IOT APPLICATION IN CONTROL SYSTEM USING WIRELESS SENSOR FUSION

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Abstract: *A wireless controller based on data fusion algorithm and IoT technology is designed and applied for an active QZS isolator. Firstly, an IoT sensor modular using wireless instead of wired connection is proposed. The wireless sensors of acceleration, velocity and distance are used in the active QZS isolator in order to eliminate unpredictable disturbance causing by wire of sensors. Secondly, the data fusion algorithm embedded in wireless sensor module is described to show how to combine acceleration, velocity and distance data into one kind of information. The fuser with advanced fusion technique will protect control system from a suddenly disabled sensor. Lastly, the system controller uses data fusion to compute control signal for producing a governing force of the isolator. The experiment result shows out 60% better eliminating vibration of the proposed controller.*

1. Introduction

Today, smart grid, smart homes, smart water networks, intelligent transportation are infrastructure systems that connect our world more than we ever thought possible. The common vision of such systems is usually associated with single concept, the internet of things (IoT), where through the use of sensors, the entire physical infrastructure is closely coupled with information and communication technologies; where intelligent monitoring and management can be achieved via the usage of networked embedded devices.

A wireless sensor network (WSN) is a network formed by a large number of sensor nodes where each node is equipped with a sensor to detect physical phenomena such as light, heat, pressure, speed, etc. The sensors collecting data which are combined in one kind of information is called sensor fusion. The control systems using wireless sensors fusion have been found many benefits of not only reducing the monetary and time expenses associated with the installation of wire-based systems but also guarantee for some missing sensors. The use of wireless communications within a structural health monitoring data acquisition system was illustrated by Straser and Kiremidjian [1]. In addition, multi-sensor data fusion is the process of combining observations from a number of different sensors to provide a robust and

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complete description of an environment or system states which is used in many areas of robotics such as such as object recognition, environment mapping, and localization [2].

In this paper, a wireless sensor fusion module is designed and applied for an active QZS isolator for some purposes: Firstly, using wireless sensor in the active QZS isolator is to eliminate unpredictable disturbance causing by connecting wires of the wired sensors for the isolator system with almost zero stiffness is easily effected by sensitive noise [3]. Secondly, the data fusion technique embedded in wireless sensor module is to protect control system from a suddenly disabled sensor while the system is running. Lastly, the system controller uses data fusion to compute control rule for producing a governing force of the isolator.

2. Wireless sensor fusion module

2.1. Hardware configuration of wireless sensor module

The wireless sensor model includes two parts: Sensing and control interfaces as shown in Figure 1. The sensing interface is the Texas Instruments ADS834 AD converter which offers a 16-bit conversion resolution and 4 sensing channels which is capable of digitizing any analog signal in the 0- 5 V range at sample rates as high as 100 kHz. The control interface is designed with a 16-bit digital - to - analog converter (Analog Devices AD5542) which receives binary number from the microcontroller and converts them to analog voltage signals. Both use the Atmel ATmega128 microcontroller for computational core where embedded software is stored to execute data acquisition and transition. Two WiFi/DSL routers, ENC28J60 Ethernet controllers are selected for wireless communication channel in both interfaces.
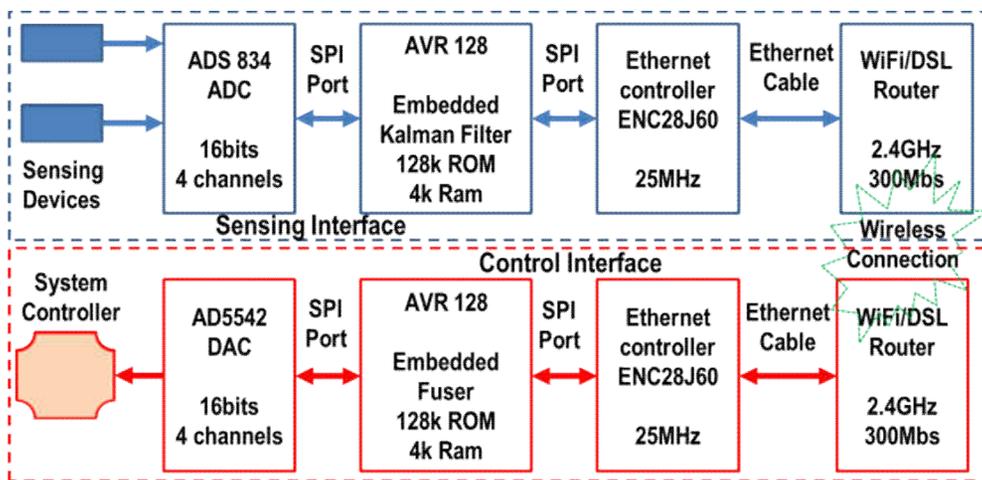

Figure 1. *Architecture of a wireless sensor interfaces*

2.2. Multi-sensor fusion based on Kalman filter

In discrete-time controlled process, a Kalman filter is governed by the linear stochastic difference equations (1) and (2) which is described by an ongoing cycle as shown in Figure 2:

$$x_k = Ax_{k-1} + Bu_{k-1} + w_{k-1} \qquad (1)$$

$$z_k = Cx_k + v_k \qquad (2)$$

where A, B, and C are coefficient matrices; k is the time index; x is system states; u is control signal; z is measured states; w and v represent the process and measurement noise.

