Ministry of Science and ICT

IITP Institute of Information & Communications Technology Planning & Evaluation

APPLICATION FORM (JOINT RESEARCH)

HIGH POTENTIAL INDIVIDUALS GLOBAL TRAINING PROGRAM)

AGREEMENT

As stated above, I submit this application form to IITP that conducts "High Potential Individuals Global Training Program" supported by Ministry of Science, ICT in South Korea. IITP may disclose the information below to the public for the purpose of providing information and matching a research partnership between your institute and a Korean university.

* IITP : Institute for Information & communications Technology Planning & Evaluation

Printed Name of Chief of Research	Martin Byung-Guk Jun	Date(mm-dd-yyyy)	01-23-2020
Signature of Chief of Research			

☞ ***(Note)*** *This application is to identify the willingness to participate in this research and to find a research partnership for research institutes in Korea. Therefore, in its sole discretion, it is acceptable to contain only minimal information. (max. 3 pages)*

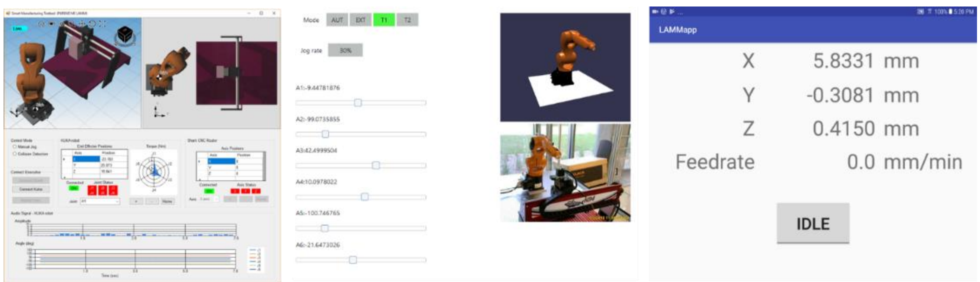
1. Research Title	IoT and AI based Machine Monitoring and AR/VR-based Human Interaction and Decision Making						
2. Research Area	**A.I.**	**Big Data**	**Cloud Computing**	**Block Chain**	**AR/ VR**	**ICT/SW Convergence**	**Other ICT /SW**
	X				X	X	
3. Chief of research	Title	Associate Professor	Contact	E-mail : mbgjun@purdue.edu			
	Name	Martin Jun		Tel : +1-765-494-3376			
4. Affiliation	Name	Purdue University	Classification	(X) University ( ) Research Institute ( ) Industry ( ) ETC.			
5. Capacity for students (5 or less)	5	**Support for students *(all necessary)***	(X) Visa support (X) Research Mentoring (X) Research Space (X) Accessibility to Research equipment				
6. Research Objective	1. Two-way Communication for Real-Time Digital Twins 2. IoT Based Machine Monitoring 3. AI-based Classification of Machine Monitoring Data 4. AR/VR-based Human-Machine Interactions and Operation						

7. Research Summary

1. Two-way Communication for Real-Time Digital Twins

We have developed two-way MTConnect framework using raspberry PI, which is a Linux-based palm-sized small computer. Using raspberry PI as a PC, connectivity to each machine or sensor can take place at extremely low cost and space, allowing easy integration and creation of digital twins. Figure 1 illustrates the system setup. A CNC router consists of three stepper motors for XYZ axis. The MTConnect adapter commands the controller to get positions. A message generator adds time stamp to the positions and sends to MTConnect agent using HTTP protocol. The integrated program is developed using C++ with QT framework for Linux desktop application on raspberry PI. In the same way, an industrial robot (KUKA) communicates with MTConnect adapter program using Ethernet. KUKA proxy and JOpenShowVar is open source program which access and change variables of KRC4 controller. Since the open source programs use JAVA language, the integrated program is also made by JAVA and is running on another raspberry PI. Two Raspberry PI 3+ (RPI) are used as PC because of its affordable price with various communication such as serial, Ethernet, Bluetooth, and WiFi. Two RPIs send machine data to the MTConnect agent using WiFi. User apps such as digital twin and dashboard shows the data after receiving them from the agent. They also command machine to move, but the target is not to have real-time machine controllers but to communicate integrated programs the machine.

Several user applications with different platforms are developed so far. Figure 1 illustrates dashboard applications with different operating systems. Figure 1(a) is a recently developed dashboard application that shows geometric twin of the testbed, machine positions such as end effector of the robot, movement of axis, axis positions, stethoscope sound signals, joint torques of the robot. The program uses Eyeshot, commercial 3-D CAD library for windows application, and Windows application using C# language. Several applications are also created for Web browser and Android devices as Figure 1(b) and 1(c) to show the flexibility of our smart manufacturing framework.



(a) (b) (c)

Figure 1. Developed user applications: (a) Dashboard for Windows desktop, (b) Dynamic web page, (c) Android application.

