LIMS DATA COLLECTION AND ANALYSIS FOR MACHINING MONITORING

Tobechukwu D. Nwabueze¹, Nat Frampton², Christopher Tyler³, Jaydeep Karandikar³, and Tony Schmitz^{1,3}

¹Mechanical, Aerospace, and Biomedical Engineering University of Tennessee, Knoxville Knoxville, TN, USA

²Engineering Management LECS Energy LLC Morris Plains, NJ, USA

¹³Manufacturing Science Division Oak Ridge National Laboratory Oak Ridge, TN, USA

ABSTRACT

This paper describes the use of a Learning Integrated Manufacturing System (LIMS) appliance for collecting operational data from manufacturing equipment and analyzing the data to monitor process performance. The aim is to optimize operations for the manufacturing facility. A Haas VF-4 CNC milling machine in the Machine Tool Research Center (MTRC) at the University of Tennessee, Knoxville serves as the machine and facility, respectively, for this case study.

INTRODUCTION

Machining data monitoring, collection, and analysis can be carried out for various reasons, such as minimizing energy consumption [1, 2], where the power usage of the subsystems (e.g., spindle, coolant pump, automatic tool changer, etc.) of a machine are independently analyzed and compared to determine how best to operate machine. Predictive maintenance machines can also be improved by identifying degradation more accurately and detecting hidden defects [3]. By monitoring data from vibration, power, acoustic emission, temperature sensors, for example, manufacturers can detect tool wear, breakage, and chatter [4]. The various techniques for data analysis collection and available manufacturers today are ultimately geared towards improving environmental, equipment, and economic conditions.

In this study, a router and laptop computer are used to connect a Learning Integrated Manufacturing System (LIMS) appliance to a Haas VF-4 CNC milling machine by creating an ethernet communication network that connects the router, the computer, the LIMS appliance, and the machine. See Fig. 1.

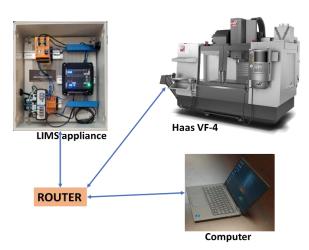


FIGURE 1. Three ethernet cables connect the router to the Haas VF-4, the LIMS box, and the computer.

The computer serves as a digital control for accessing data from the machine via MTConnect, through a LIMS software known as Solution Builder®. See Fig. 2. Using Solution Builder®,

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data from the machine can be monitored, collected, and stored in the computer as a CSV file. Solution Builder® also provides various means for data to be exported to cloud servers or monitored via open source cloud-based dashboards, such as Grafana.



FIGURE 2. Solution Builder® interface showing Haas VF-4 data samples.

It was determined that, for a Haas machine, it is easier to achieve high sampling frequency using a separate data acquisition system than it is to use the MNET communication protocol available with the Haas controller. A desktop application was created to test the Haas MNET interface while monitoring the (X, Y, Z) axis positions. The intent was to determine the highest achievable sampling frequency. The average time from a test of 1000 cycles was 47 ms/read (21.3 Hz sampling rate).

Low sampling frequency machining monitoring using external sensors and controller signals can be achieved on the Haas VF-4 using the LIMS appliance directly. In addition, external sensors can be connected to a separated microcontroller incorporated in the LIMS appliance to collect data at high sampling frequencies. To test a direct connection from the machine to the LIMS appliance, a power sensor (three-phase Rogowski coils) was attached to the three power leads connected to the main circuit breaker in the electrical cabinet of the Haas VF-4 to measure the average current drawn by the machine. To measure the average current of the machine's spindle, the coils were connected to the cables powering the spindle motor only as shown in Fig. 3. The coils were then connected directly to the LIMS appliance. To test a microcontrollerenhanced connection, a Raspberry Pi PICO microcontroller, with sampling frequencies up to 500 kHz, was used.



FIGURE 3. Three-phase Rogowski coils (red, yellow, and green) connected to three pairs of cables powering the spindle motor.

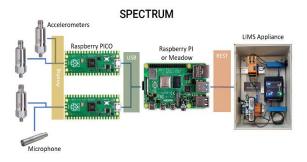


FIGURE 4. SPECTRUM architecture showing component connections.

