Applied Mechanics and Materials Vols. 278-280 (2013) pp 714-718 Online: 2013-01-11
© (2013) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMM.278-280.714

Applications of Doppler Radar Sensors on Railroad Crossing Safety Alerting System

Sheng-Hang Wang [1, a], Kuang-I Chang [2,b], Jyun-Long Chen [3,c], Mu-Yu Tsai [4,d], Bor-Nian Chuang [5,e]

[1,2,3,4,5] Center for Measurement Standards, Industrial Technology Research Institute
Rm. 302A, Bldg. 7, 321, Sec. 2, Kuang Fu Rd., Hsinchu, 30011, Taiwan

[a] shwango@itri.org.tw, [b] AlanChang@itri.org.tw, [c] chenjounlong@itri.org.tw, [d] tsaimuyu@itri.org.tw,
[e] B.N.Chuang@itri.org.tw

Keywords: Doppler radar, vibration, ultra-wideband, railroad safety, alert, sensor

Abstract. Radar sensors like ultra-wideband Doppler radar sensors may be utilized as a vibration sensing device in a restricted area for railroad monitoring. As long as something or someone enters the restricted area, the alert signals will be sent to the control center or train driver to stop the moving train and prevent accidents. Combining with visual monitor system, the radar sensors may compensate for the insufficient information under poor lighting, fogging, or raining environment. The simulations and experimental results supported its feasibility in a railroad system. The feasibility of further radar application is also discussed.

Introduction

Railroad accidents can cause huge economic loss and damages to the society, refer to Fig. 1a, To reduce or prevent such risk, it is necessary to monitor obstacles in certain control areas. There are many sensors for monitoring the signals of obstacles in a control area, such as accelerometers and microphones. However, the received signals are prone to interference by ambient noise and consequently the signal discrimination is poor. The laser interferometer is an option for its non-contact design and accuracy. But due to small light spot and localized sensing area, there is a limitation to be used in a large range at the same time. Besides, lasers can cause damage to the eyes and are relatively expensive and do not receive much usage for public transportation. Visual recognition is another option, too. But under certain situations as shown in Fig. 1b, like poor lighting, raining, fogging or dirty camera lens, the visual recognition will become malfunction in a control area.

(a) (b)

Fig. 1 a) Importance of Railroad Crossing b) Importance of Railroad Crossing Safety in Night Construction, Raining, Fogging

Fortunately, the radar sensor can improve this situation. In nature, bats use the Doppler characteristic signals to capture insects. It will also be a good technique for human to monitor the target [1,2]. V. Chen [3] proposed a mathematical model for Micro-Doppler effect. Based on simulations and experiments, high resolution time-frequency transform that was able to analyze variation of Micro-Doppler characteristics was derived. Bailed [4] suggested the variable frequency radar in recognizing object movement for indoor scene monitoring, especially be used in the airport to detect suspicious passengers. Li and Lin [5] proposed the 22 GHz-40 GHz radar sensors to analyze and simulate the wide-angle occurrence rate effect, which were able to measure the dynamic displacement accurately with properly selected radio frequency. The Doppler radar technique is non-contact and very suitable for monitoring human cardiopulmonary system [6]. Wang et al. [7] proposed that the vibration signals can be measured precisely when using Nano-second Pulse Near-field Sensor (NPNS) by comparing the laser interferometer, the Eddy current displacement sensor and the accelerometer as well as the radar sensor when detecting rotational vibration measurement. In this paper, the safety alert simulation system within one square meter was achieved with ultra-wideband (UWB) sensor. All the signals were transmitted via Bluetooth to computer and displayed on the LCD screen. The alert system could be activated by any abnormal signals to notify the train driver and control center as well as slowing down the train, forming a safety net to reduce accidents.

