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NATURAL-LANGUAGE CHAT & CONTROL HMI FOR MANUFACTURING SHOPFLOOR

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ABSTRACT

The ability to instantly and successfully interact among technical engineers, management team and machines is vital to the productivity and efficiency of manufacturing shopfloor. Chat messenger with smart mobile has obvious advantages for shopfloor management in group communication, instant notification and remote control. This paper presents a natural-language chat & control HMI for manufacturing shopfloor. The system successfully realizes a smooth two-way communication between users and shopfloor machines. Users can access just-in-time information, receive instant notifications, and remotely control shopfloor machines. All relevant parties can communicate over shopfloor matters in a chat group. The system comprises of four core modules, i.e. Chat Messenger, Chat Service Engine, Control & Communication Engine and Local Command Service. Chat Messenger provides chatting user interface and group management dealing with end-user's enquiries and notifications via natural language. Chat Service Engine and Control & Communication Engine are two cloud-based service modules, which process questionnaire logic and transmit relevant commands and data bi-directionally

between Chat Messenger and Local Command Service. Local Command Service is a local service terminal which implements interfaces and protocols directly interacting with shopfloor machines. It processes the requests and commands from Chat Messenger to shopfloor machines. It also checks real-time machine anomalies and automatically generates corresponding notifications. The system has been implemented in the advanced manufacturing shopfloor at Nanyang Polytechnic. The results and validation show the improvement of manufacturing shopfloor efficiency.

Keywords: *Chat HMI, manufacturing shopfloor, smart factory, remote control, instant notification, industry 4.0*

INTRODUCTION

Under the current digital manufacturing trend of Industry 4.0, the remote access of the Just-in-Time information of manufacturing shopfloor is an emerging demand from the prospective of shopfloor management. The ability to easily interact with diverse manufacturing systems is vital to maintaining shopfloor efficiency and productivity [1, 2]. Over last decades, many applications have been developed for shopfloor monitoring and control, which are either standalone or web-based software [3, 4]. The obvious shortcomings of these applications are: (a) not able to easily share data or discuss shopfloor matters among a team group; (b) not able to receive the instant notifications and anomalies from shopfloor with mobile devices; (c) not easy to be used by non-technical people such as management team. To deal with such communication gaps, industry has been expecting mobile-based solutions to realize an easy communication with manufacturing shopfloor.

With the quick development of IoT technologies, Human Machine Interface (HMI) has been playing an important role in shopfloor control and monitoring. Furthermore, HMI has become an information hub and communication gateway to improve shopfloor efficiency and productivity by triggering the automated alerts and notifications and transferring manufacturing data from the diverse manufacturing systems of shopfloor among relevant parties including supervisors,

operators, marketing representatives and management executives [5]. As the latest mobile media, chat messengers such as WhatsApp, Viber and WeChat are getting more and more popular for group sharing and discussion. These mobile chat platforms have recently been able to build reliable communication with various industrial devices leveraging on stable web clouding services and technologies. Thus, the date sharing and remote control of shopfloor systems are feasible in terms of the required security and reliability. These chat platforms can provide a group sharing site for the Just-In-Time notifications and further the remote access and control of shopfloor machines. Additionally, Natural Language Processing (NLP) embedded with Machine Learning has enabled mobile apps to understand and process human natural language in extracting information and semantic understanding [6-10]. Incorporating natural language user interface into HMI is increasingly demanding from industry because it has the advantage of easy communication to shopfloor matters among non-technical people.

Recently, several chat HMIs were developed to communicate with the CNC machines of manufacturing shopfloor [11-13]. These chat HMIs can receive the instant notifications and access the working conditions of CNC machines with mobile tablets and devices. They have significantly improved the efficiency on shopfloor monitoring by introducing mobile devices compared to by using fixed workstations and CNC controllers. However, these HMIs were developed based on their own messenger platforms rather than using popular chat messengers like WhatsApp and Viber. This constraint limits their chat HMIs for further standardization and popularity in manufacturing industry. Moreover, these HMIs can only receive the notifications and access the information from shopfloor machines, but cannot send commands back to machines for remote operations and immediate actions. Responding to these constraints and industrial emerging demands, this paper presents a chat & control HMI leveraging on a popular chat messenger (i.e. Viber) to realize a two-way communication between the CNC machines of manufacturing shopfloor and relevant end users including both technical and non-technical people. All parties can access shopfloor information and control shopfloor machines in a chat group with natural language contents and commands

CHAT & CONTROL HMI

The objective of this work is to build a two-way communication chat HMI between manufacturing shopfloor and end users by introducing the mobile chat messenger, i.e. Viber. With the presented HMI, end users would be able to communicate with the manufacturing systems of their local manufacturing shopfloor via a mobile chat messenger without the constraints of time and physical place as illustrated in Figure 1.

