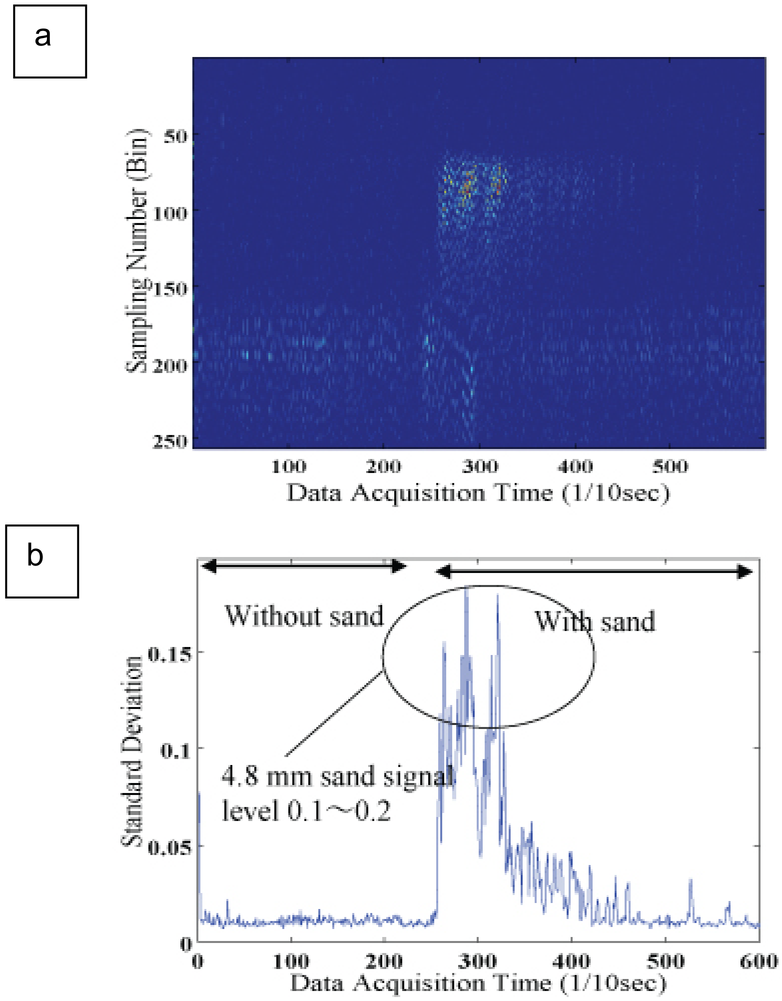

Figure 3. (a) Raw data measured by radar, Slope=1/50; (b) Standard deviation (1:600, 75:120), Slope=1/50.

We found that the radar signal amplitude increases when the diameter of the sediment is increased and noticed that when the volume of the sediment is high and moves in bulk, the radar amplitude is also high.

The main attractive feature of the state of the art is that the background noise level is low and the data acquisition is easier than the manual process. The system would be robust if the radar antenna was fixed in a strong concrete block or some other special arrangement. The system is very simple so it can be operated by laymen (with some computer knowledge) with a couple of days training. The laboratory experiment yielded very reliable data and promising results; however, field experiments have not yet been carried out. It is still in a research and development stage and considerable time, energy and finance have been spent in research and development; hence, the approximate cost cannot be specified as yet. At the present stage, a simple signal processing algorithm has been used, but it would be highly desirable to develop advance signal processing algorithms to operate in various test conditions.

6. Conclusions:

We have reported the application of ground penetrating radar system to bedload monitoring for the first time. We found that the acoustic waves and radar waves have similar characteristics in terms of signals reflected from targets. However, background noise is high with acoustic signals, whereas it is low with radar signals. Therefore, we have chosen the ground penetrating radar as a technology for bedload monitoring.

We carried out laboratory experiments to calibrate the radar signals (indirect measurement) with the manual bucket samples (direct measurement). There are linear relationships between the radar signals and manually measured sand and gravel density data. When the diameter of the sand increases, the radar signal amplitude is increased and the sand and gravel density is also increased. The measured sand and gravel density (Fig. 4) and the radar signal amplitude of 0.8 mm sand diameter are lower than the 20 mm diameter, which is shown in Fig 5.