SPECTRUM

The microcontroller-enhanced edge computing architecture was selected for a frequency domain evaluation of milling performance, SPECTRUM, which was based on the sensor frequency content. The LIMS appliance is designed around the Raspbian OS (operating system) which provides basic access to I/O (input/output) at minimum sample periods of 100 ms (10 Hz sampling maximum). Monitoring vibration and acoustic signals typically requires higher sampling frequencies (e.g., 50 kHz). A Raspberry Pi PICO microcontroller was selected to serve as the processor for sampling and processing the analog signals from accelerometers and microphones. The Raspberry Pi PICOs are capable of sampling up to 500 kHz [5], but the initial sampling rate was set to 50 kHz. The implementation architecture is shown in Fig. 4.

The analog signals from the accelerometer and microphone are connected to the input channels of the Raspberry Pi PICOs. Analog anti-aliasing filters will be applied to filter the input signals based on the sampling rates. The Raspberry Pi PICO collects the data until its internal buffers are full and calculates the fast Fourier transform (FFT) to convert from the time to frequency domain. For the initial implementation, the power for the eight dominant frequencies is determined during each sampling/calculation interval. These frequencies and powers are sent via the USB port to the Raspberry PI or Meadow processor. The Raspberry PI Processor is responsible for aggregating the signals received from the two Raspberry Pi PICOs and presented in a REST Interface. The Raspberry PI Processor will maintain a circular buffer of the aggregated frequency spectrums as received by the two Raspberry Pi PICOs. The REST Interface will enable external applications to request the history of the spectra.

The first client of the Raspberry Pi PICO REST interface will be the LIMS appliance which will be responsible for data collection and possible control reactions. The LIMS appliance has a rich set of communications and hardware interfaces that allow to host data collection, the chatter identification algorithm, and possible associated control reaction. The first application will be for the LIMS appliance to present a Grafana histogram of the latest observed dominant frequencies. The intention of the design team is to provide "open source" implementation for both the software and hardware in the SPECTRUM appliance. The source code for the Raspberry Pi PICO application will be provided as "open source" using the MIT License.

RESULTS

Figure 5 shows a screenshot of the eight dominant frequencies and their power observed during the sample time of the Raspberry Pi PICO for 250,000 test samples. Figure 6, on the other hand, displays the results from simultaneous low-frequency sampling of the spindle current and spindle speed to study how the spindle current changes with increasing spindle under no load. Although both data sets were monitored and collected with the LIMS appliance, the spindle current was measured and communicated to the LIMS appliance using a power sensor (three-phase Rogowski coils).

