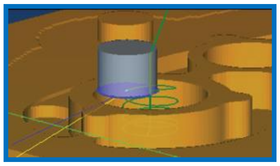

NSERC Canadian Network for Research and Innovation in Machining Technology (CANRIMT2)
NSERC Project Number: NETGP 479639 - 15

Project Interim Progress Report
(Rapport d'avancement de project intérimaire)
Apr 31, 2019-Nov.1, 2019

Please submit by Oct 25, 2019
(Attn: Lu Pan management@nserc-canrimt.org)

Instructions

This progress report, updated milestones and the Form 300 are required as a condition of research funding support from the sponsors of the NSERC CANRIMT. ***Please report for activity in the current reporting period only.***

SUMMARY

THEME V: Integration of Innovative Technologies into Virtual and Physical Platforms	**Leader/ Chef:** *(Y. Altintas)*
PROJECT V.II: Integration of Sensor Assisted Digital Machining Algorithms to Industrial CNC's	**Leader/ Chef:**
PROJECT DURATION/DURÉE DU PROJET : July 1, 2016 to January 31, 2021	
STATUS/STATUT: *(**Milestones** to be updated by each Project Leader)*	

Ahead of Schedule		On Schedule		Delayed		Cancelled	
			X				

PROJECT DESCRIPTION/ DESCRIPTION DU PROJECT *(Brief description in point form, including role of project in Theme.)*
The new sensors and sensing systems to be developed in Themes I and II will be integrated to Heidenhein and Fanuc CNC systems at UBC for test bed.

PROJECT OBJECTIVES & METHODOLOGY/ OBJECTIFS DU PROJET & MÉTHODOLOGIE *(Include alignment with Network objectives.)*
The algorithms developed by the researchers will be demonstrated to industry on UBC's research machines which are equipped with sensors and real time communication with Heidenhein and Fanuc CNCs. The objective is to create a modular test platform for the research team members.

PROJECT # & TITLE: V.II Integration of Sensor Assisted Digital Machining Algorithms to Industrial CNC's

1. RESEARCH TEAM/ ÉQUIPE DE RECHERCHE

(Summary for the current reporting period)

1a: Research Personnel (Supervisors, Co-Supervisors, Collaborators)/ Personnel de recherche

Name, given name/ Nom., prénom	*Organization/ Organisation*	*Sup./Co-Sup./ Collaborator*	*E-mail/Courriel*	*Phone No./ Téléphone*
Altintas, Yusuf	UBC	Supervisor	altintas@mech.ubc.ca	604-822-5622

1b: Students, Postdoctoral Fellows, Research Assist./ Assoc./Eng., Technical/Professional, Guests *(from outside Province; from outside Canada)*/ Étudiants, Boursier de recherches postdoctorales, assistants, techniciens et invites *(invite hors Province; hors Canada)*

Name, given nam Nom., prénom	*Position*	*Organization/ Organisation*	*Name/Nom. (S) or /ou (C)**	*Start/ Début*	*End/ Fin*	*CANRIMT Salary/Mo incl ben.*	*Extern. funding amount*	*Extern funding source*
Ramon Kallli	**Research Engineer**	**UBC**	**Yusuf Altintas (S)**	**Nov. 1, 2016**	**Oct. 30, 2017**			
Tayfun Ozdemir	**Research Engineer**	**UBC**	**Yusuf Altintas (S)**	**Nov. 2017**				
Germain Le Chapelain	**Research Engineer**	**UBC**	**Yusuf Altintas (S)**	**July 2019**				
Bruce Long	**MEng Student**	**UBC**	**Yusuf Altintas (S)**	**May 2018**	**Aug.31, 2018**			
Lincoln Ng	**MEng Student**	**UBC**	**Yusuf Altintas (S)**	**May 2018**	**Aug.31, 2018**			
Yudi Wang	**MEng Student**	**UBC**	**Yusuf Altintas (S)**	**May 2018**	**Aug.31, 2018**			
Adhi Jaganath Vasudevan	**MEng Student**	**UBC**	**Yusuf Altintas (S)**	**May 2019**	**Aug. 2019**			
Haoran Zhou	**MEng Student**	**UBC**	**Yusuf Altintas (S)**	**May 2019**				
M. Hossein Rahimi	**MASC**	**UBC**	**Yusuf Altintas (S)**	**Sept. 2018**				

