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SMART DUST APPLICATIONS IN PRODUCTION ENVIRONMENT

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Abstract: *Autonomous embedded computers that form a sensor network can be applied in various fields. In the domain of industrial manufacturing sensor networks can be used for detecting events or phenomena at shopfloor, collecting and processing data and transmitting sensed information to either a central database or directly to the handheld computer used by the production manager. Smart dust can be used at CNC machine tools to measure vibration, noise and other essential parameters. The proposed solution helps to detect changes in shopfloor and predict possible problems, thus avoiding unplanned pauses in production.*

Key words: smart dust, wireless sensor network, manufacturing, e-diagnostics.

1. INTRODUCTION

High utilization and fault detection of metal working machinery is an issue of high importance in industrial applications. Operation in an undesirable mode can cause poor production quality, perversion of material but also in extreme cases tool failures and damages to the machinery. Two of the last damages are especially harmful for production, causing unplanned breaks in production and delays in fulfilling customer orders.

The process of developing metal working machinery is ongoing. Building up more sophisticated working processes, using wear resistant tool materials, raising speeds and powers permit the production of more complicated parts and also shorten the time of machining. The increased efficiency and speed of production may also result in faster changes in manufacturing equipment state – the step from regular working process to machinery unstable condition is potentially also shorter. As the result machinery in modern manufacturing process requires effective on-line monitoring and fault prediction.

Machinery monitoring options are rarely mentioned in case of new machinery. In case of modern manufacturing equipment a monitoring system is assumed to be part of the machinery. However in many cases the manufacturing equipment can be destroyed either because of wrong operating modes or trivial part failures without any advance indication of potential trouble from the onboard monitoring system. The main reason for this is the fact that a complex monitoring system will add to the cost of the machine which of course is a competitive disadvantage in the low budget metal working machinery market.

Machinery that is 30-40 years old is typically quite massive, which assures stable machining and suppresses vibrations. These properties make also these machines valuable and they are still running at shopfloors tens of years into service. The main disadvantage of such machines lies in the fact that they are not equipped with a monitoring system or the functionality of the monitoring system is too limited.

The abovementioned cases require installation of modern wireless monitoring system to maintain the advantages of the existing machinery and ensure safe operation on the manufacturing floor. Installing a monitoring system based on wireless sensor nodes is relatively cheap and it can be fitted to both old and modern manufacturing equipment.

Attaching embedded computers with a wireless communication interface which form a wireless sensor network (WSN) onto low budget machinery for monitoring machinery condition keeps the price of the solution reasonable but provides extra safety to existing process. The installation cost of cable in industrial plant can vary greatly based on the type of plant and physical configurations. Studies have shown that average cable installation cost is between 10$ and 100$ per foot [1], but in nuclear plant even 2000$ per foot.

Research in the field of wireless sensor networks (also called smart dust) was started as a research project in 1997 by University of California computer science professor Kris Pister. A smart dust mote is a tiny computer equipped with a processor, some memory, a wireless communication interface, an autonomous power supply and a set of sensors appropriate for the task at hand. The motes can communicate with each other and activate themselves only if it is required by the application to prolong battery life. At the time (this is true also currently to a certain extent) smart dust was very advanced compared to existing solutions as it potentially enabled to build networked intelligence into everything from walls to laptop computers. In last decade many researches have been made to transform the dream into reality. Examples can be brought from machinery monitoring research community where the technology has been applied in condition monitoring in end-milling [2] and in drilling machine [3].

In condition monitoring applications a parameter that reflects the state (condition) of the machinery is monitored. Before a condition monitoring application can be deployed, models are developed that reflect the correlation between the state of the machine and the monitored parameter. From the value of the parameter the state of the machine is then estimated at runtime, enabling the detection of failures and critical modes of operation. Condition monitoring is one of the major components of predictive maintenance. The use of conditional monitoring allows maintenance to be scheduled, or other actions to be taken to avoid the consequences of failure, before the failure occurs. Nevertheless, a deviation from a reference value (e.g. temperature or vibration behaviour) must occur to identify impeding damages. Predictive maintenance does not predict failure; it only helps predicting the time of failure. The failure has already commenced and sensor system can only measure the deterioration of the condition. Performing repair or maintenance operations in a predictive manner is typically much more cost effective than allowing the machinery to fail.