Such communication and user application platform need to be developed for the newly established Intelligent Manufacturing Testbed at Purdue as shown in Figure 2. This is a factory-scale testbed where data collection can occur as actual products are produced. This will be an excellent opportunity for joint research with universities in Korea. Students from Korea will be able to access and experiment at factory-scale testbed for IoT/AI and AR/VR related research.

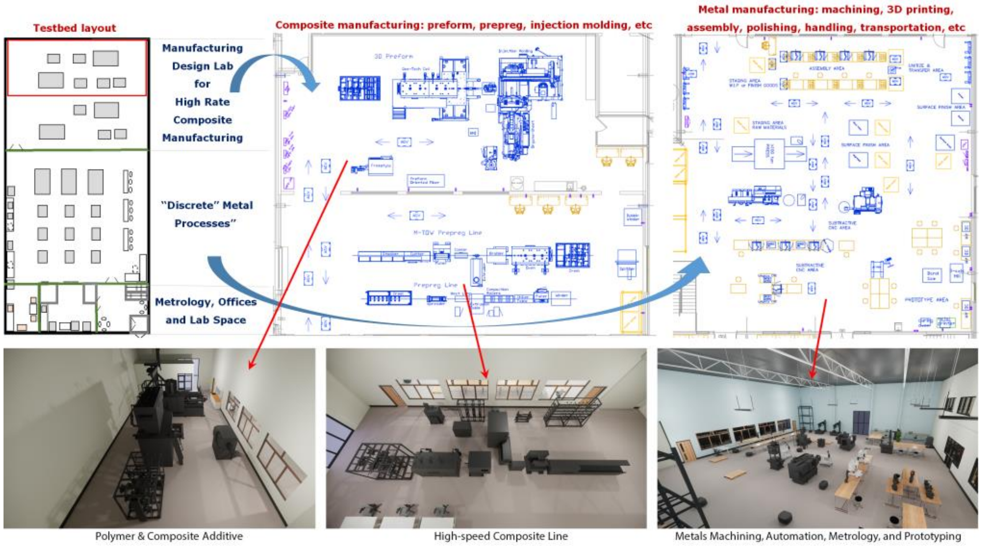


Figure 2. Schematic layout of factory-scale IMT that consists of composite manufacturing, metal manufacturing, metrology, office, and computer lab spaces.

2. IoT Based Machine Monitoring

The recent studies on machine health diagnosis and estimation have utilized variety of sensors to capture physical attributes of machines such as forces, vibrations, acoustic emissions and currents. The gathered data from sensors are handled with signal processing techniques applying Short-term Fourier Transform (STFT) or wavelet analysis in a sense that rotating parts generate vibration with certain frequencies. Nowadays, the signal processing techniques are related to Neural Network (NN) with advances in machine learning technology. Especially, frequency domain features from vibration analysis of machinery are used for classification problem. Convolutional Neural Network (CNN), one of popular NN architectures, is widely applied for anomaly detection of machinery. However, the performance of commercial sensors such as accelerometers and acoustic emission sensors are far beyond the range of interest in some operations. In those cases, the out-of-range data which are not in user's interests produce unnecessary amount of signal collection. Thus, we utilize audio signals obtained from commercially available stethoscopes to monitor and analyze the KUKA robot arm. Use of audio signals allows easy signal collection using low-cost, IoT-based audio recording devices. Two stethoscopes and an accelerometer are mounted on wrist and waist of KUKA robot arm. The stethoscopes are connected to microphones and transmit audio signals to PC directly. For the reference, the accelerometer is wired to the same PC using NI-DAQ adapter. In addition, torques and angular velocities of KUKA robot are acquired by MTConnect, and they are compared to sound signals in time domain. The framework is described in Figure 3.

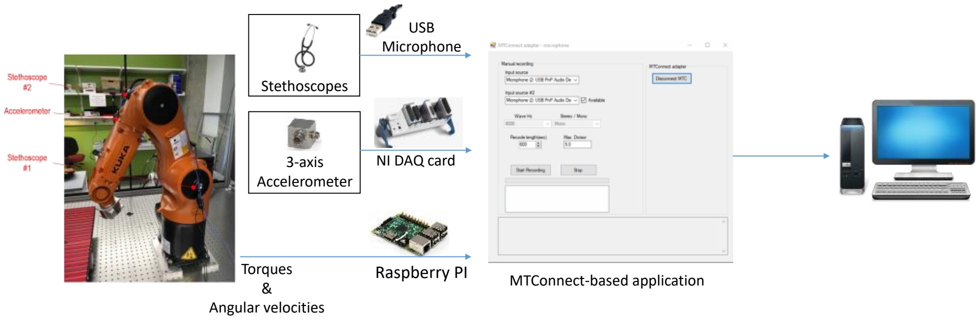


Figure 3. Framework of data collection from multiple-sensor using MTConnect-based application

3. AI-based Classification of Machine Monitoring Data

The KUKA robot arm is programmed to rotate its each axis, and spectrograms of sound signals from the stethoscopes are collected. Figure 4 demonstrates that each axis movement has its own audio signal spectrum. We speculate that the amplitudes and spectral patterns of audio signal are related with loads and feed rates of robot arm. It can be seen that the audio signal spectrum shows difference during different axis movements. We are also building CNN model to identify faulty status of robot arm. The inputs are features from part of spectrograms separated by joint torques, and the output is predicted fault of the robot.