Figure 1: Chat & control HMI FOR manufacturing shopfloor

Figure 2 describes the schematic diagram of the presented chat & control HMI system. It consists of the following main components: Chat Messenger (CM), Chat Service Engine (CSE), Control & Communication Engine (CCE), Local Command Service (LCS) and Cloud Host. CM provides the user interface of group chat for end users. CSE processes users' inputs with natural language content library and questionnaire interpretation engine, and ensures the enquiry and command transmission from CM to other cloud services. CCE bridges the question intents and machine commands between LCS and CSE with respective web service APIs. The LCS, running as a local client server at shopfloor, bi-directionally processes the enquiries and machine commands between CCE and shopfloor systems. It enquires data from shopfloor systems and executes machine commands based on the requests from CCE. On the other hand, it automatically receives the instant notifications from shopfloor systems and transmits them to CCE. Cloud Host serves two main roles for the chat & control HMI, i.e. the provision of cloud data sockets and the deployment of the web services of CSE and CCE. In this work, Amazon Web Services (AWS) is

selected to host the web APIs and the cloud data. Integrated with all these components, the system can eventually realize a 2-way communication between end users and shopfloor machines.

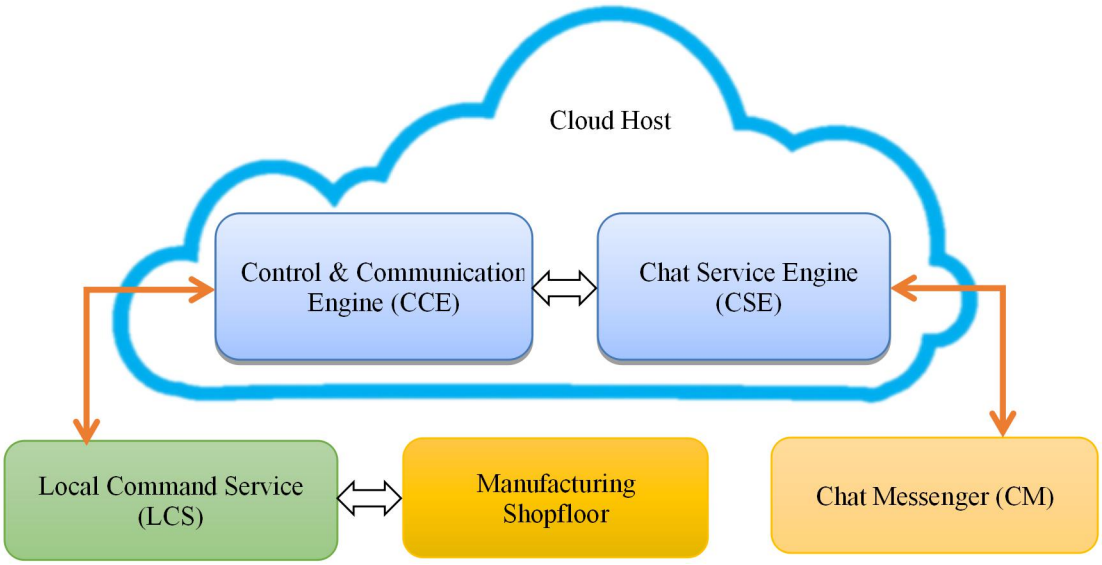


Figure 2: Schematic diagram of the chat & control HMI for manufacturing shopfloor

Chat Messenger (CM)

CM provides the chatting UI to manage the user communication group. In this work, a popular chat messenger, Viber, is selected to develop the chat & control HMI platform. Viber REST API [14] is used to develop the chat platform handling messages, conversation status, failure & errors, account authentication, exception handle, etc. Working with CSE in a feedback system, CM provides the below functionalities for the chat & control HMI:

- Initialize and process users' enquiries and commands forwarding to the specific shopfloor machines.
- Display the notifications, alerts and data from shopfloor systems to the end users.
- Manage user account and administrative rights for the chat group.
- Handle the exceptions and system errors occurring at chat group and mobile network.