Radar system principles and hard are architecture

After the electromagnetic wave is emitted via the antenna, the reflection wave from the object can be received and the moving speed and related vibration and movement signals for the object were derived by Doppler Effect. If the transmitted signal frequency is f and the object speed is V and the distance to object is D (Eq. 1,), the frequency change f_0 can be considered by (Eq. 2,), in which c is 3×10^8 m/s, the light speed, d stands for the displacement of object, expressed as $d = C \cdot T$, and the unit is m. Period is the reciprocal of frequency, expressed as T=1/f, and the unit is s:

$$D = d - V \cdot T. \tag{1}$$

$$f_0 = \frac{1}{T_0} = \frac{c}{d - VT} = f\frac{1}{1 - V/c} = \frac{f}{1 - V/c}. \tag{2}$$

For Doppler radar sensing system, the velocity component of the object will be obtained by Doppler Effect. The frequency of reflected signal will be derived from that of the transmitted signal. If the frequency of transmitted signal is f, and the object velocity is $V = V_S \cdot \sin(\omega_s t)$, and the object relative travel distance is $V \cdot T$, and the object relative distance is $D_s = d - TV_s \cdot Sin(\omega_s t)$, the period of pulse wave change will be :

$$T_s = \frac{d - TV_s \sin(\omega_s t)}{c}. \tag{3}$$

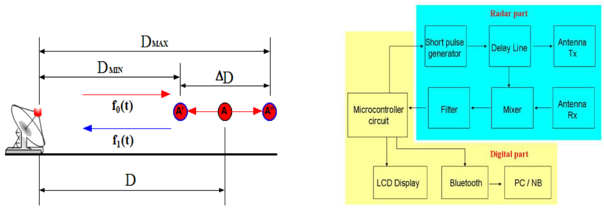
the frequency change for pulse wave will be：

$$f_s = \frac{1}{T_s} = \frac{c}{d - TV_s \sin(\omega_s t)} = \frac{f}{1 - \frac{V_s \sin(\omega_s t)}{c}}. \tag{4}$$

in which Ts is the period after change and its unit is second, c is light speed 3×10^8 m/s. The frequency changes in accordance with the displacement of the object.

As shown in Fig. 2a, the transmitted radar signal to the object A is $f_0(t)$. When the object A moves from A' to A'', its displacement is ΔD, and the generated echo signal is $f_1(t)$. Through time difference t, transmitted signal and received signal $U_0(t)$, ΔD can be obtained by Doppler effect. The hardware architecture of the circuits for the alert system can be found in Fig. 2b. The microcontrol chip module can transmit the signal to the short pulse generator. The delay line can modulate the time difference for transmitted signal and send out the signal via antenna Tx to the moving object. Due to vibration of the object, reflected wave will be sent back into antenna Rx. The

signals will pass the mixer and then sent to the filters and be processed by the micro control unit. Finally, the LCD on the device will show the signal status as well as the computer. When the transmitted signal (Local oscillation, LO) and the received signal (Reflect frequency, RF)are collected by the mixer, the vibration information of object can be obtained.
Transmitted signal wave and received signal wave can be found . Although both of the continuous waves and the UWB waves can detect movement and vibration signals of objects, fields of applications are different. For wide range and long distance sensing, the UWB waves may perform better due to better anti-noise ability. The radar system here can be divided to two parts, analog circuit and digital circuit. Analog circuit includes: transmitting and receiving antenna, mixer and filter. After vibration frequency is calculated, it will be shown on the LCD module. Besides, the data can be sent to computer via Bluetooth and the vibration signal can be shown by self-designed LabVIEW software.

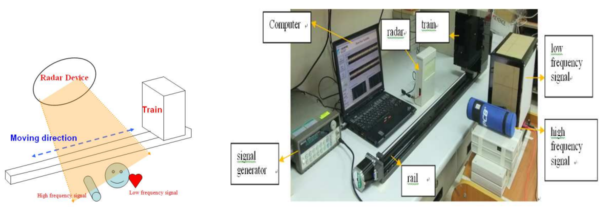


(a) (b)

Fig. 2 a) Radar Wave Doppler Sensing b) Circuit Architecture for Alert System

Experimental setup

Building a complete railroad safety alert system is quite expensive. To understand the real situation, a model system was built in the laboratory to simulate railroad train safety device within a limited area. Fig. 3a, is an illustration for the system setup. The experimental setup is shown in Fig. 3b, A 1-meter single-axis stage is set up with an object on it to simulate a moving train back and forth (controlled by LabVIEW). A signal generator HP 33120A was set to provide 10 Hz (input amplitude around 3 V)sinusoidal signals to the speaker as a low frequency vibration. At the same time, the calibrated accelerometer (PCB Model 394C06) was attached to confirm signal reliability (159.2 Hz, acceleration 9.81 m/s2). The objective was to provide two different but stable vibration frequencies and then used radar sensor to detect the two different vibration frequencies and amplitudes. The stage stopped as soon as the radar received the vibration signals.