(S) – Supervisor
(C) – Co-Supervisor

TOTAL #	**BASc**	**MASc/ M.Eng.**	**Ph.D.**	**PDF**	**Res. Asst.**	**Res. Assoc.**	**Res. Eng.**	**Tech./ Prof.**	**Guests/ outside Province**	**Guests/ outside Canada**
10		**7**					**3**			

1c: Partners & Contributions/ Partenaires et Contributions

PROJECT # & TITLE: V.II Integration of Sensor Assisted Digital Machining Algorithms to Industrial CNC's

Organization / Organisation	*Acronym/ Acronyme*	*Contact*	*Cash/ Espèce*	*In-Kind/ Nature*	*Overhead/ Frais généraux*	*Total*
ITRI Taiwan	**ITRI**					
Sandvik Coromant	**Sandvik**					
Pratt & Whitney Canada	**P&WC**					

PROJECT # & TITLE: V.II Integration of Sensor Assisted Digital Machining Algorithms to Industrial CNC's

2. RESEARCH PLAN FOR THE CURRENT PERIOD/PLAN DE RECHERCHE POUR LA PÉRIOD ACTUELLE (*Please list both the technical objectives, methodologies and milestones as stated in the previous report.*)
Focas of Fanuc and TNC Scope of Heidenhein systems will be connected to external CNC either independently or via ITRI's VMX communication interface. **Real time monitoring and control functions will be integrated to CANRIMT Real Time Monitoring system to be developed at UBC, and the researchers will be able to plug and play their methods.**

3. ALIGNMENT OF RESEARCH PROJECT WITH NETWORK OBJECTIVES/ ALIGNEMENT DU PROJET DE RECHERCHE AVEC LES OBJECTIFS DU RÉSEAU (*Please comment on the alignment of the research project with the overall Network objectives.*)
The research algorithms developed in Themes I and II are integrated to Digital Machining Platform to demonstrate their use in industry, which is the main objective of Theme V.

4. PROBLEMS and RESOLUTIONS/ PROBLEMES ET SOLUTIONS PROPOSÉES (*Please summarize any problems arising during the current reporting period and their resolution or plans for resolution.*)
Problem/ Problème: *Resolution / Résolution:*

5. RESEARCH PROGRESS and RESULTS/ PROGRÈS DE LA RECHERCHE et RESULTATS: (*Summarize progress and results below.*)

5a: MILESTONES/ÉTAPES

Summarize progress on milestones – including % completed – as outlined in the Research Plan for the current reporting period and any modifications since the last reporting period. (Milestones document also to be updated for each project.)

MILESTONE/ ÉTAPE:
% Completed / Rempli

NSERC CANRIMT - NETGP 479639 - 15 (2016-2021)
Interim Progress Report – May 1, 2018 – Oct 31, 2018
PROJECT # & TITLE: V.II Integration of Sensor Assisted Digital Machining Algorithms to Industrial CNC's

Tasks	% Completed
Real time communication with VMX to CNC	100
Kalman filter compensated real time force readings from spindle integrated force sensors	100
Kalman filter compensated real time force readings from feed and spindle drive motors	100
Synchronization of virtual and real time force models	100
Adaptive process control	100
Tool breakage detection	100
Chatter	100
Contour Error	100
The following new tasks are added to achieve on-line, integrated monitoring	
Automated Kalman Filter Design from On-line identified Spindle Servo Dynamics	40%
Detection of chatter using energy method	40%

PROJECT # & TITLE: V.II Integration of Sensor Assisted Digital Machining Algorithms to Industrial CNC's

5b: PUBLICATIONS and PRESENTATIONS / PUBLICATIONS ET PRESENTATIONS

Please list all publications directly arising from Network-funded research during the current period. Do not include abstracts.