Chat Service Engine (CSE)

CSE is a cloud-based service engine to process end users' questions and enquiries from CM. In this work, CSE is developed based on the Unification Engine [15] provided by our industry partner, UIB. The UE Messaging API and UE AI API [16] of the Unification Engine empowered CSE with the ability to process and understand users' inputs using cloud-based NLP and AI engines, with the algorithms including sorting processor, question logic, keywords indexing and extraction, meaning extraction, continuous question queries and contextual meaning logic analysis. In addition, a customized language content & command library was built and integrated into CSE to handle those specific enquiries and commands relevant to manufacturing shopfloor. Consequently, CSE is able to deal with both general industrial question queries and the specific enquiries for manufacturing shopfloor. More specifically, CSE provides the below bi-directional functionalities to support the chat & control HMI:

- Response and process the enquiries and commands from CM (i.e. end users) to clearly understand the question and command.
- Translate natural language contents to the specific questions and commands sent to CCE (i.e. towards to shopfloor) by calling its specific web API.
- Response and receive the data and notifications from CCE (i.e. from shopfloor), and process and send these data and notifications to CM (i.e. end users) using text or pictures.

Control & Communication Engine (CCE)

CCE is a cloud-based web service module communicating with CSE and LCS. It provides a list of the web APIs corresponding to all the shopfloor functions, commands and notifications of the chat & control HMI and calls the corresponding predefined APIs of LCS as listed in Table 1. CCE also manages and transmits the various web data at cloud sockets storage such as text, image, table, command lines, etc. While CSE bridges the Viber messenger and cloud services, CCE bridges cloud services and the local shopfloor server LCS. It ensures the two-way communication smoothly carried out. End users will be able to access the Just-in-Time information of shopfloor and to control the shopfloor machines remotely. CSE mainly provides the functionalities as below:

- Receive and interpret the enquiries and commands from CSE, and invoke the corresponding APIs of LCS to request data or send operation command to manufacturing machines.
- Receive the data and notifications of shopfloor systems from LCS, and forward to CSE towards to end users.
- Manage and synchronize the cloud storage data with respect to the data and information of shopfloor.
- Generate the respective URLs for the images and data at cloud socket, and transmit tem to CSE towards to CM.

Local Command Service (LCS)

LCS is the local terminal service running at the shopfloor server, which can directly communicate with and control shopfloor machines by means of diverse protocols and interfaces such as TCP/IP, FTP, RS232/RS422, MTConnect and DNC [17, 18]. LCS bi-directionally processes the relevant data and commands between shopfloor machines and web services CCE towards to CM and end users. It provides with three groups of functionalities to communicate with shopfloor machines, i.e. access data and information instantly, control machine operations remotely and monitor machine behaviors automatically. It can access the shopfloor information such as layout, machine list, production data, job data, machine status, working parameters, etc. It checks machine alerts, errors and anomalies periodically and automatically, and sends respective notifications to end users. It can further remotely control shopfloor machines by invoking corresponding machine commands. More specifically, it provides the below functionalities to support the chat & control HMI:

- Response to the enquiries from CCE, and collect the corresponding data and information from shopfloor systems.
- Response to the machine control commands from CCE, and invoke the correct machine operation commands to CNC machines.

- Verify or deny the requests and commands from CCE before taking further actions to shopfloor machines.
- Process and analyze the shopfloor data related to operations and machines so as to generate the informative or summarized results required by end users, such as machine utilization, job schedule and machine health indicators.
- Check machine alerts, errors, logs and anomalies periodically and automatically, and send respective notifications to CCE.