The aim of the paper is to present concept of measuring and identifying operation modes of machinery for detecting unwanted status and preventing tool braking.

Prototype measuring devices were designed and assembled and test measurements conducted in controlled conditions. Measured parameters were acceleration for vibration detection and acoustic signals. Experiments were conducted in turning lathe.

2. ACCELERATION MEASUREMENTS

2.1 Measurement method

Vibration of the unit was measured with solid-state MEMS (Micro Electro Mechanical System) accelerometer LIS3LV02DQ. This device is capable of measuring acceleration in 3 directions in the range of +-2g at 12 bit resolution. Gravity of Earth is included in measurement results. The sensor type was selected as it has a suitable measurement range and accuracy, small footprint (7x7x2mm), internal digital conversion unit with noise suppression, suitable electrical interface and is readily available in prototyping form. Same sensor can be used in final and optimized WSN scenario as it has suitable electrical interface (SPI) and very low power requirements (0.8mA@3.3V). The sensor was interfaced to a computer during the experiments via the low-voltage SPI bus. An additional data acquisition / interface board was installed between the sensor and the main data acquisition computer as the computer was not equipped with the SPI interface. The data acquisition board was a WSN node prototype based on Atmel AVR XMEGA microcontroller. As the data acquisition board is essentially a full fledged WSN node it is also capable of reading sensor data, buffering it and later forwarding it to computer in serial (RS232) format. Considering the constraints of the interface board memory, processing power and serial communication acquisition speed 640 samples/s and 30 s measuring period was chosen. The resulting data sets consist of 19200 samples for each axis.

In the final and optimized WSN scenario serial (RS232) data link will be replaced with a wireless communication module that is already present on prototype board. Depending on analysis results and firmware it is possible to transmit live measurement information continuously or just the identified state of the machinery being monitored.

2.2 Measurement process

All measures were made in CNC turning lathe 16A20F3RM132. The acceleration sensor was bolted to CNC turning lathe carriage and 5 sets of data acquisition experiments were conducted. Ideal positioning of the sensor would show offset of the result that is caused by gravity in one direction only. Current results show offsets in other 2 axes also.

Test 1 and 2 were made just at empty spindle at speed 2400 min^{-1}. Test 3 was made at spindle speed 600 min^{-1}, feed rate 0.3 mm/s with real turning. Test 4 was made at spindle speed 2400 min^{-1}, feed rate 0.3 mm/s with real turning; this test also includes an event of failure. Test 5 was made at spindle speed 600 min^{-1}, feed rate 0.3 mm/s with real turning; this test also includes an event of failure. The result of failures in tests 4 and 5 was tool breakage. Tests parameters are shown in table 1.

Table 1. Acceleration tests parameters

test no	spindle speed (rev/min)	feed (mm/s)	turning	failure
1	2400	0		
2	2400	0		
3	600	0.3	x	
4	2400	0.3	x	x
5	600	0.3	x	x

2.3 Analysis of the results

Results were analyzed in time domain. Mean values of the acceleration series show that offset doesn't drift and this means that sensor was fixed reliably during whole measuring process.

Standard ranges of the acquired data series that are presented in table 2 shows extreme values at test 4, but also high value in test 5. Both of these tests include tool breakage. Other tests seem to be quite similar. Distinction between different modes of the turning lathe can be observed better in graphical representation of the acceleration values presented in figures 1-5 corresponding to test 1-5. Every figure contains measurements of acceleration in 3 directions presented in same scale.

Table 2. Range values in every axes

test no	x axis	y axis	z axis
1	116	160	88
2	119	156	94
3	125	161	89
4	185	234	385
5	133	200	94

Tests 1 and 2 that were conducted with exactly the same turning parameters show that their value difference is negligible (max 7% in Z axis). It shows that test results are repeatable and test values are reliable.

