Wireless Sensor Networks (WSNs) for Machine Tool Monitoring

Andrew Redfern, Eva Markiewicz, Jessy Baker, and Paul Wright
University of California, Berkeley

Abstract

A wireless sensor network (WSN) was used to create the enabling infrastructure for MEMS-based-accelerometer monitoring of machine tool vibrations. The research focus is not on vibration analysis *per se*. Rather, experiments have been carried out to show that wireless sensor networks, and their individual wireless sensor platforms, provide new tools for research in predictive maintenance and condition-based monitoring of factory machinery in general, and for "smart machining systems" in particular. The small-scale wireless sensor platforms bundle together the main essentials for laboratory studies in process manufacturing: USB programming capability, an IEEE 802.15.4 radio with integrated antenna, low power MCU with extended memory and an optional sensor suite. In the present experimental work, an accelerometer was mounted on the casing of the spindle head of a CNC 3-axis milling machine. The output from the accelerometer was processed by the sensor node and then relayed through the WSN to a nearby base-station for additional processing and data logging. High speed steel end milling tools were used to machine stainless steel work piece materials at various feed rates over the range 125-500 mm/min. Through these tests it was found that both surface finish and feed rate can be positively correlated to the machine's vibrations. The accelerometer-based WSN platform, supported by the WSN, was shown to be an easily deployable technology for the identification of such correlations. The use of the WSN to acquire data enabled an inexpensive retrofit of appropriate sensors to a standard CNC machine tool. In related work, the authors have shown the additional benefit of accessibility to rotating spindles that would normally be very hard or impossible to monitor with wired sensors.

Keywords: Wireless sensing, MEMS accelerometers, surface finish, monitoring.

1. Wireless sensor networks (WSNs) and their potential impact on manufacturing

Wireless sensor networks (WSNs) are *ad hoc* local area networks (LANs) created from small, inter-connected wireless platforms, or 'beacons.' Each platform carries one or more sensors suitable for the desired industrial, residential, or civil application. Often, the small hardware platforms are colloquially referred to as *smart dust* and/or *motes* because of their miniature size. The research community has enthusiastically embraced WSNs -- for example, see the articles on *ambient intelligence* by Basten *et al* 2003 and Mukherjee *et al* 2006; and the well-known *Scientific American* article written by M. Weiser [1991] on *ubiquitous computing.* This enthusiasm has consequently spurred the commercial availability of the hardware platforms ('motes') and system software, (such as TinyOS [Hill and Culler, 2002]). New companies [see Conner 2006 for a list of commercial websites] have been formed around the technology and, for example, successful prototype systems have been installed for low duty-cycle temperature monitoring in commercial buildings where radio transmission is relatively robust. Such 'early adopters' will hopefully create experience and know-how that will facilitate the wider adoption of wireless sensor networks. Such experience and know-how will be important for a 'second wave of adopters' in the manufacturing area, where radio transmission and reliability is obviously more challenged by the presence of metallic machinery, which can reduce the signal strength of the wireless communication channel, create packet-losses within the data exchange, and require more robust protocols.

2. Experimental work and results

Machining and materials: Conventional end-milling of AISI 304 stainless steel was carried out with high speed steel M2 grade tools. The tools were 12.5mm in diameter. Slot end-milling was followed by surface finish measurements. The Talysurf profilometer data acquisition system v.1.2 using Talsurf 10 was used to collect the surface finish measurements. A minimum of 6 measurements were made on each cut. The depth of cut was held constant throughout the experiments at 2.5mm. Cutting speed was varied in the range 10 to 50 m/min and feed rate in the range 125 to 500 mm/min

Sensor platform and accelerometer: The wireless sensor platforms (e.g. Figure 1) were supplied by the Moteiv company (www.moteiv.com.) They employed a16-bit MSP430-F1611 microprocessor [from Texas Instruments] with eight 12-bit analog to digital converters (ADCs) and a 2.4 GHz RF transceiver [from Chipcon]. An ADXL 320 digital MEMS accelerometer [from Analog Devices] enabled a high sampling rate, low power consumption, appropriate sampling range, and small footprint. A sampling rate of 1 kHz was used for the machining tests. The accelerometer itself was mounted to the flange of the spindle-head casing of the CNC milling machine, while cuts were made at various feed rates. The combined sensor and wireless platform was then used to obtain the vibrations of the spindle-head casing in the vertical (z) and horizontal (y) directions.