Table 1 lists the functions (i.e. APIs) of LCS for the interactive communication with shopfloor machines. These functions can be grouped into three categories, i.e. machine information and status enquiry, machine interactive control and shopfloor information enquiry. Through the APIs (1-5), several key machine information and status can be obtained including machine status, running program, working condition as well as machine controller interface. The functions (6-10) are provided to interactively control machines, including start or stop a NC program, adjust machining parameters like RPM and feedrate. The function 10 is developed to automatically scan shopfloor anomalies and machine errors and generate instant notifications and alerts. The function 11 is a method to enable end users directly talking to machine controllers by sending and receiving messages. The functions (12-15) deliver the general shopfloor information to end users, including shopfloor layout, machine list, machine utilization and job related data.

Table 1: list of the functions (APIs) of LCS

No.	Functions (API)	Command Intents
1	Machine status	To enquire machine status
2	Current program	To enquire current running program
3	Controller interface	To see instant CNC controller interface
4	Working condition	To enquire current RPM and feedrate
5	Coolant status	To enquire current coolant condition

6	Start operation	To start a specific machining program
7	Stop operation	To stop current machining program
8	Adjust feedrate	To adjust current machining feedrate
9	Adjust RPM	To adjust current machining RPM
10	Receive notification	To receive machine notifications
11	Talk to machine	To send/receive messages to/from machine controller
12	Shopfloor layout	To display shopfloor layout
13	Machine list	To list all shopfloor machines
14	Machine utilization	To enquire machine utilization
15	Job information	To enquire job information

IMPLEMENTATION AND RESULTS

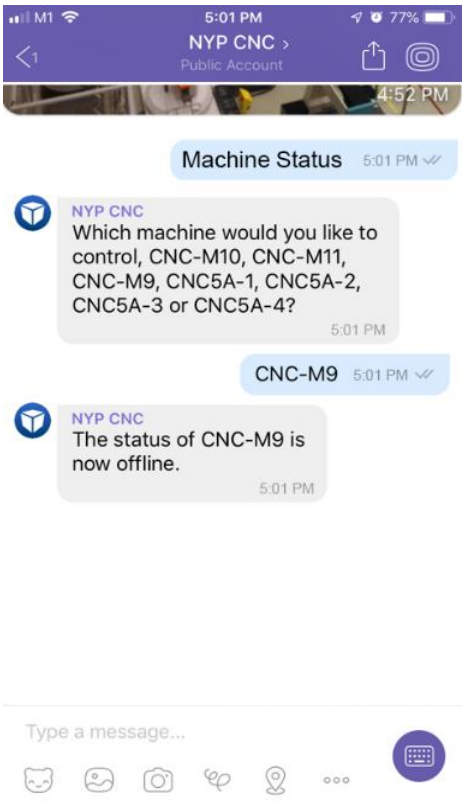
The natural language chat & control HMI platform has been developed and implemented at the manufacturing shopfloor of School of Engineering at Nanyang Polytechnic (NYP) as shown in Figure 3. This shopfloor comprises of diverse CNC machines from different makers and models (as shown in Table 2), and is suitable for the validation and benchmark of the presented HMI system.

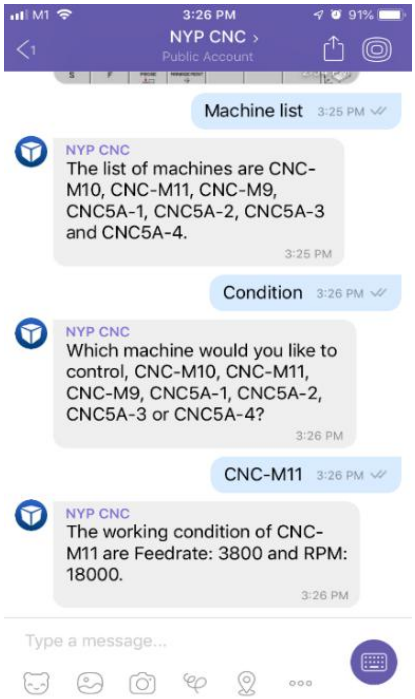
Figure 3: The manufacturing shopfloor of NYP