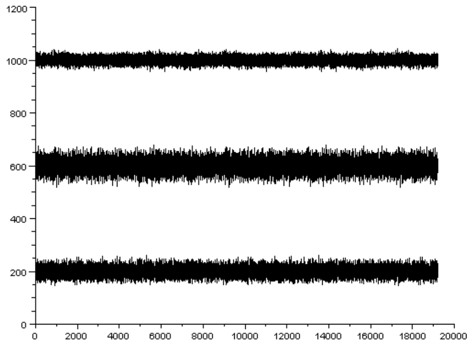

Fig. 1. Acceleration test 1

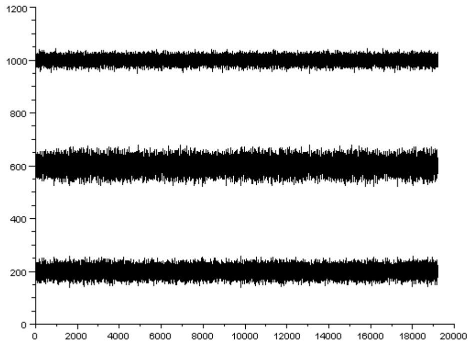

Fig. 2. Acceleration test 2

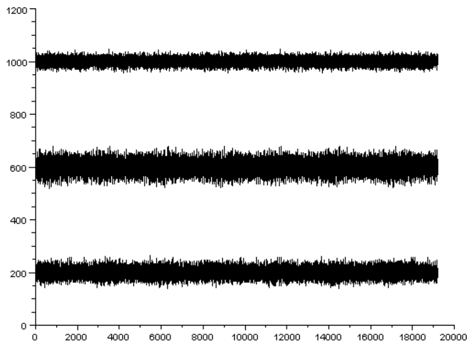

Fig. 3. Acceleration test 3

Comparison of tests 3 and 5 illustrates the difference between normal operation and failure during operation. Tests 3 and 5 were made in same operational parameters; the only difference was the failure of the tool. Y axis value was 24% higher in fault situation than in normal operation mode. This distinction allows fault identification.

Comparison of tests 4 and 5 illustrates rapidly growing vibration in breaking situation in higher spindle speeds. With higher spindle speeds the failure pattern is more distinct.

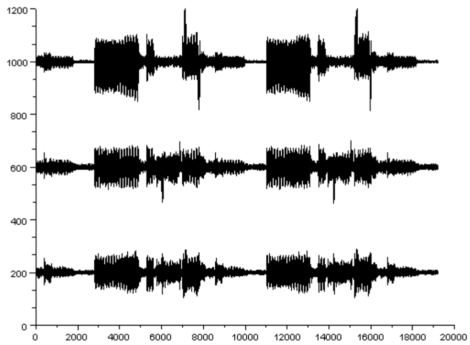

Fig. 4. Acceleration test 4

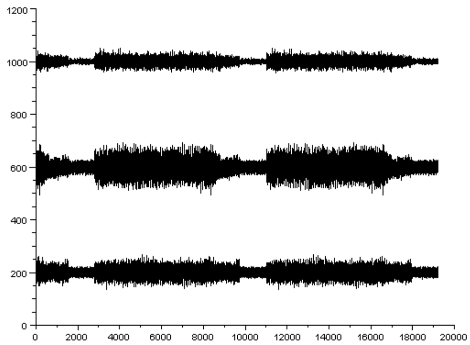

Fig. 5. Acceleration test 5

2.4 Conclusion of the measurement result analysis

It is possible to identify different modes of operation by measuring acceleration in turning lathe carriage. The identification task is simpler at higher spindle speeds as the pattern is more distinct in that case.

3. ACOUSTIC MEASUREMENTS

3.1 Measurement method and description

Acoustic signal of the unit was measured with SM58 microphone and the analogue signal was converted to digital using Roland Edirol UA-25EX audio signal processor. The digitized signal was recorded in a PC. All measures were made in CNC turning lathe 16A20F3RM132. The microphone was positioned near the cutting place. The acoustic signal was sampled at a sampling rate of 22050 Hz and recorded to a *wav* file. Data was sampled during a turning work cycle (starting up engines, turning, turning fault and turning off engine).

3.2 Measurement results

Operation mode classification was made by applying spectral analysis to the sampled signal. Fourier transforms were performed on sections of recorded samples acquired during different modes of operation and the resulting frequency spectrums were compared with each other.