Figure 2. *Continuous cycle of Kalman filter*

A fusion technique is studied and embedded into the control interfaces of the wireless sensor module. In detail, displacement and velocity measurement signals are used for estimating acceleration, velocity and displacement signals based on Kalman filter algorithm. The outputs of the Kalman filters are data sources for a data fuser which will compute fused data providing for a system controller. The schematic model of sensor fusion is shown in the Figure 3 and the fusion algorithm is sketched in the Figure 4.
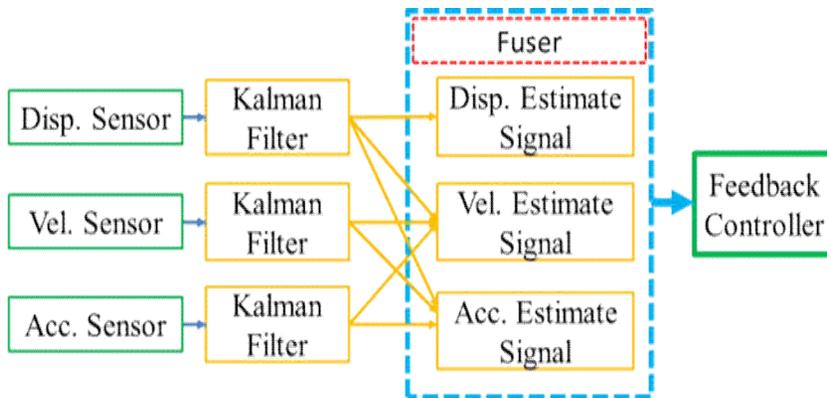

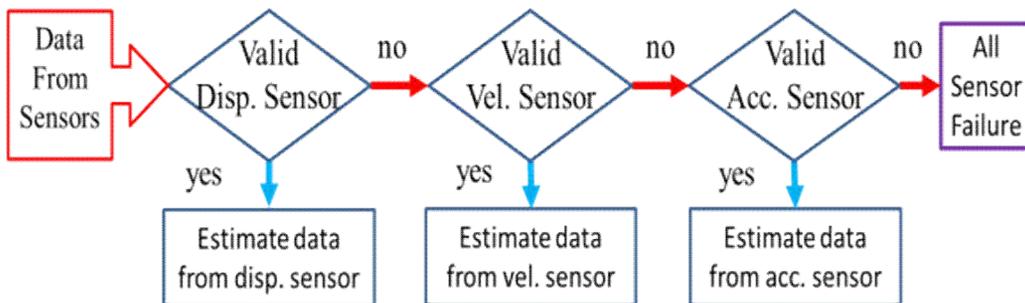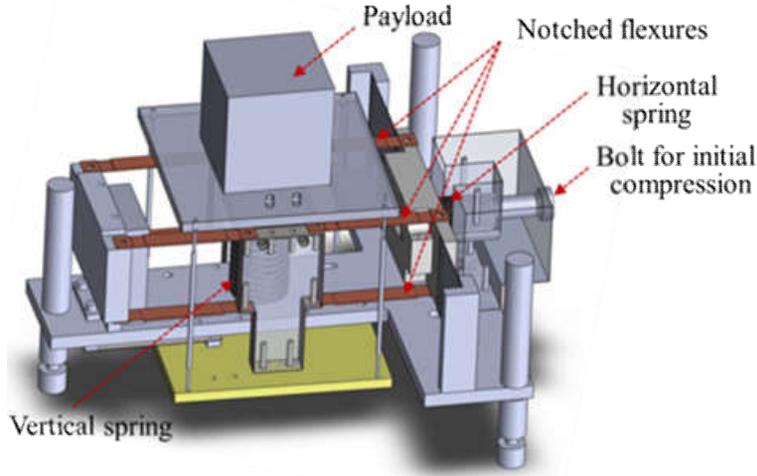**Figure 3.** *Sensor fusion model*

Figure 4. *Algorithm of data fusion*

3. Active control model of QZS isolator

3.1. The QZS isolator using flexure

Figure 5. *QZS isolator using flexure [3]*

A mechanism of QZS isolator using flexure studied in this research is shown in the Fig. 5. The mechanism consists of three main parts: the horizontal coil spring, vertical coil spring and notched flexures. While the vertical coil spring produces positive stiffness, the notched flexure under compressive force of initially deformed horizontal spring generates a negative stiffness which allows obtaining quasi-zero stiffness (QZS) characteristics.

