NanoPC ARM-Based Panel Saw Machine with Industrial Internet of Things

Mohannad Farag
Faculty of Engineering Technology, Universiti Malaysia Pahang, 26600 Gambang, Kuantan, Pahang, Malaysia
Email: mohanadfaraj@gmail.com

Ehsan Aboosaeedan and Eugene Ng Keng Leong
Formahero Machinery Sdn Bhd, Bandar Bukit Beruntung, 48300 Rawang, Selangor, Malaysia
Email: ehsan.aboosaeedan@gmail.com, eugene.nkl@gmail.com

***Abstract*—Panel saw machines are available in different shapes and sizes, from small hand-held power saw machines to floor-mounted types. Floor-mounted machines comprise of a loading station and cutting surface where panels are transferred from the loading to the cutting station. Cutting wooden panel problem in furniture industry is one of the highest computation complexity optimization problems and belongs to rectangular layout problem. In this paper the mechanical design of floor-mounted panel saw machine is proposed. NanoPC ARM-based control system design with IIoT applications for remote and real-time monitoring, diagnostic and Machine-to-Machine (M2M) interfacing are described. The results of the cutting process are evaluated and discussed with achieved cutting size error less than 0.2 mm. In addition, the cutting wastage reduction and the cutline quality have been improved to 90% and 91% respectively based on the results of customer satisfaction survey.**

***Index Terms*—panel saw, ARM controller, NanoPC, Industrial Internet of Things**

I. INTRODUCTION

Panel saw machines are available in different shapes and sizes, from small hand-held power saw machines to floor-mounted types [1]. Floor-mounted machines comprise of a loading station and cutting surface where panels are transferred from the loading to the cutting station [2]. Cutting wooden panel problem in furniture industry is one of the highest computation complexity optimization problems and belongs to rectangular layout problem [3], [4]. Therefore, solution techniques to minimize wasted material and optimize cutting results are highly needed such as genetic algorithm [5]–[7].

Programmable Logic Controller (PLC)-based cutting machines may provide a part of these solutions [1], [8] but at higher designing and development cost compared to nanocomputer (NanoPC)-based machines. In addition, NanoPC-based systems increases the system adaptivity in terms of hardware platforms, programming languages and communication protocols at high-speed rates for Industrial Internet of Things (IIoT) applications [9], [10].

In this paper the mechanical design of floor-mounted panel saw machine is proposed in Section II. NanoPC ARM-based control system design with IIoT applications are described in Section III. Section IV discusses the results and the paper is concluded in Section V with future work suggestions.

II. MECHANICAL DESIGN

The mechanical structure of the panel saw machine is indicated in Fig. 1. This design allows the wood panel to be fed through three float tables into the main body shown in Fig. 2. Tow-Degrees of Freedom (DOF) side aligner helps to position the panel at the zero point of cutting line while the pressure beam holds the panel during the cutting process. The position of the circular saw blade can be controlled according the desired cutting width by moving the saw carriage using a servo motor.

The saw carriage mechanism, as shown in Fig. 3, contains two blades, main blade and scoring blade. These two blades are rotated in opposite directions to avoid chipping. In addition, the saw carriage allows can be moved up and down using a pneumatic cylinder to hide or unhide the saw blades for safety purpose.

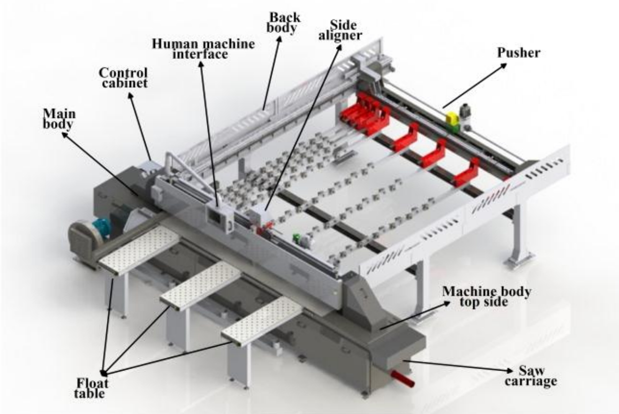

Figure 1. The mechanical structure of the panel saw machine

Manuscript received August 7, 2018; revised July 17, 2019.
This work is registered under the Intellectual Property Corporation of Malaysia (MyIPO), Patent No. PI2018001384, August 1, 2018