Figure 1
Wireless node carrying a sensor board at lower right with the MEMS accelerometer

Calibration of the MEMS sensor: The MEMS, capacitance-based accelerometer on the wireless node (Figure 1) was first calibrated, with known forces, against a higher accuracy piezoelectric accelerometer [from PCB Piezotronics.] Figure 2 shows readings for the two kinds of accelerometers in different xy directions. Good agreement is shown.

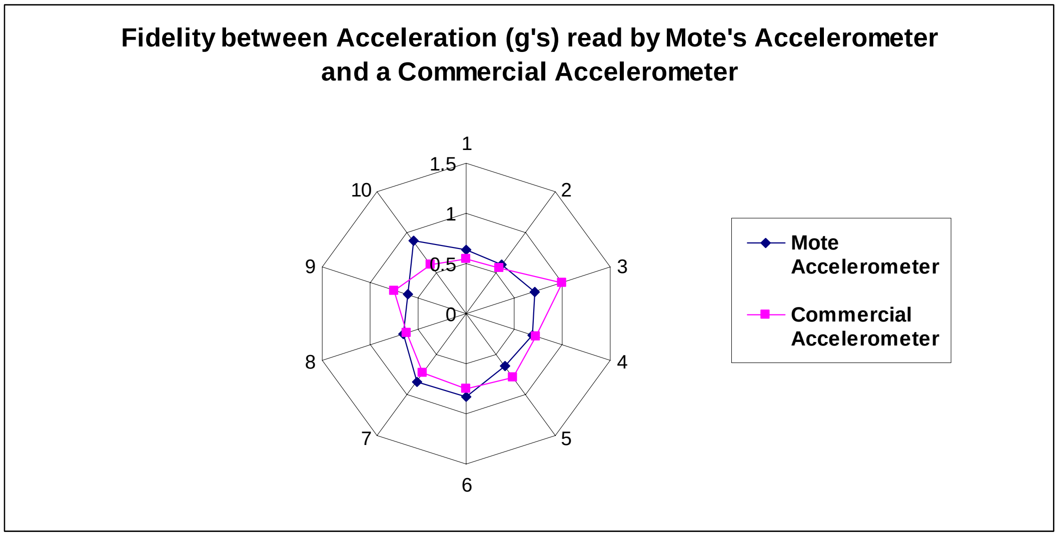

Figure 2: *Accelerations (in g's) in various directions showing good calibration*

3. Results and Conclusions

1. Figure 3 shows that increased vibrations - from higher rates of metal removal and tool wear - created a rougher surface finish as would be expected. Vibrations are measured on the x-axis. Vibrations and surface roughness increase as higher speeds and feed rates are used (moving from left to right in the graph). In Figure 4 for a feed rate of 250 mm/min (10in/min), surface finish data of the end-milled slots are plotted against tool wear. There was linear relationship between surface finish, tool wear and vibrations of the machine tool. Plots for other feeds, 125 to 500 mm/min showed the same trends.