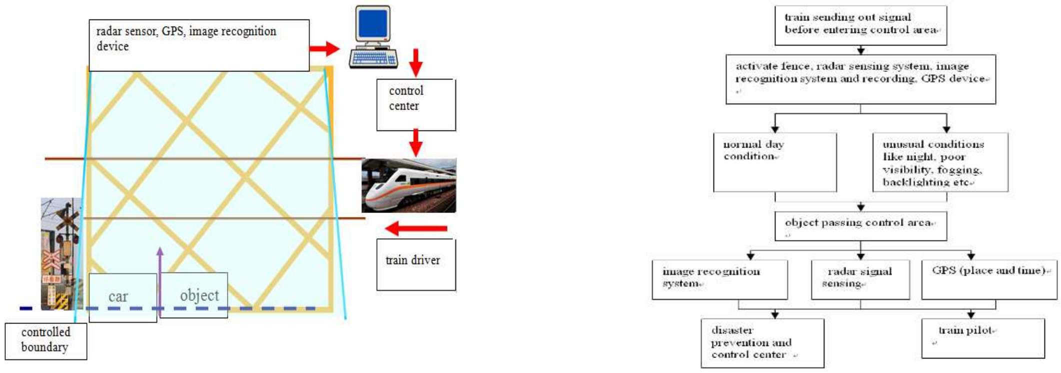


(a) (b)

Fig. 3 Experimental Architecture in Simulated Control Area (a)Illustration of Experimental Architecture (b)Experimental Architecture for the Simulation

The simulation device was expected to be used for a real safety alert system. Its architecture can be found in Fig. 4a, The components and sensing signals in the architecture of an real railroad crossing control area include directional signal (train moving direction), computer, radar, low frequency signal (object) and high frequency signal (car). Radar wave was used to detect object vibration within a limited area. If a train is passing the control area and a car (engine or other mechanical vibration is of relatively high frequency) or an object (human and animal walking is of relatively low frequency), the radar wave identified the vibration signal and notified the control center and the train (notification of

train passing time, GPS signal location, vibration signal, image recognition and video surveillance), so the train driver can slow down or stop the train after obtaining the information within the control area. An accident could be stopped as a result.
This system may be combined with a visual system. When a train is going to pass through a control area, the radar sensor will be activated for monitoring as well as the visual system. Under normal condition (without poor lighting or fogging), the image recognition and monitoring will operate normally; if the control area has unusual condition (poor lighting or strong backlight) to cause poor recognition, the vibration signals can be used to determine whether an obstacle exists in the control area. If a normal signal is detected, the control center will be notified. This additional layer of protection can reduce the risk. The built alert control system and the flow diagram for radar sensor to detect abnormal signals and messages can be found in Fig. 4b,

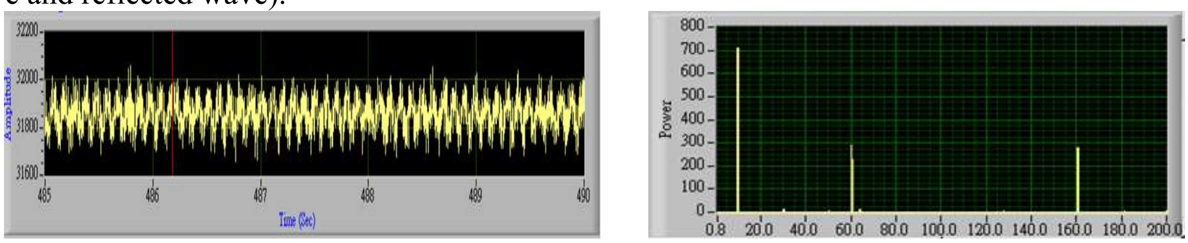


(a) (b)

Fig. 4 a) Illustration for Hardware Architecture of the Alert System in the Control Area b) Alert System Signal Control Flow Diagram

Results

When radar sensors were used to measure the vibration signals within a limited area, according to the architecture in Fig. 3, and self-developed LabVIEW software, different frequencies like 10 Hz and 159.2 Hz could be captured at the same time. The result is shown in Fig. 5a, which is time field and its x-axis represents time with second as the unit and the y-axis represents radar wave vibration sensing amplitude with volts as the unit. Fig. 5b, is the signals in frequency field after Fast Fourier Transform (FFT) whereas the x-axis represents the frequency with Hz as the unit and the y-axis represents the radar wave vibration sensing energy (i.e. energy after Mixer frequency demodulation for transmitted wave and reflected wave).