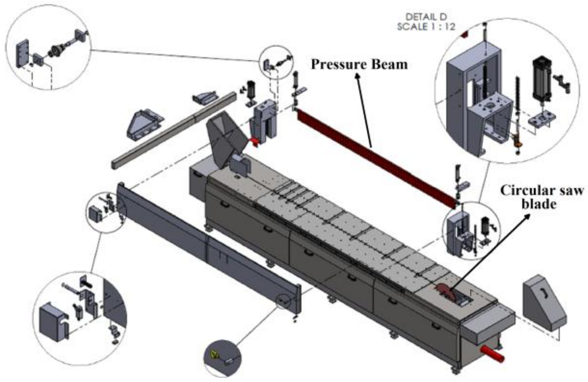

Figure 2. The top side of the panel saw machine

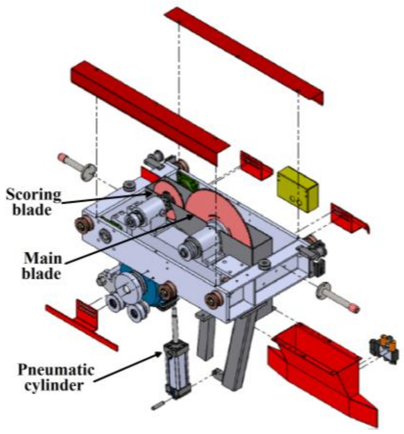

Figure 3. Saw machine mechanism

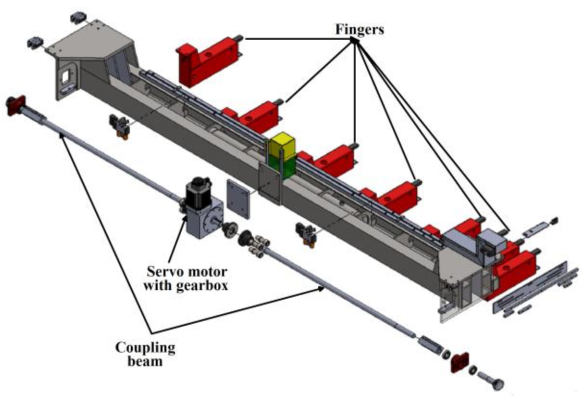

Figure 4. The pusher at the back side of the machine

Fig. 4 shows the pusher at the back side of the machine equipped with eight single-DOF pneumatic fingers and one servo motor with a gearbox. According the illustrated machine structure the saw carriage can be moved up and down for safety purpose. and positioned from home position to the cutting point. The circular saw blade can be turned on and off to start cutting process. Using 2-axis side aligner the panel can be aligned to the zero point while the pressure beam is used to hold the panel during the cutting process. The float table, shown used to feed the panel and the pusher to push the panel to the pre-determined positions by holding the panel using multiple fingers and moving the pusher forward

During the cutting process, the pusher holds the wood panel and move it forward to cutting surface at the main body, shown in Fig. 2, for a certain distance according the desired cutting settings. Cutting process can be controlled and monitored either locally through the Human Machine Interface (HMI) or remotely through IIoT applications. Table I shows the technical specifications of the panel saw machine.

TABLE I. TECHNICAL SPECIFICATIONS OF THE PANEL SAW MACHINE

Maximum length of cut	3150 mm
Maximum thickness of cut	100 mm
Main saw blade diameter	400 mm
Scoring saw blade diameter	180 mm
Saw blade motor	13.4 kW
Saw carriage motor	2 kW
Pusher servo motor	1 kW
Air blower	5 HP
Floating table (three sets)	400 x 1200 mm
Working air pressure	5.5-6 bar
Pusher speed	0-38 m/min
Saw carriage speed	0-60 m/min
Machine dimension	5950 x 5700 x 3510mm
Gross weight	4500 kg

III. NANO PC ARM-BASED CONTROL DESIGN WITH IIOT

Many recently proposed industrial solutions utilize either PLCs or powerful computers to process a huge size of data and graphs. Their usability and flexibility often come at a high cost [11]. The recent promising researches successfully achieved the building of Low-cost NanoPCs [12], [13] such as ARM-based NanoPC.

A. NanoPC ARM-Based System Configuration for IIoT

Fig. 5 illustrates the smart system configuration of the NanoPC ARM-based panel saw. This configuration improves the cutting process and implements the Industrial Internet of Things (IIoT) for remote Machine-to-Machine interface [14]. By this type of interface, the machines can exchange the data and synchronize in the whole process. Full remote access and high-speed communication, through either 4G or LAN internet connection, enable the remote diagnostic, maintenance, update, real-time status monitoring and fault notification.