A: REFEREED CONTRIBUTIONS - ARTICLES *Include articles in refereed publications – please specify whether the article has been submitted (S), accepted (A) or published (P).*			
Last Name, Initial	*Year*	*Title, Journal, Volume*	*Status*

B: REFEREED CONTRIBUTIONS - OTHER *Include papers in refereed conference proceedings, letters, notes, communications, review articles, monographs, books, book chapters and government publications.*			
Last Name, Initial	*Year*	*Description*	*Status*
		Conference Title, Location and Date (Status: Invited, Not invited)	
		Journal/Book/Publication Title (Status: S-submitted; A-accepted; P-published)	

C: NON-REFEREED CONTRIBUTIONS *Include papers in non-refereed conference proceedings, papers, letters and review articles.*		
Last Name, Initial	*Year*	*Description*
		Conference Title, Location and Date
		Journal/Book/Publication Title

D: SPECIALIZED PUBLICATIONS - PRESENTATIONS *Include theses, presentations, industrial/technical reports, internal reports, discussions of abstracts and symposium records.*		
Last Name, Initial	*Year*	*Description*
		Thesis or Conference Title, Location and Date
		Journal/Book/Publication Title

E: PUBLICATIONS – ***Not originally funded by NSERC CANRIMT but continuing or completed with Network funding***		
Last Name, Initial	*Year*	*Description/Title* ***(include start date of NSERC CANRIMT funding)***

F: PUBLICATIONS – ***Not funded by NSERC CANRIMT but related to the Network research focus***		
Last Name, Initial	*Year*	*Description/Title*

PROJECT # & TITLE: V.II Integration of Sensor Assisted Digital Machining Algorithms to Industrial CNC's

5c: PATENTS and LICENSES/ BREVETS ET LICENSES

Non-disclosure agreements signed, patent applications filed, patents issued, copyrights, licenses under negotiation, licenses granted, etc.

Category	Owner	Description

5d: OTHER COMMUNICATIONS, AWARDS/ AUTRES COMMUNICATIONS, PRIX

Provide information on additional communications related to your work, such as awards and distinctions, news stories, interviews, public forums, press releases, etc. for the current reporting period (please provide copies or links.)

Name, given name/ Nom, prénom	Details	Date	Link or copy attached

6. TRAINING/ FORMATION

(Describe the extent of cross-network and partner involvement in training for the current reporting period.)

Research engineers will develop the software platform, which will be used by the students to plug their functions and test them in real time machining. The students will be exposed to real time software engineering, sensors and integrated monitoring and control tasks.

7. RESEARCH PLAN FOR NEXT 6 MONTHS/ PLAN DE RECHERCHE POUR LES 6 PROCHAINS MOIS

(Describe Planned Research Activities for the next 6 month period and include any modifications made during the current reporting period.); also please list both the technical objectives and milestones.)

Develop the software platform with modular – open architecture for Heidenhein and Fanuc

8. OPTIONAL – Comments, Questions and/or Feedback/ OPTION – Commentaires, questions et/ou des commentaires

Include any supplemental comments or questions pertaining to the Network here.

9. NETWORK EVENTS ATTENDED or SUGGESTIONS / ÉVÉNEMENTS RÉSEAU ONT ASSISTÉ ou SUGGESTIONS

Please list any Network-related events attended and include comments and suggestions for events which may be helpful and informative for Network members to attend in future.	
Event	*Comments/Suggestions*

REPORT (July 1-Dec. 31, 2016): Progress Report

Research engineer Ramon Kaili with software expertise was hired on Nov. 1, 2016.
TNC Scope and Focas have been connected to CNCs.
Preliminary adaptive control and tool breakage detection have been successfully conducted on Heidenhein.

Software platform is able to connect to Heidenhain, and obtain and store scope data such as position and nominal current.
Software platform plots real-time tool position alongside simulated data, and displays force, power and torque vs time or vs distance travelled along tool path.

REPORT (May 1-Oct. 31, 2017): Progress Report

A 3D representation of the workpiece shows material removal as the tool performs the operation. Warning messages are shown when the tool approaches points in the operation where sudden increases in tangential force occur. The warning time for these messages can be modified by the user. A Kalman filter compensation feature allows for compensated X and Y cutting forces to be displayed on the 2-D graph.

PROJECT # & TITLE: V.II Integration of Sensor Assisted Digital Machining Algorithms to Industrial CNC's

REPORT (Nov 1, 2017-Apr 31, 2018): Progress Report

Research engineer Ramon Kaili left UBC, and he was replaced by Tayfun Ozdemir on Nov. 1, 2017.