(a) (b)

Fig. 5 a) Time Field and b) Frequency Field Signal for Simulating Train Passing Control Area

The results indicated the radar system can measure 10 Hz and 159.2 Hz. Since the displacement of 159.2 Hz signals is very small (10μm), the signal is only slightly larger than 60 Hz noise. As long as the vibration signals can be obtained, the system can successfully detect micro-vibration in a limited area. In a practical application, the vibration information (i.e. frequency and amplitude) is the subject to be analyzed to determine whether the vibration signal is a signal from a human or a car in a control area. After the signal is identified, the signal was sent to the control center or the train driver to slow down or stop the train to prevent disasters from happening. Current radar sensors bandwidth is set for the hardware filter range from 0.1 Hz to 200 Hz. In the future, when it is applied to railroad vibration measurement, the bandwidth will be slightly adjusted.

Conclusions

The vibration signals in a real measurement environment are very complicated. The railroad safety alert device built in the laboratory to simulate the use of radar sensor was proved to be a good method for future monitoring in a real control area. The key advantage for the technology is the self-designed software and hardware, which is very convenient and can meet custom specifications. Compared to other non-contact vibration sensing device, its price also has competitive advantage； the Bluetooth device in the sensor can transmit the signal to the computer for signal analysis or display on the LCD monitor for the related information analysis. Besides, the benefit for the radar sensing technology in this application is to allow non-contact large-area sensing of vibration signal within a large area at invisible wavelength. Compared to visual recognition device as monitoring method, it was further proved to be a good method or tool to sense object vibration by radar sensor under strong backlighting or fogging condition and differentiate the obstacle in the control area. In addition to the safety alert device for railroad train passing a safety control area, the technology can also be used for flight control zone or traffic accident scene as a simple alert device. Utilizing the core sensor to construct a railroad crossing safety alert device is worth promoting.

Acknowledgements

This research is a joint project between Mechanical and System Research Laboratories and Center for Measurement Standards in ITRI. And it was financially supported by the Ministry of Economic Affairs in Taiwan.

References

[1] H.-U. Schnitzler, “Echoes of fluttering insects: Information for echolocating bats”, Cambridge University Press, pp. 226–243, May 1987.

[2] R. C. Roverud, V. Nitsche, and G. Neuweiler, “Discrimination of wingbeat motion by bats, correlated with echolocation sound pattern”, Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology, vol. 168, pp. 259–263, Feb 1991.

[3] Chen, V.C., Li, F., Ho, S.-S., and Wechsler, H. ”Micro-Doppler effect in radar: phenomenon, model, and simulation study”, Aerospace and Electronic Systems, IEEE Transactions on Volume: 42 , Issue: 1, Digital Object Identifier: 10.1109/TAES.2006.1603402, pp. 2-21, Jan 2006

[4] Bailed, A.; Woodbridge, K.; Chetty, K., “Frequency-agile non-coherent ultrasound radar for collection of micro-Doppler signatures’’, Radar Conference (RADAR), 2011 IEEE Digital Object Identifier: 10.1109/RADAR.2011.5960496, pp. 045 – 048, May 2011.

[5] Changzhi Li, and Jenshan Lin, ’’Non-Contact Measurement of Periodic Movements by a 22-40GHz Radar Sensor Using Nonlinear Phase Modulation’’, Microwave Symposium, 2007. IEEE/MTT-S International , Digital Object Identifier, pp. 579 – 582, Jun 2007.

[6] Igor Y. Immoreev, Sergey Samkov, Teh-Ho Tao, ’’short - Distance Ultrawideband Radars’’, Aerospace and Electronic Systems Magazine, IEEE, Volume : 20, Issue:6, pp.9-14, June 2005.

[7] S.H. Wang, Kuang-I Chang, Yu-Jen Su, Jyun-Long Chen, Mu-Yu Tsai, Yeu-Jong Huang and Bor-Nian Chuang, “Study of Nano-second pulses near-field sensing device in rotating vibration measurement”, The 19th National Conference on Sound and Vibration, Dacun, Changhua, June 2011.

Advances in Mechatronics and Control Engineering
10.4028/www.scientific.net/AMM.278-280

Applications of Doppler Radar Sensors on Railroad Crossing Safety Alerting System
10.4028/www.scientific.net/AMM.278-280.714