For adaptive system configuration, the remote i/o is used for data acquisition and controlling the actuators. In addition, the system configuration can be expanded with the standard Machine-to-Machine (M2M) interfacing where different off-the-shelf peripherals can be connected to the machine. Panel cut optimization algorithm is improved to achieve an advanced nesting results reducing the wastage cut-off material and to decrease the total cut length [15]

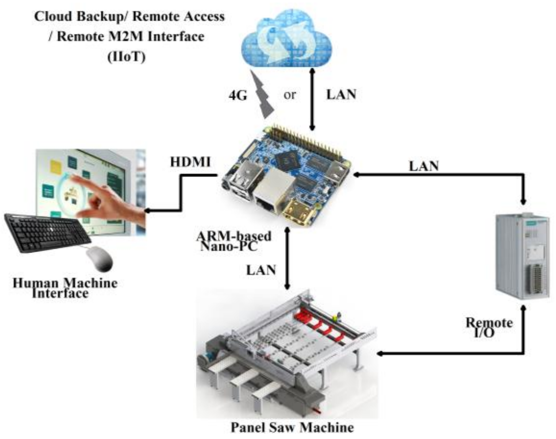

Figure 5. System configuration of NanoPC ARM-based panel saw

Using ARM-based Nano-PC with the remote i/o reduces the cost of designing and developing the control systems compared to PLC-based control systems. In addition, ARM-based Nano-PC increases the system adaptivity in terms of hardware platforms, programming languages and communication protocols.

B. Servo Drives System Configuration

Servo drives system at the machine is fully controlled by the ARM-based Nano-PC using the serial Modbus RS-422 communication protocol. Two Mitsubishi servo drives MR-J4-A-RJ series are used, one for the pusher and the other one for the saw carriage. With fully closed loop positioning control mode the cutting size accuracy can be highly improved using a load side linear encoder. Fig. 6 shows the configuration diagram of the servo drive system.

C. Java Code for Machine Control

Fig. 7 shows the machine user interface with multiple options. As the control architecture of the machine is modular, the control process is based on Stateflow. The code is comprised of multiple threads which are running simultaneously to communicate with all the modules, sensors, drives and the interface. Each thread has access to global flags defined in the code. However, the main thread reads the flags and decides on the current State of the machine and plans the next State. By switching the State, machine proceeds to next task while threads read the sensors and modules and report back the ongoing process constantly to the main thread. Meanwhile, if any thread detects fault in its ongoing task, it will raise the emergency stop flag to put all the other threads on hold. The outcome of this teamwork is a redundant control process.

The HMI is designed to be a colorful user-friendly. The hierarchical design of the HMI is in a way to imitate a daily notebook with different sections for tasks. Hence, each category of functions is grouped inside a sub-tab and each sub-tab contains multiple tabs to deliver the functions of the machine, accordingly. As a result, user always can see the where he's standing and can find the way back to other functions. Similarly, the graphical objects have been designed to mimic the real objects can be found in industries, e.g. buttons, knobs, etc. Likewise, each object is tagged with label while depicted with a familiar logo.

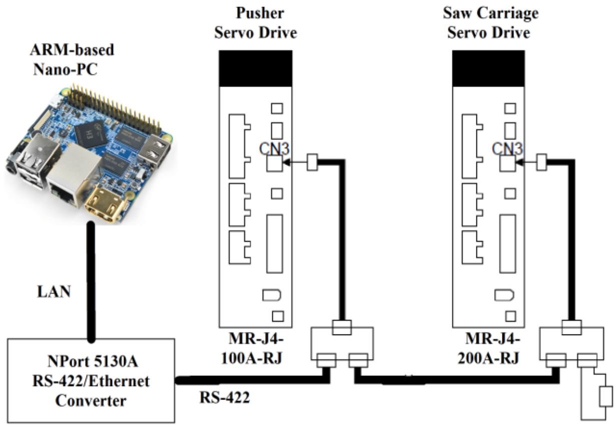

Figure 6. Servo drive system configuration diagram

Figure 7. User Machine Interface

The control code is written in Java language and targeted for Android OS and the HMI is written in XML and bounded to the main Java code.

IV. Results and Discussion

In this section the results of the cutting process are evaluated and discussed based on the measurement of the cutting size error and the customer satisfaction survey.

A. Cutting Size Error

The evaluation protocol is defined by measuring the actual cutting dimensions (length, width and diagonal) of the 37 wood panels with varied sizes. Then, the Root Mean Square Error (RMSE) is calculated based on the following formula

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(x_{r_i} - x_i\right)^2}{n}} \tag{1}$$

where x_{r_i} is the reference value and x_i is the achieved value.

Fig. 8 shows the RMSE column chart of the length, width and diagonal of the wood panels. The results show that the diagonal has the lowest RMSE at 0.05 mm, while the RMSE of the length and the width are 0.14 mm and 0.19 mm respectively. These results can guarantee the cutting resolution less than 0.2 mm.