The aim of this project is to monitor real-time CNC data and control it by looking at user provided simulated data. The main control functions are:

- Adaptive control
- Tool breakage
- Chatter

The work which was done so far is moved to a new Graphical User Interface (GUI). The reason for this is to give users more flexibility and good view. Since this project is to monitor and control real-time CNC, a new software architecture is provided to make it fast and efficient, as well. This new GUI basically provides:

- Connects to Heidenhain CNC. IP address for CNCs can be entered and named as desired.
- Tracks the user provided simulated data line by line and takes a required action if necessary.
- All data taken while running can be recorded if desired.

Besides of the main functionality, the followings are added:

- A new 2D Kalman filtering data matrix is provided. It allows to enter the data flexible, or load from a file, and save it again.
- A new 2D graphical system is provided. Multiple charts can be opened if required.
- For the visual view, the existing workpiece cutting is made more efficient, because it consumes more CPU time and may cause insufficiency on main running process.
- Besides, a new functionality is added to customize the program according to user requirements by enabling/disabling the processes and functions.

REPORT (Apr 31-Oct. 31, 2018): Progress Report

The aim of this project is to monitor on-line CNC data and control it by looking at user provided simulated data which is produced from a MachPRO output file. The main control functions are:

- Adaptive control
- Tool breakage
- Chatter (No need any simulated data file)

A new Graphical User Interface (GUI), named intelCUT, is created for this purpose to give users more flexibility and good view as well as providing fast, multi-tasking and efficient software architecture.

Currently, intelCUT only supports Heidenhain iTNC530 CNC, but is being planned to support other models of Heidenhain CNCs as well as Fanuc and Siemens.

The basic functionalities of intelCUT are as follows:

- Connects to Heidenhain iTNC530 CNC. Multiple CNC machines for connection can be defined by entering specific names and CNC's IP addresses.
- Tracks the user provided simulated data file line by line and takes a required action if necessary. Simulated data file is only required for Tool Breakage and Adaptive Control functionalities.
- Work-piece cutting tracking is provided on-line by plotting tool position coordinates in a 2D-Graph.
- There are also 4 on-line graphics, they are, Fa and eta1 for Tool Breakage control, and Force and Feed Rate for Adaptive Control.
- User notifications like program running status, process running time and alarms like tool breakage occurred, or Chatter occurred etc.
- Also tracks NC code running on CNC and accesses to CNC tool table to get actual tool geometry info like tool diameter, length etc.

Besides of the main functionality, the following optional functionalities are added:

- **Visual work-piece cutting**: Currently, loading a shape of work-piece is added for now, and cutting the shape is not developed yet.
- **Recording**: All data collected while cutting can be recorded if desired.
- **Kalman Filtering**: A new 2D Kalman filtering data matrix is provided. It allows to enter data or load from a file, and save it again, but the usage of it is not developed yet.
- **Test Mode**: Sometimes, some works need multiple cutting testing. To minimize these testing and to get time efficiency, a test mode is added. In this mode, processes can be tested by using a data record which has tool positions, their currents, feed rate, spindle speed and its current. This data is used as if CNC is sending the data to intelCUT.
- **Customization:** A new customization dialog is added to control some parameters obtained from user requirements by enabling/disabling the processes and functions.

There are also 2 functionalities which are controlled by view menu item as follows:

- A new 2D graphical system is provided to plot some specific recorded data. Multiple charts can be opened if required.
- Raw recorded data can be listed. Multiple lists can be opened if required.

REPORT (Nov 1, 2018 - Apr. 30, 2019): Progress Report

This project is now covers the following functionalities:

- Adaptive control
- Tool breakage

- Chatter
- Contour Error (On-line and off-line tracking)

A new Graphical User Interface (GUI), named intelCUT, is created for this purpose to give users more flexibility and good view as well as providing fast, multi-tasking and efficient software architecture.

Adaptive control and Tool breakage functionalities require simulated data which is produced from a MachPRO output file, but the others, Chatter and Contour error don't.