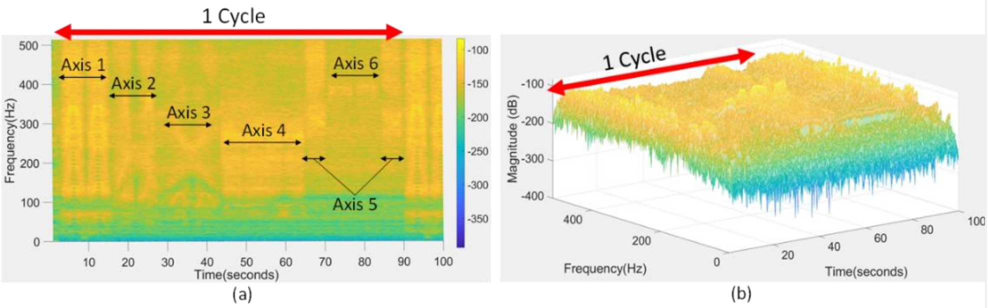


Figure 4. Audio signal spectrogram of single axis operation of 6-axis KUKA robot arm (a: 2D, b: 3D view)

Once measurements are obtained from IoT sensors, they are often pre-processed to eliminate redundant information and unnecessary noise before applying machine learning. Signal processing (e.g., digital filters) and feature engineering (e.g., extracting features from time, frequency, time-frequency domains) are common methods used in pre-processing. In Figure 5a, raw signals obtained from one sampling trial are plotted. In order to classify the pump conditions using the collected acceleration signals, a convolutional neural network (CNN) is employed. CNN is known as a popular method to classify 2-D data types. Therefore, 1-D acceleration signals in the time domain were converted into the time-frequency domain using a power spectral density (i.e., spectrogram). A spectrogram using a power spectral density presents the power contests of a signal at various frequencies over time, and mathematically, it can be written as,

$$p(f)=\frac{\Delta t}{N}\left|\sum_{n=0}^{N-1}h(n)x(n)e^{-i2\pi fn}\right|^2,\quad -\frac{1}{2\Delta t}<f<\frac{1}{2\Delta t} \qquad (1)$$

where Δt is a sampling frequency. In the analysis, the hamming window function is employed, and the time-frequency features of each sampling trial are computed. Then, the processed data are used to train and test the CNN model shown in Figure 5b. For the CNN architecture, two convolutional and two max-pooling layers followed by a fully connected layer are used between the input and output layer.

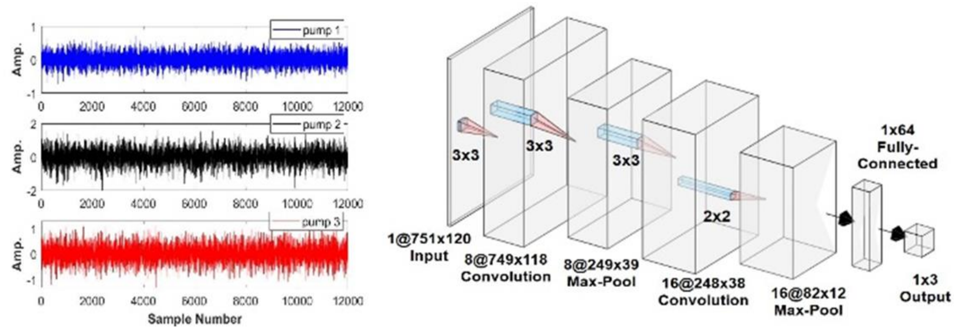


Figure 5. (a) Raw signal examplesand (b) CNN architecture.

We plan to establish such IoT-based monitoring technologies for the IMT mentioned before. AI-based monitoring of various machines (CNC machine, AGVs, robots, molding machine, bending machine, etc.) using such IoT devices will give unique opportunities for AI-based monitoring research, which will be very beneficial to individuals from universities in Korea.