3.2. The motion equation of the isolator model

Based on the dynamic analysis of this isolator model that is presented in the reference [3], the motion equation of dynamic model is derived as Eq. (3):

$$m\ddot{y} + c\dot{y} + k_l y + k_n y^3 = f_c A_2 y + w(t) \tag{3}$$

where y is vertical displacement; m is mass; c is system damping; k_l and k_n are linear and nonlinear stiffness respectively; f_c is control force.

3.3. Active control rule

In studying the case of the horizontal actuation, the actuator force is derived based on the dynamic equation (3). The control law is derived and converted to the horizontal actuator force as shown in Eq. (4).

$$f_{nl} = a_1 \frac{y}{\max(y, y_0)} + a_2 \frac{\dot{y}}{\max(y, y_0)} - a_3 \frac{y^3}{\max(y, y_0)} \tag{4}$$

where a_1, a_2, a_3 are Lyapunov control tuning gains. The a_3 is gained for nonlinear feedback to cancel out the system nonlinear characteristic. The actuator force near equilibrium point ($y=0$) is considered to avoid saturation.

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4. Experiment configuration setup

The experiment configuration consists of passive QZS isolator, digital controller, sensors, actuator, and wireless sensor interface module as shown in Figure 6. Vertical passive isolator specification is summarized in the Table 1.

Table 1. *Isolator specifications*

Parameter	Value	Parameter	Value
m	25 - 40(Kg)	Stroke	± 0.005(m)
k_{hs}	3.626×10^5(N/m)	k_{vs}	1.02×10^4(N/m)
c	2.87(Ns/m)	f_n	1 (Hz)

Several analog sensors are used for sensing system state data such as velocity sensor, acceleration sensor, and displacement sensor. The dSPACE controller computes and generates control signal from data provided by wireless sensor module. The control signal regulates the actuator through amplifier to stop vibration of the mass.

Experiment Model   **Experiment Setup Diagram**
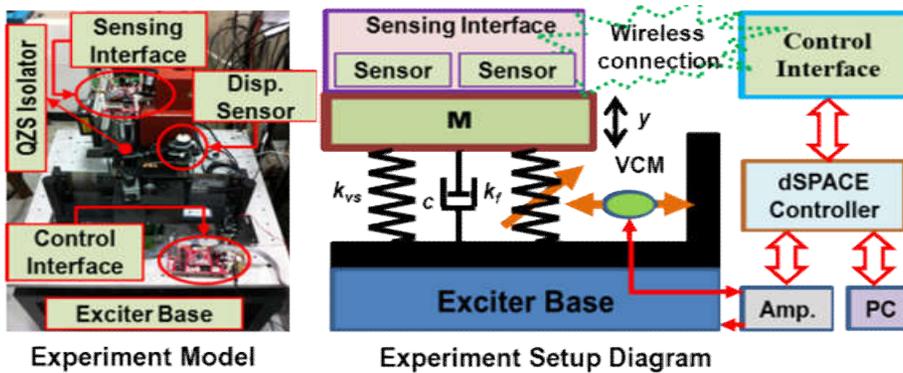
Figure 6. *Experimental setup*