Besides, some of these functionalities do not work simultaneously. Here is the working sets:

- Adaptive Control and Tool Breakage
- Chatter
- Contour Error

Basic functionalities for intelCUT GUI like connection to CNC, loading simulated data, tool data entry, real-time graphics etc. are completed.

Besides of the basic functionalities, the following optional functionalities are also completed:

- **Visual work-piece cutting**: Loads a shape of work-piece, and visually cuts the shape according to the simulated data.
- **Recording**: Records all data collected while cutting can be recorded if desired.
- **Kalman Filtering**: 2D Kalman filtering data matrix can be provisioned but the usage of it is not developed yet. (not planned now)
- **Test Mode**: Runs by using a previously recorded data which has tool positions, their currents, feed rate, spindle speed and its current. This data is used as if CNC is sending the data to intelCUT.
- **Customization:** Customizes some control parameters obtained from user requirements.

Apart from above developments, a new enhancements are added to the GUI view and it also shows:

- Kt value
- G-code current running line number and code
- Tool status like cutting or air stage
- Optional file name entry

REPORT (Apr. 30, 2019 - Nov. 1, 2019): Progress Report

A new energy based method was started to detect chatter by acquiring sound data via a microphone. If chatter is detected, it attempts to avoid it by selecting a new speed and the feed automatically in real time. It was found that PC card's sound data was always filtered by the its sound card which led to the loss of useful machining vibration data. If the sound was sampled by regular DAQ sytem, the data was not distorted.

GUI has been created, named as ChatterPro-X. The following capabilities are added:

- **Connection**: It connects to the following CNCs:
  - Heidenhain iTNC530
  - Fanuc Focas30i
- **Detection settings**:
  - Load profile: required to understand whether CNC is cutting or not
  - Sound connection: Microphone was connected to DAQ
- **Graphics**: There are 2 types of plotting:
  - PCM (Pulse Code Modulation, it does Analog to Digital conversion)
  - FFT (Fast Fourier Transform)
- **Recording**
  - Audio
  - Chatter data like sound amplitude, chatter frequency
- **Spindle setting**: There is a provisioning field which holds the the flute count of the tool.
- **Maintenance**: allows the change feed rate and speed of the spindle
- **LOGs**: Any important result is logged immediately to this area to let the users know, then they may take an action according to that if necessary.

The sound data is acquired and processed on-line. If a chatter is detected, the following actions take place:

- The feed rate is set to 0, that is, it is stopped,
- The process calculates a new spindle speed
- The speed of the spindle is changed according to that and waits till it gets stable
- Then resumes the feed rate again.
- If a new chatter is detected, the algorithm is repeated

Currently, we faced some problems for chatter detection, because of the quality of the acquired sound data. Currently, the PC sound card is used, but to overcome this, NI DAQ devices will be used instead.

A new software engineer has been hired to work on the Real-Time aspect of the Closed-Loop Machining System.
I.e. the algorithms will run on a deterministic computer infrastructure, thus allowing for timing with a precision a scale of a microsecond, as opposed to dozens of milliseconds for traditional General-Purpose architectures.

The task is currently defined as two steps:

1) The monitoring routines will be integrated into such Real-Time loop to provide feedback to the control module. The adjustments made to control will still occur online (i.e. from a General-Purpose architecture) due to technical constraints.

2) If the architecture is validated and provided we are given access to the control interface of the CNC-machine at a Software Development level, then the control adjustments will also be incorporated to the Real-Time loop.

The National Instrument PXI Express architecture has been selected for such purpose, due to its superior specification capabilities. (`PXI' stands for `PCIe eXtensions for Instrumentation'.)

Since it was acquired in June, the device has been configured to its production settings; and preliminary experiments have been successfully conducted using it.

Those experiments have been using the LabVIEW™ development platform from National Instrument; geared toward scientific research and industrial prototyping.

Development has started on an intermediate platform to unify the experimentation of monitoring and control processes.

A new project has been started to detect chatter using machine learning methods, in order to utilize the current knowledge of machine tool vibration and chatter detection and combine it with machine learning methods to compensate for the detection inaccuracies.

The project consists of three major components, 1. The on-line processing unit 2. Measurement and real-time processing unit 3. Machine and its external and internal sensors. Below, further explanations about each of the mentioned components are provided.