Table 2: List of the CNC machines at shopfloor

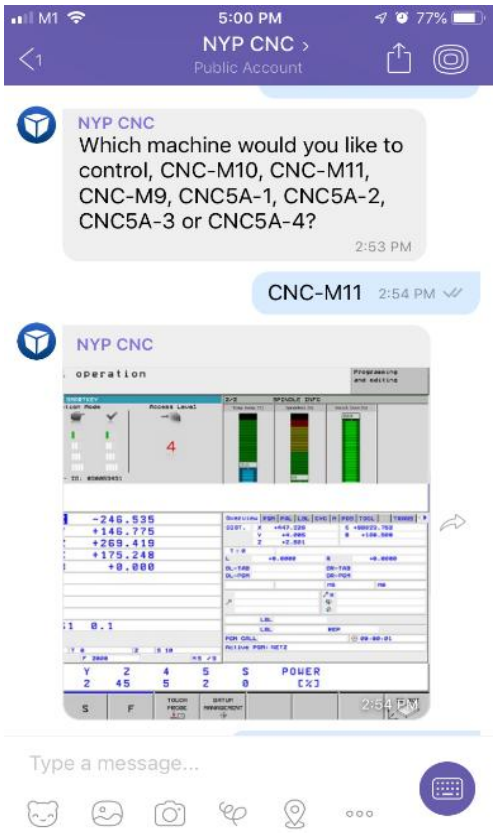
Index	CNC machines	Quantity
1	DMU 40 Evo (5 axis milling)	4
2	Mikron 400 U (5 axis milling)	1
3	Mikron 500 LP (3 axis milling)	1
4	Mikron HSM 400 (HSM milling)	2
5	DMU 50 Evo (5 axis milling)	1
6	Kern 500 Micro (micro milling)	1
7	Okuma LB3000 (turning)	4
8	Amada MS G3 (profile grinding)	1
9	Studer S31 (grinding)	1
10	Mazak I-200 (turn-mill centre)	2

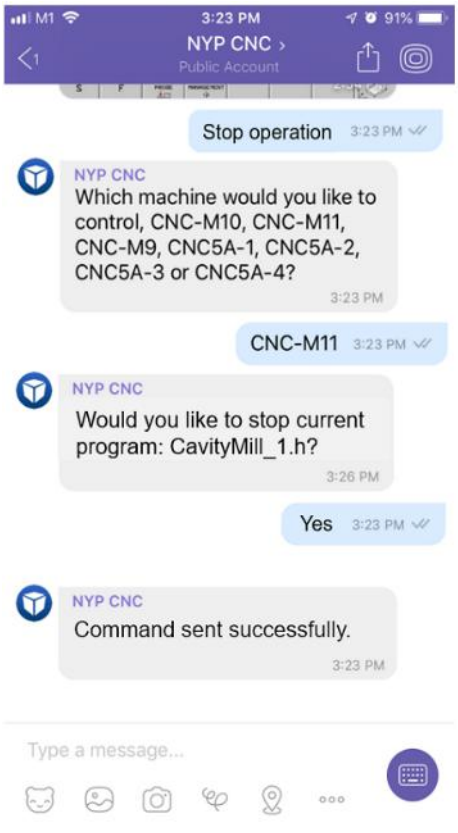
With Viber messenger platform, a chat group named “NYP CNC” was created to host the end users and shopfloor communication. With the current implemented functions (as listed in Table 1), end users can enquire machine, job and shopfloor information as well as control CNC machines via Viber chat HMI. Figure 4 shows several screenshots of the chat & control HMI for the remote access and control of shopfloor systems. Figure 4 (a) shows the shopfloor layout enquired by end users. Figure 4 (b) shows the machine list and the current status of a CNC machine. Machine working conditions (i.e. machining RPM and feedrate) can be obtained via chat HMI as shown in Figure 4 (c). In Figure 4 (d), the CNC controller interface of a machine is displayed at the chat messenger. Figure 4 (e) shows that a remote control command is sent to a CNC machine via Viber to successfully stop its current CNC program. Figure 4 (f) shows the ability of the chat HMI for the exception handling for the unknown inputs from end users. The chat CM will request for further clarification with given clues. Overall, the implementation results show the presented chat & control HMI leveraging on Viber messenger can access the instant information of shopfloor machines as well as remotely control the CNC machines of the shopfloor. The chat & control HMI eventually realized a convenient 2-way commination platform between end users and the shopfloor machines via mobile chat messenger.