5. Experiment result

The experiment of the active QSZ isolator using wireless sensor fusion module is implemented to investigate the performance of wireless sensor fusion module and control response. The wireless fusion signal is verified by wired sensor signal and examined under suddenly disabled sensors as shown in Figure 7 and Figure 8. Control performance is obtained with two vibration isolation testing standards: impulse disturbance rejection and vibration transmissibility. The result of impulse disturbance rejection is shown in Figure 9 and the result of the vibration transmissibility is shown in Figure 10. Both results show that the active QSZ isolator using wireless sensor fusion data has a good performance of vibration isolation. In the time domain, settling time is reduced 75 percent by active control system comparing to the passive isolator. In the frequency domain, the resonance magnitude is degraded about 60 percent.
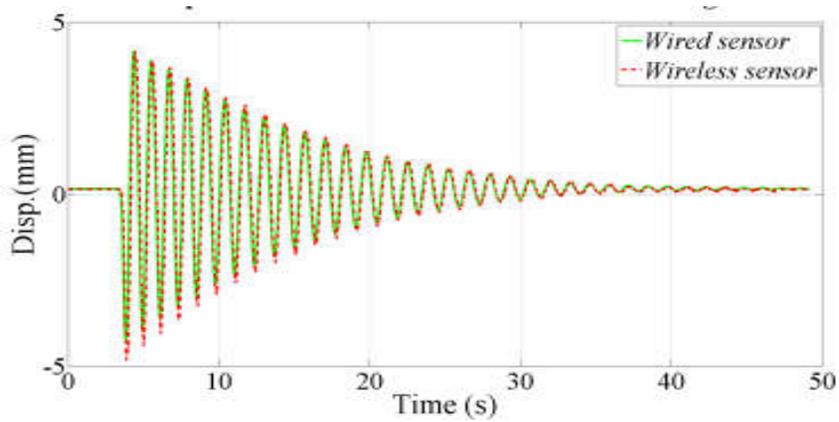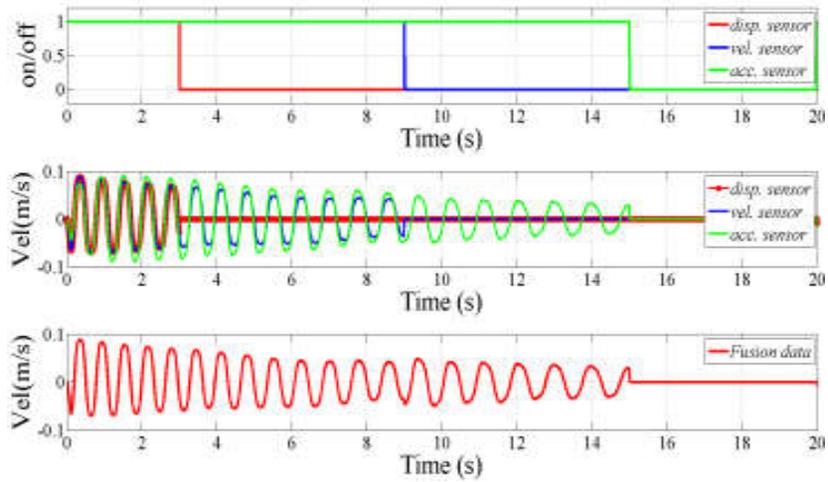
Figure 7. Signals verification

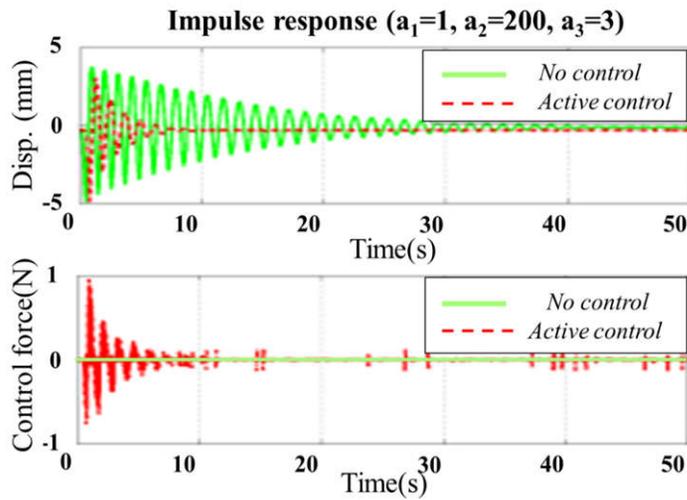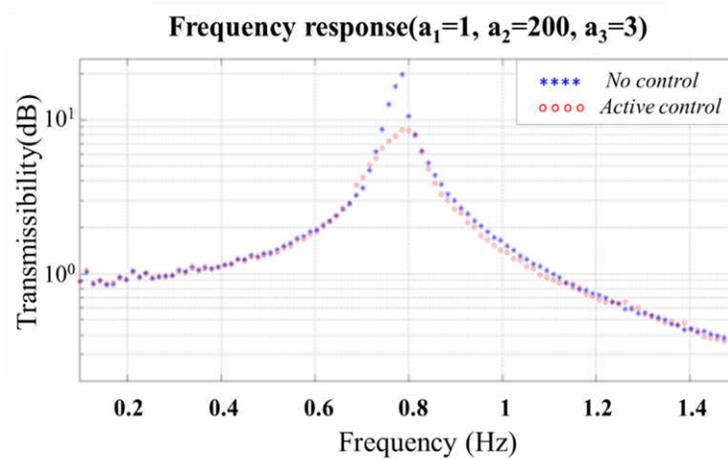*Figure 8.* Fusion signals under missing sensors

Figure 9. Disturbance rejection [3]

Figure 10. *Transmissibility [3]*

6. Conclusion

The active QZS isolator based on sensor fusion using IoT technology is proposed and investigated through the experiment. The proposed wireless sensor fusion module works well with data acquisition and system monitoring. The experiment results of active system responses show a good performance to vibration isolation in both time domain and frequency domain of the active QZS isolator by using fused data.

References

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