The first component is a PC, processing the measurements and running the chatter detection methods as well as the machine learning algorithm in an on-line manner. In order to acquire the measurements, on-line processing unit needs to communicate with the Real-time processer. The PC is connected to the measurement and real-time processing unit over a LAN network; moreover, it is able to access the mentioned unit through a secure wireless connection. The prepared windows executable application on the PC client makes users able to monitor the machine, cut and the sensors on-line. The application user interface renders the graphs of sensors group by group as well as their FFTs and the FFT peaks. It shows the results of real-time FFT based chatter detection and let the users tweak the parameters of detection. Moreover, it provides user with a connection map of the sensors and settings such as data storage method, output voltage, sampling rate, and etc.

The second component is the real-time processor and the measurement unit. This unit is a National Instruments PXIe machine, running a LabView VI code, in order to pass the measurements to the on-line processing unit as well as taking care of the real-time mathematical and arithmetical operation. For this part a National Instrument PXIe has been purchased and equipped with a multifunctions data acquisition card, DSA analog input card, programmable DC power supply card, and function generator card. The

PXIe runs a LabView application for all of the real-time measurements. The machine has been prepared by installation of the drivers on both PXIe side and the programming station site.
The last part is the machine sensors. The internal sensors will be read by the PC client and the external sensors, like current sensors, dynamometer, microphone, and accelerometer, will be read by the PXIe.
Currently, the real-time code is equipped with FFT based chatter detection. The LabView code has an FTP API to transfer stream of data over FTP in order to communicate with third-party applications. The Matlab function for this purpose is ready, and addable to any Matlab application.
A Matlab application has been written for automated reading, storing, and basic analysis of the PXIe reading through the network. The application reads the data and store it in a Matlab structure, alongside tool and cut description and details. The mentioned code can calculate statistical measures of the measurements automatically and soonly, after careful examination of the methods, it will be able to perform machine learning algorithms on the measured data and perform feature selection using genetic algorithm in order to integrate the traditional methods of chatter detection with machine learning methods in the most reliable way possible.
For the machine learning algorithm learning phase, a Matlab code has been designed to generate the HCode for performing slope cuts, based on the workpiece, machine, and mounting properties. The cuts, start from a certain depth of cut, in which chatter will not happen. As machine proceeds in the cut, the depth of cut increases such that tool chatters for the few last seconds of the cut. The outputs of the sensors will be acquired by the system explained above. So far, more than sixty cut data has been collected, stored in the database, and processed by the system.

A new project has been started to communicate with Mori Seiki NT3150 DCG turn-mill center using Fanuc FOCAS library as well as ITRI's library.
With FOCAS library, it is possible to read servo and spindle data, including axes position and position errors, feedrate, spindle speeds, remaining distance, spindle and servo load meters, feedrate and turning spindle override. It is also possible to write turning spindle override and PMC parameters. The read and write frequency is around 330 Hz.
With ITRI's library, it is possible to read servo data at 4000 Hz and spindle data at 1000 Hz. For servo data, summation of position feedback pulse data, position error, velocity command, torque command and speed feedback signal can be read. For spindle data, torque command, load meter data and spindle speed data can be read.

The following states are obtained from Fanuc :

Data type	Sampling frequency		Library used
	One axis	All axes	
Position (absolute, machine, relative, remaining distance)	330 Hz	250 Hz	FOCAS
Feedrate	330 Hz		FOCAS
Spindle speed	330 Hz	300 Hz	FOCAS
Spindle load		320 Hz	FOCAS

Servo load		165 Hz	FOCAS
Position error		4000 Hz	ITRI
Spindle torque command		1000 Hz	ITRI
Turning spindle speed override	320 Hz		FOCAS
Feedrate override	320 Hz		FOCAS

The procdure pmc_wrpmcrng is used to send data back to Fanuc to control it. Currently, we only controlled the turning spindle speed, and could not the others like milling spindle speed and feed rate, because of the PLC Mori Seiki NT 3150 DCG CNC was not configured to do this. Mori Seiki Engineers can chane the PLC settings as they did few years ago for Mori Seiki DMV5000 Machining Center at UBC MAL.