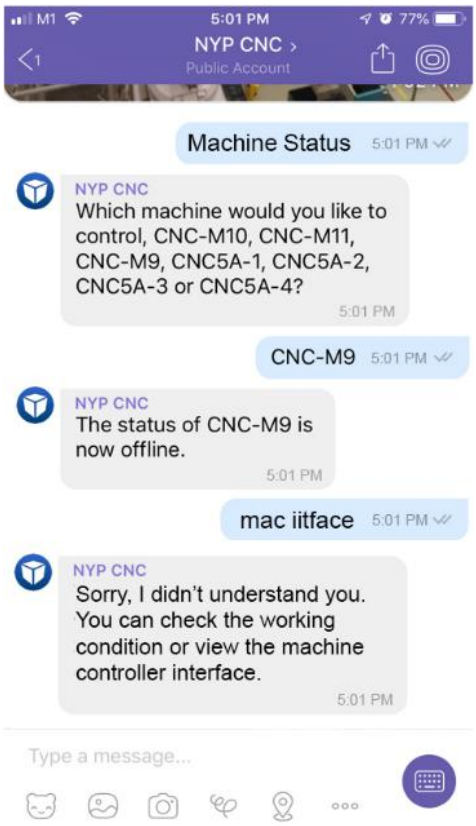




(a) shopfloor layout **(b) machine status** **(c) working condition**


M1
5:00 PM
77%
NYP CNC
Public Account
NYP CNC
Which machine would you like to control, CNC-M10, CNC-M11, CNC-M9, CNC5A-1, CNC5A-2, CNC5A-3 or CNC5A-4?
2:53 PM
CNC-M11 2:54 PM
NYP CNC
operation
Type a message...


M1
3:23 PM
91%
NYP CNC
Public Account
Stop operation 3:23 PM
NYP CNC
Which machine would you like to control, CNC-M10, CNC-M11, CNC-M9, CNC5A-1, CNC5A-2, CNC5A-3 or CNC5A-4?
3:23 PM
CNC-M11 3:23 PM
NYP CNC
Would you like to stop current program: CavityMill_1.h?
3:26 PM
Yes 3:23 PM
NYP CNC
Command sent successfully.
3:23 PM
Type a message...


M1
5:01 PM
77%
NYP CNC
Public Account
Machine Status 5:01 PM
NYP CNC
Which machine would you like to control, CNC-M10, CNC-M11, CNC-M9, CNC5A-1, CNC5A-2, CNC5A-3 or CNC5A-4?
5:01 PM
CNC-M9 5:01 PM
NYP CNC
The status of CNC-M9 is now offline.
5:01 PM
mac iitface 5:01 PM
NYP CNC
Sorry, I didn't understand you. You can check the working condition or view the machine controller interface.
5:01 PM
Type a message...

(d) CNC machine controller **(e) stop program** **(f) exception handling**

Figure 4: The implementation screenshots of the chat & control HMI

CONCLUSION AND DISCUSSION

This paper presented a natural-language chat & control HMI platform for manufacturing shopfloor. It has been implemented at the manufacturing shopfloor of Nanyang Polytechnic to realize the remote access and control of shopfloor systems via Viber chat messenger platform. Through the verification and validation, the chat & control HMI platform has shown a great enhancement of shopfloor efficiency and productivity with the below advantages:

- Realize the group sharing and communication over shopfloor matters via mobile messenger
- Easy use by non-technical people with natural language communication
- Realize a 2-way communication among end users and shopfloor facilities
- Receive instant shopfloor notifications and information via mobile messenger
- Realize the remote control of shopfloor facilities via mobile chat platform
- Enhance shopfloor management efficiency towards smart factory with mobile services

Cybersecurity and data protection are critical for the remote access and control of shopfloor machines via mobile devices. They are not the core topics and not discussed in detail in this paper. In fact, the three layers of cybersecurity methods were implemented to deal with the cybersecurity issues relevant to the presented chat and control HMI for manufacturing shopfloor. Firstly, Nanyang Polytechnic (NYP), as a Singapore government institute, must apply "Singapore's Cybersecurity Strategy" at the whole campus. Secondly, the development and deployment of mobile apps must comply with three NYP's policies (i.e. "Policy on Network Security", "Policy & Procedure on Mobile Apps Deployment & Decommission" and "NYP Firewall Policy") for cybersecurity and data protection. Moreover, a real-time cybersecurity module, called "Data-driven cyber-attack damage and vulnerability evaluation for manufacturing systems", is running at the manufacturing shopfloor to monitor the real-time Damage Index (DI) and Composite Vulnerability Index (CVI) of all CNC machines. All these methods assist in protecting the chat and control HMI from potential cybersecurity issues to certain extent.