587229@1100	Hz	107365038100		269021@8125		42819@8150		1656488175 H	875288	186 H	5483@8225		3661@8250		
580356@1100	Hz	1071657@8100		270262@8125		43487@8150		17037@8175 H	9017(88)	20 Hz	5559@8225		3827@8250		
584638@1100		107441488100		26873498125		43846@8158	Hz	16950@8175 Hz	888688	100 Hz	544868225		370088250		
578200@1100	Hz	107361626100		269210@8125		42996@8158		16785@8175 Hz	882888	100 Hz	5371@8225		369488250		
578948@1100	Hz	107285498100		270246@8125		43074@8150		16697@8175 Hz	884888	100 Hz	5587@8225		388588258		
579247@1100	Hz	107260628100		269457@8125		4296888150		16710@8175 H	8895(88)	20 Hz	5501@8225		375088250		
576291@1100	Hz	107340528100		268793@8125		42796@8150		16829@8175 Hz	8905(88)	20 Hz	5443@8225		3657/28250		
576977@1100	Hz	1074145@8100		268515@8125		42671@8150		16783@8175 Hz	8775(88)	100 Hz	5493@8225		352888250		
574728@1100	Hz	1072799@8100		26835698125		42871@8150		16569@8175 Hz	862998	200 Hz	538468225		3 188250		
584212@1100	Hz	1072643@8100	Hz	269700@8125		43326@8150	Hz	16727@8175 Hz	900108	200 Hz	5540@8225		38.398250		
576799@1100	Hz	107224398100		269863@8125		43326@8150		16875@8175 Hz	896188	200 Hz	5542@8225		3813@8250		
578996@1100		107182488100	Hz	27022488125	Hz	43419@8150	Hz	17897@8175 Hz	9105(88)	20 Hz	5633@8225		383688250	Hz	
581375@1100		107361888100	Hz	26846688125	Hz	42893@8150	Hz	16513@8175 Hz	874298	188 Hz	535568225	Hz	363888258	Hz	
576479@1100	Hz	107232698100		26874488125	Hz	42813@8150	Hź	16680@8175 Hz	891088	186 Hz	5445@8225	Hz	369388250	Hz	
58516661100	Hz	1074872@8100	Hz	269126@8125	Hz	42931@8150	Hz	16692@8175 H	877188	100 Hz	544508225	Hz	368888258	Hz	
583512@1100	Hz	107233396100	Hz	27024698125	Hz	43197@8150	Hz	16910@8175 Hz	901688	ee H:	561108225	Hz	3812@8250	Hz	
58145801200	Hz	1073103@6100	Hz	269520@8125	Hz	43153@8150	Hz	16892@8175 Hz	887688	100 Hz	559568225	Hz	3719@8250	Hz	
574685@1208	Hz	107225288100	Hz	269357@8125	Hz	4386888158	Hz	16870@8175 Hz	891688	286 Hz	547568225	Hz	3712@8250	Hz	
57343061200	Hz	1073839@8100	Hz	268663@8125	Hz	42957@8150	Hz	16641@8175 Hz	8877(88)	186 H	550468225	Hz	363298250	Hz	
583549@1200	Hz	1074089@6100		269475@8125		42889/88150		16692@8175 Hz	874988	100 Hz	551968225		365598250		
57603401200	Hz	1072952@8100	Hz	268945@8125		42620/88150		16636@8175 Hz	8737/88	100 Hz	5445@8225		361298250		
580277@1200	Hz	107245008100		26967698125		43186/08150		16968@8175 Hz	891098	100 Hz	555668225		3752@8250		
578435@1200	Hz	1074371@8100		269035@8125		42916@8150		16779@8175 Hz	893888	100 Hz	5479@8225		363888258		
581651@1200		1072799@8100		26949888125		42926@8150		16757@8175 Hz	8851/88	188 Hz	551968225		370388250		
7293001200		107269398100	Hz	26890888125		42805@8150		16560@8175 Hz	888468	100 Hz	5364/48225		3639@8250		
575516@1200		107363386100		267965@8125	Hz	42841@8150		16671@8175 Hz	8829(88)	100 Hz	5424@8225		3621@8250		
97202168100		269858@8125	łz :	7999@1325 H	2 6	7279@8075 H	4	8847(88150 Hz 1	16939@61	5 Hz	897888200	Hz !	5615@8225	Hz	
73278@1300	Hz	1073552@8100	Hz	269199@8125	Hz	43147@8150	Hz	16758@8175 Hz	888298	188 Hz	549968225	Hz	368498250	Hz	

FIGURE 5. Frequencies and power calculated during each sampling interval for the Raspberry Pi PICO (250,000 samples).

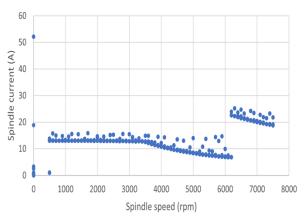


FIGURE 6. Changes in spindle current as spindle speed increases (no spindle load).

Further tests were carried out to understand how the spindle current reacts during cutting operations. Figures 7 and 8 show the changes in spindle current during cutting tests with a 76 mm diameter face mill cutting at 2500 rpm and 5000 rpm, respectively. The time when machining is identified. Also, the spindle current increased at the beginning and end of the plot which indicates the times at which the spindle is turned on and off.

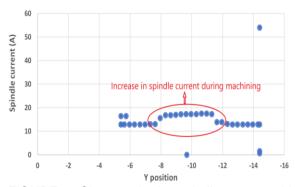


FIGURE 7. Changes in the spindle current with the Y axis position (inches). The cutting time is identified. The spindle speed was 2500 rpm and the feed rate was 508 mm/min.

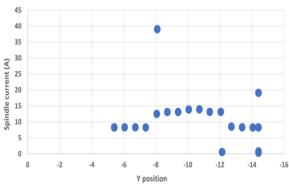


FIGURE 8. Changes in the spindle current with the Y axis position (inches). The cutting time is identified. The spindle speed was 5000 rpm and the feed rate was 1016 mm/min.

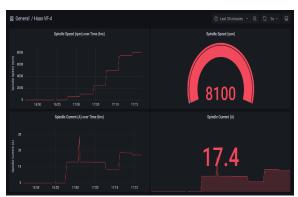


FIGURE 9. Grafana dashboard displaying spindle speed and spindle current over a period of 6 hours.

Future work will include new interfaces to enable real-time updating for milling process monitoring. For example, data from the LIMS Solution Builder® software can be monitored via Grafana (a third-party cloud-based visualization web application) as shown in Fig. 9.

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