4. AR/VR-based Human-Machine Interactions and Operation

A digital twin that contains geometries of the testbed will be developed using Unity Engine in order to allow digital twin integration to VR environment. It is a game engine that renders 3D shapes using GPU (Graphics Processing Unit) acceleration. At first, 3D models of machines are required to construct geometric digital twin. Then, each sub models are used to create a hierarchical structure. ROSbridge module in Unity will be used to subscribe messages from ROS. It uses Websocket protocol, message communication method using JSON format. The ROSbridge server is installed in the PC where ROSMaster is. Figure 6 illustrates the system. The machine should publish joint positions to ROS master. A robot has an application program to publish joint data to the PC where ROS master is. It also has a subscriber to control the robot position as the subscribed joint angles, which is not necessary for creating digital twin only. Figure 7 shows the digital twin of the robots and CNC router. 3D geometries are imported from CAD model (STEP file converted by Solidworks 2016) and all individual entities are regrouped by axis. After the digital twin receives joint angles of the robot and positions of the CNC router, the algorithm inside translates or rotates the regrouped CAD entities. The digital twin works as the same as looking at real testbed, and it is also VR compatible. Using the VR environment, a smart factory in a different location far away can be virtually visited, where the digital twins operate in real time in the same way as the physical counterparts in the factory. Any information regarding process or machine conditions can be displayed as the user walks around the virtual factory and taps each machine.

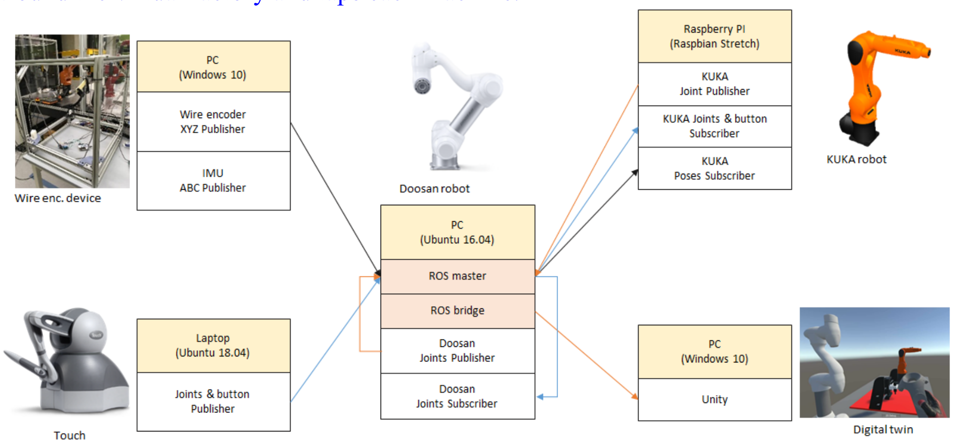


Figure 6. A Schematic of the geometric digital twin in VR environment (Unity).

The digital twins can also be used to simulate and optimize the factory operations. After a series of operations and operation data collections, the data can be used to more accurately simulate the entire factory operations, which can be used to optimize the factory operations as well as identify bottlenecks. In addition, digital twins will be used to implement learning environment for reinforced deep learning by creating millions of random scenarios virtually. The beauty of digital twin is historical digital data of physical system. In true digital twin, digital data of all system components can be collected for lifecycle. Trained model using lifecycle data can help to predict the maintenance requirement. Measured sensor data will be collected for long period of time and it will be used to train and test the model.

	 **Figure 7. The digital twin generation: use of VR headset for real-time interaction with physical machines via digital twins**
8. Need for funding from Korean government	The Intelligent Manufacturing Testbed (IMT) at Purdue is a unique facility that is a production-scale pilot factory for students and faculty members to have access to assess, test, and validate the emerging technologies such as 5G, AI, IoT, AR/VR, and cybersecurity for manufacturing applications. IMT is originally established for the exact same purpose of evaluating the emerging technologies during a real production of parts and assembly. IMT houses a series of machines and tools for subtractive, additive, and assembly processes. Batch production of three different items will take place at IMT: bicycle crank arm, packaged raspberry pi, and a commemorative token. Bike crank arm consists of many parts including carbon fiber reinforced polymer (CFRP) composite, metal, and off-the-shelf parts. During machining and assembly of the crank arm components, for example, data from sensors and machine controllers will be generated and monitored. During the batch production, new technologies related to sensors, AI, data visualization, adaptive control, etc. will be tested and validated. Different manufacturing and assembly operations are involved for other items, e.g., packaged raspberry pi, and the batch production will be utilized similarly to evaluate different digital and smart manufacturing technologies. IMT will give unique opportunities to train students and researchers from Korea and conduct joint research between Purdue and universities in Korea. Funds from IITP is requested to provide these unique opportunities to visiting students from Korea to Purdue. The experience will establish a foundation in the students because they will be trained with digital and AI technologies in real-life industry-like environments.
9. Request for Korean Universities	- Research areas of student roles are identified before selection of students through mutual discussion and meetings. - The selection of students studying abroad should be conducted after mutual consultation, and please cooperate as much as possible to prepare for VISA.