Figure 6 represents the spectrums of signals acquired in different modes of operation. In mode 1 feed engine works only, in mode 2 spindle engine is turned on, in mode 3 the lathe is normal operational mode and in mode 4 a fault occurs.

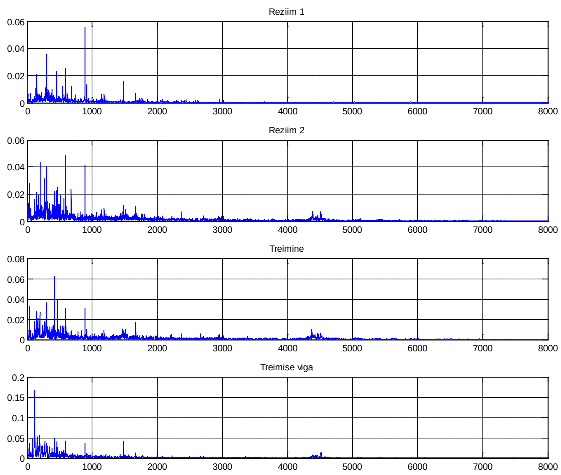

Fig. 6. Regimes 1-4 in turning

The spectrums of signals acquired in modes 2 and 3 are similar and distinguishing them from each other is difficult. For that reason the spectrum for mode 3 is discarded and only the spectrums of signals acquired in modes 1, 2 and 4 are analysed. In figure 7 acoustic signals are measured with 0.2 s interval. The whole length of the test was 40 s.

Figure 7 shows different pattern of the signal in feed engine working mode, turning mode and in the occurrence of a fault.

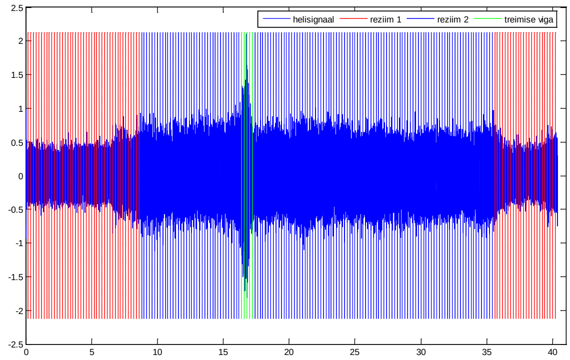

Fig. 7. Acoustic signals in different modes

The location and number of acoustic sensor(s) (microphone) plays an essential role in the signal evaluation. It can be predicted that increasing the number of sensors will yield better results.

4. MONITORING WITH SMART DUST

The tests described in the paper were performed using wired sensors. For real applications in manufacturing floor it is essential to employ wireless sensors that are integrated to an e-manufacturing system [4]. As suggested in the introduction wireless sensors or smart dust motes can be used in such monitoring applications in addition to the wide range of other smart dust potential applications [5]. Smart dust motes can be equipped with a wide range of sensors, so depending on the application the properties of a smart dust mote can vary substantially as the processing unit of the mote may be also different to be able to process the data collected by the sensors.

For monitoring various types of machinery (and different properties of specific manufacturing equipment), different sensors must be used and the motes must be assembled correspondingly from modules [6].

5. FURTHER RESEARCH

The test results presented in the paper were just a little touch of machinery monitoring.

Further research is required to develop and implement practical solutions.

1. The optimal sensor placement must be determined for every type of machine in order to acquire the parameters of interest
2. Manufacturing equipment must be categorized from the monitoring perspective to develop and employ fixed configurations of monitoring equipment on different machines.
3. In order to determine tool wearing pattern experiments must be conducted also with different tool wear levels.

6. CONCLUSION

Experiments showed that different operational modes of manufacturing equipment can be determined using basic sensors and signal processing methods. Measurements made with accelerometer show vibration range that allows to recognize fault situation from normal operation. Acoustic measurements allow to distinguish idle operation, normal operation and fault situation.

In order to implement an automated monitoring system for manufacturing equipment the patterns for different modes of operation must be determined initially, after which a WSN can be used to detect the modes of interest.

7. ACKNOWLEDGEMENT

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