Moreover, machine safety is also important for the Chat & Control HMI especially for remote machine control. The future work could aim to two methods to enhance the safety protection level of the Chat & Control HMI. One is to control users accessing remote functions with properly administrative rights. The other is to apply the real-time monitoring of machine actions by integrating Digital Twin [19] with the Chat & Control HMI in order to avoid any unexpected situations and misbehaviours.

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REFERENCES

[1] Alison Coleman. How to increase efficiency in production, Future of Manufacturing 2016, Nov. 22, 2016

[2] James Hoerig. Visibility & Efficiency: Why shop floor control is key to manufacturing success, VP Manufacturing, CGS - 12/21/2015

[3] R. Teti, K. Jemielniak, G. O'Donnell, D. Dornfeld. Advanced monitoring of machining operations. CIRP Annals-Manufacturing Technology, Vol. 59, 717-739, 2010

[4] Mourtzis, E. Vlachou, N. Milas, N. Xanthopoulos. A cloud-based approach for maintenance of machine tools and equipment based on shopfloor monitoring, Procedia CIRP 41, 655 – 660, 2016

[5] Dr.-log. Klaus Wucherer. HMI, The window to the manufacturing and process industry, IFAC Analysis, Design and Evaluation of Human-Machine Systems, Kassel, Germany, 2001

[6] HMI - Natural language User Interfaces. http://www.talp.upc.edu/EXPERTISE-AREA-DETAIL/431/HMI, accessed Oct. 10, 2018

[7] Prakash M Nadkarni, Lucila Ohno-Machado, Wendy W Chapman. Natural Language Processing: an introduction, J Am Med Inform Assoc. 2011 Sep-Oct, 18(5): 544–551. 2011

[8] Natural Language Processing (NLP) techniques for extracting information, "Cruising the Data Ocean" blog series - Part 4 of 6 ESSENGE, https://www.searchtechnologies.com/blog/natural-language-processing-techniques, accessed Oct. 10, 2018

[9] A. A. Sattikar, R. V. Kulkarni. Natural Language Processing for content analysis in social networking, International Journal of Engineering Inventions, ISSN: 2278-7461, Volume 1, Issue 4, PP: 06-09, Sep. 6, 2012

[10] Cloud Natural Language, https://cloud.google.com/natural-language/, accessed Oct. 10, 2018

[11] HMI development with virtuosity automation, http://virtuosityautomation.com/services/hmi-development/, accessed on Oct 2018

[12] The CompanyMessenger in the Industry 4.0, https://company-messenger.com/, accessed Oct. 10, 2018

[13] HMI: New ways to chat with your machines, industry 4.0, our highlight, Jan. 2016 http://emag.directindustry.com/article-long/hmi-new-ways-to-chat-with-your-machines/, accessed Sep. 6, 2018

[14] Viber REST API, https://developers.viber.com/docs/api/rest-bot-api/, accessed Mar. 15, 2018

[15] Unification Engine, https://www.mobileforcesoftware.com/sites/default/files/mobileforce_unification_engine_databrief_v17.1.pdf, accessed Mar. 15, 2018

[16] UE messaging API, UE AI API, https://uib.ai/developer-api/, accessed Mar. 15, 2018

[17] MTConnect overview, http://mtconnect.org/index.php?option=com_content&task=blogcategory&id=0&Itemid=26, accessed Mar. 15, 2018

[18] DNC connectors, https://en.wikipedia.org/wiki/Direct_numerical_control, accessed Mar. 15, 2018

[19] Gartner's Top 10 Strategic Technology Trends for 2017, https://www.gartner.com/smarterwithgartner/gartners-top-10-technology-trends-2017/, accessed Oct. 10, 2018