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Inertial Measurement Unit for Measuring and Processing of Axial Thermal Displacement Signal of a Machine Tool

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Abstract

In this study, the inertial measurement unit (IMU) with accelerometers and gyroscopes was employed to measure the accuracy of a machine tool. When measuring the acceleration signals of a machine tool in the dynamic process, the acceleration signals were filtered and integrated by mathematical operations to obtain the velocity and displacement from IMU signals. The velocity and displacement data were combined through data fusion to eliminate information errors caused by multiple integration in mixed data. In the verification experiment, the machine tool was set with the error values of 15μm and 50μm to verify the signal measurement and processing accuracy of the IMU module. Under 10mm moving distance, the displacement of a machine tool could be detected by the errors of 20.58μm and 47.66μm, respectively. The errors in IMU measurement accuracy were 37.2% and 4.7%, respectively. The results from this study disclosed that this method produced highly reliable thermal displacement values in real-time and could be applied to development of functions such as instant fault identification and self-compensation control.

Keywords: *inertial measurement unit; acceleration signals; date fusion*

Inertial Measurement Unit Method and Results

The accuracy of linear axial system was an important factor of a machine tool. In this study, the inertial measurement unit (IMU) with accelerometers and gyroscopes was employed to measure accuracy of the machine tool. The results could be used to develop real-time failure recognition and self-compensation control functions in the future. In Figure 1, the data fusion method was adopted to estimate the accuracy. The principle of data fusion is that the steady-state signal generated by the same geometric error can be decomposed into components in different frequencies, and the original error signal can be constructed by signal filtering recombination. According to the signal reproducibility of the operable speed and monitoring length ranges of the machine tool, 40 mm/s and 16 mm/s were selected, and the filter was split out of the main signal frequencies of 20 Hz and 350 Hz by frequency analysis. The purpose of this procedure was to acquire the steadiest detectable geometric error amount at various speeds while maintaining the spatial frequency continuity. The acceleration frequency domain diagrams obtained at the different speeds named previously in this paper should have better reproducibility in their particular temporal frequencies. Therefore, as long as the temporal frequency could be transformed into the spatial frequency domain according to the traveling speed, different signals could be fused through frequency filtering without damaging the spatial frequency continuity.

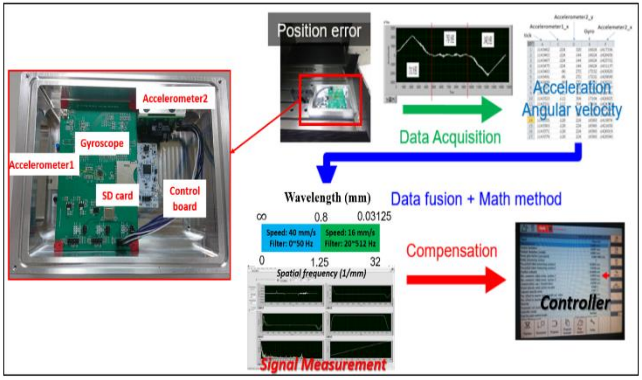
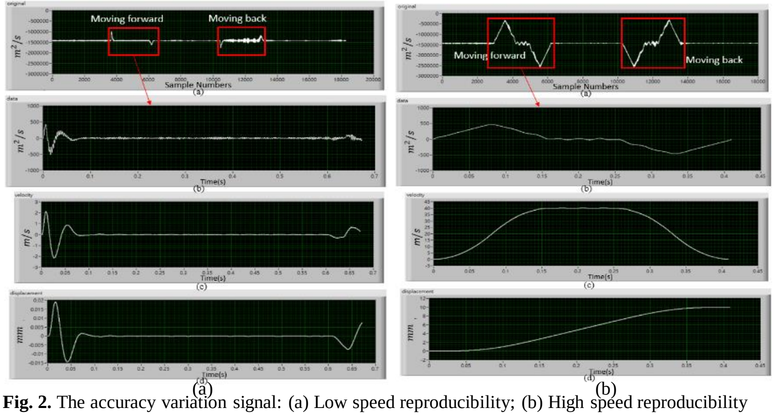


Fig. 1. Measurement System Design

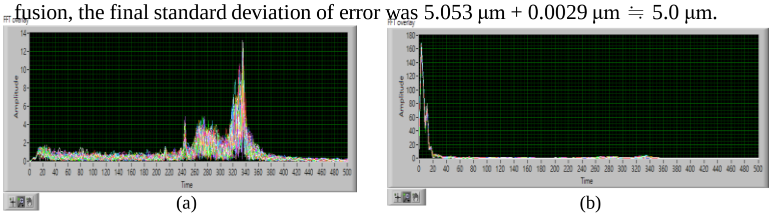
The experimental data included the reproducibility of position values after filtering at the low speed of 16 mm/s and the high speed of 40 mm/s. Once good repeatability of error values in the divided spatial frequency domain was confirmed, different offset values of 15 μm and 50 μm were set on the machine tool to attain the accuracy variation signal of the linear axis. The 10 mm distance reciprocation at the feedrate of 16 mm/s and 40 mm/s were performed 20 times and the outbound signal was captured, as shown in Figure 2(a) and Figure 2(b). In Figure 2(a), the displacement error was obtained by two integrals after bandpass filtering at 20~512 Hz. The displacement value was used in calculating the displacement variation of the short wavelength region in the spatial frequency, whereas the actual displacement error induced by the mechanical structure was the total displacement error of the continuous wavelength signals covering the short wavelength region and long wavelength region. In Figure 2(b), the displacement error was obtained by two integrals after bandpass filtering at 20~512 Hz. The sampled 3,000 to 6,200 outbound signals were adapted for data analysis and integral operation in order to obtain the acceleration signals, velocity signals and displacement error.



(a) (b)

Fig. 2. The accuracy variation signal: (a) Low speed reproducibility; (b) High speed reproducibility

Figure 3 shows the low speed frequency domain signal which was obtained by filtering 20 times of low speed signals. The positioning result was about 0.007959 mm and the standard deviation of the numerical error was 0.0029 μm, signifying a high reproducibility of the low speed. In the high-speed frequency domain signal, the positioning result was about 9.9325 mm and the standard deviation of the numerical error was 5.053 μm. As the two positioning results would be added up during the signal fusion, the final standard deviation of error was 5.053 μm + 0.0029 μm ≒ 5.0 μm.



(a) (b)

Fig. 3. Frequency domain signal: (a) Low speed; (b) High speed.

In the offset validation experiment, different offset values of 15 μm and 50 μm were set on the machine tool. Table 1 shows the compensation measurement results, the positioning result was 10.0234 μm before compensation. However, the measured positioning increased by 20.58 μm with the 15 μm compensation, and increased by 47.66 μm with the 50 μm compensation. The above two results displayed differences of 5.58 μm and 2.34 μm from the expected positioning increment.

Table. 1. Compensation measurement results

Offset value (μm)	Axial motion velocity (mm/s)		Location result (mm)	Relative offset value (μm)	Error value (μm)
	40	16			
0	10.01539	0.00801	10.0234	0	0
15	10.0359	0.00808	10.04398	20.58	5.58
50	10.06295	0.00811	10.07106	47.66	2.34

Conclusion

The error of IMU measurement accuracy with the 15 μm and 50 μm compensations were 37.2% and 4.7%, respectively. The results of this study could be a good reference for remote equipment accuracy monitoring and health recording systems in the future, as well as assisting the autonomous prognosis and control of equipment.

Acknowledgments

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