Radar data acquisition and its calibration in a real stream or river will be the topic for further research.

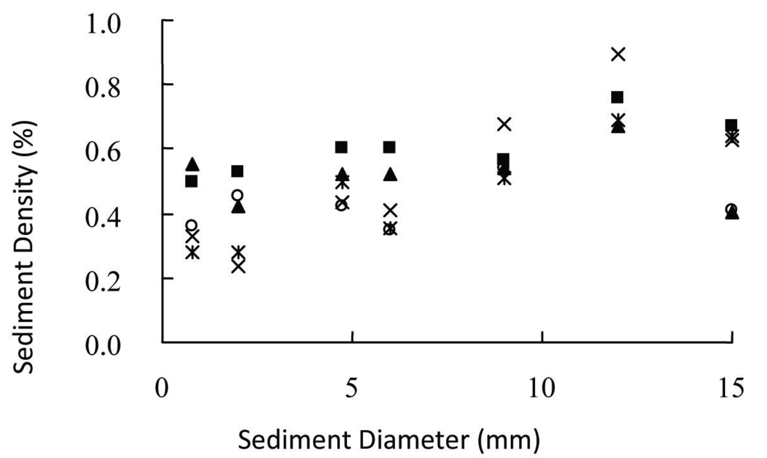

Figure 4. Scattergraph of sediment density versus diameter (slope=1/50)

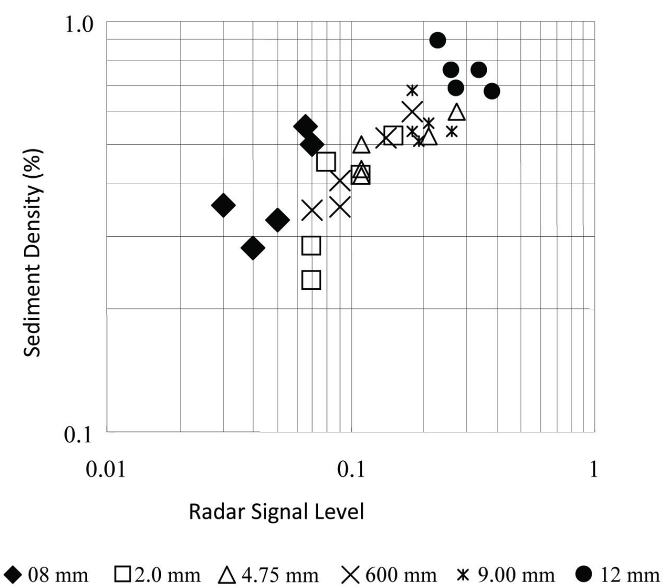

Figure 5. The relation between sediment density measured by manual sampling and by radar.

References

Laronne, J.B., Mizuyama T., Satofuka Y., Sawada T., Yamashita S., Sako S., Tamaki A., Nonaka M., May 2006, Issues in the calibration of an acoustic sensor in mountain rivers Japan. Japan Society of Erosion Control Engineering Jour. Soc. Erosion Control Engineering., Publ. No.45, pp. 72-73, May, 2006.

Gray, J.R., Melis, T.S, Patiño, Eduardo, Gooding, D.J., Topping, D.J., Larsen, M.C., and Rasmussen, P.P., 2005, U.S. Geological Survey suspended-sediment surrogate research on optic, acoustic, and pressure-difference technologies. *in*, Proceedings of the Federal Interagency Sediment Monitoring Instrument and Analysis Workshop, September 9-11, 2003, Flagstaff, Arizona, J.R. Gray, ed.: U.S. Geological Survey Circular 1276, 10 p.; available only online at: http://water.usgs.gov/osw/techniques/sediment/sedsurrogate2003workshop/listofpapers.html.

Shrestha, S.M., and Arai, I., 2003. Signal Processing of Ground Penetrating Radar Using Spectral Estimation Techniques to Estimate the Position of Buried Targets. EURASIP (European Association for Speech, Signal and Image Processing) Journal on Applied Signal Processing, Vol. 03, No. 12, pp. 1198-1209, Dec. 2003.