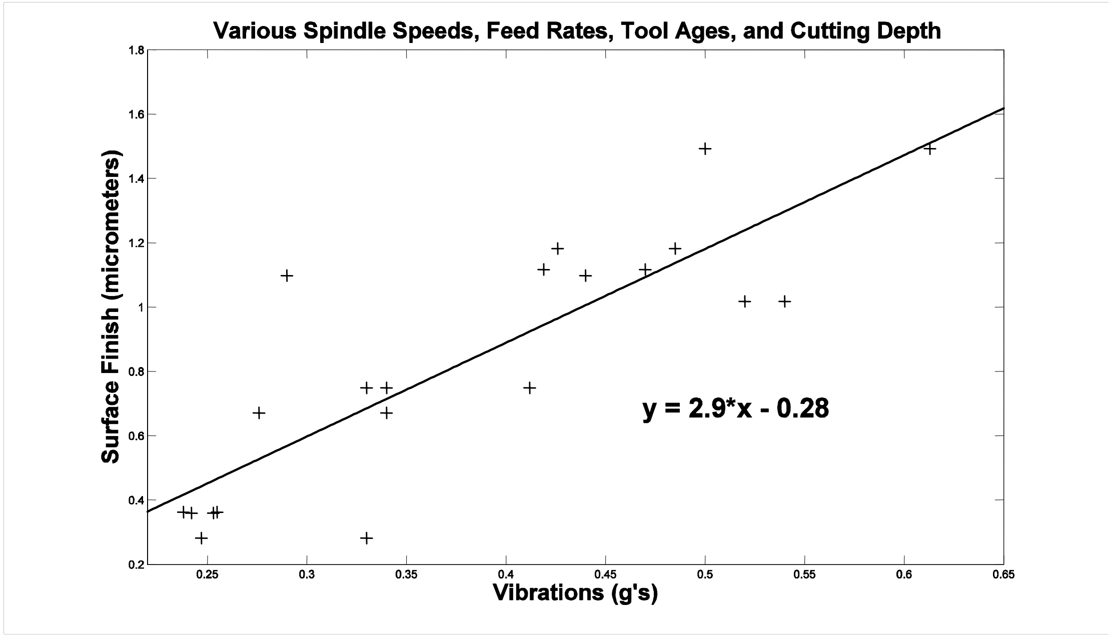

Figure 3*: Surface finish deteriorates with vibrations from increased speed and feed*

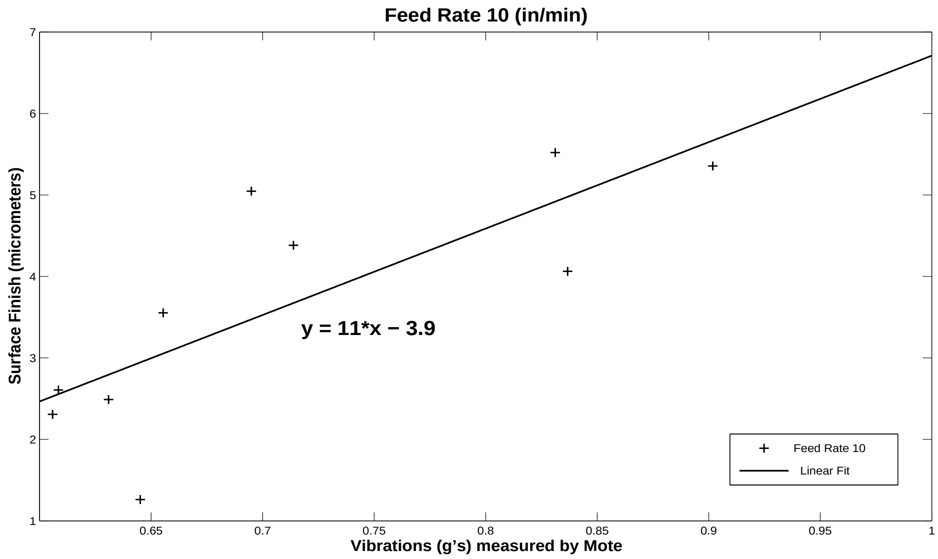

Figure 4: *Surface finish deteriorates with vibrations resulting from tool wear*

2. The accelerometer-based WSN was shown to be an easily deployable technology for the identification of such correlations. The use of the WSN to acquire such data allowed for an inexpensive retrofit of MEMS sensors to a standard machine.

3. Sensor-based, wireless sensor networks (WSNs) thus provide an excellent tool for predictive maintenance and condition-based monitoring of factory machinery. In similar work, we have focused on ‘hostile’ industrial environments in order to show that wireless communications are not hampered by heavy metallic machinery, and random interference effects. Examples include aluminum smelting and copper refining [Schneider *et al.*, 2006]. We have also studied the performance of wireless temperature sensors in rotational spindles where wired sensors are difficult to employ [Wright *et al.*, 2006].

4. References

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