B. Customer Satisfaction Survey

Satisfying customers is a fundamentally sound principle. Surveys provide an official feedback to a firm and give a positive signal to customers that the firm is interested in them [16]. As the primary commitment of a company is satisfying customers, a satisfaction survey has been designed based on industrial needs to produce high-end products. The feedback from 15 industrial companies is analyzed and summarized into three categories: cutting performance, user interface and machine functionality as shown in Fig. 9, Fig. 10 and Fig. 11 respectively.

The results show that the cutting wastage reduction and the cutline quality have gained the most satisfaction percentage with 90% and 91% respectively. This is because of using an advanced algorithm for nesting calculation such as genetic algorithm [5]–[7] and the precise mechanical structure of the cutting surface and the saw carriage. Service notification feature and graphical view have come at the end of the list with satisfaction percentage of 52% and 54% respectively. This reflects the improvement needs of these features.

By calculating the average of the satisfaction percentage of the three categories Fig. 12 will be resulted. According this result, the cutting performance has the highest percentage with 83% while the user interface has the lowest percentage with 66%. This suggests putting more efforts to improve the user interface specifications.

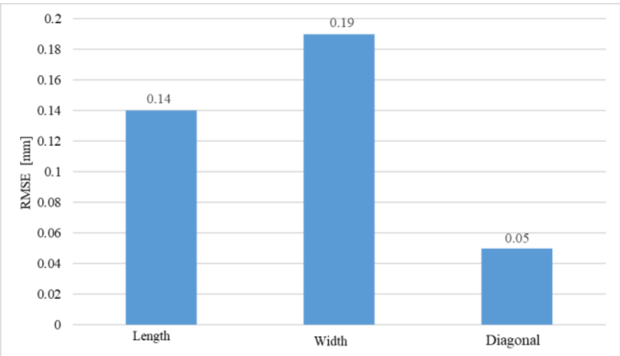

Figure 8. Root Mean Square Error of the wood panels' dimensions.

Figure 9. Cutting performance

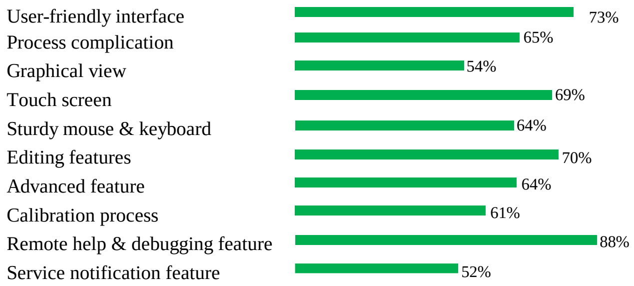

Figure 10. User interface

Figure 11. Machine functionality

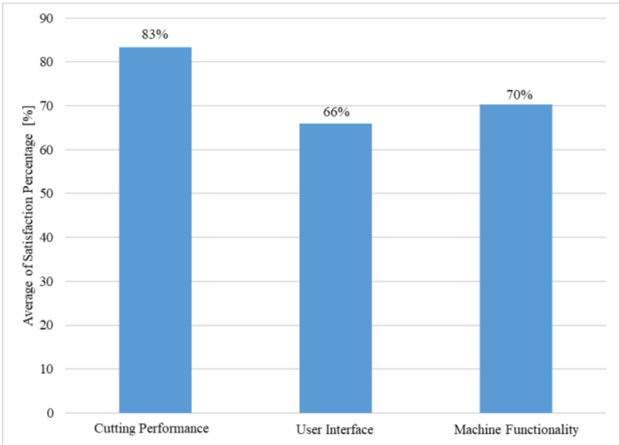

Figure 12. The average of satisfaction percentage

V. Conclusion and Future Work

This paper illustrated the proposed mechanical design of floor-mounted panel saw machine. NanoPC ARM-based control system design with IIoT applications were described for remote and real-time monitoring, diagnostic and Machine-to-Machine (M2M) interfacing. The cutting size error results can guarantee the cutting resolution less than 0.2 mm. Based on the results of customer satisfaction survey, the cutting wastage reduction and the cutline quality have gained the satisfaction percentage of 90% and 91% respectively.

For future work, the user interface features can be improved especially service notification feature and graphical view. In addition, the machine functionality can be improved to include adjustable cutting depth and label recognition techniques.

References

[1] R. Gadale, M. Pisal, S. Tayade, and S. V Kulkarni, "PLC based automatic cutting machine," *Int. J. Eng. Tech. Res.*, vol. 3, no. 3, pp. 280–282, 2015.

[2] W. Naldi, "Panel cutting machine," 5,850,774, U.S. Patent, December 22, 1998.

[3] Z. Tao, "TSP problem solution based on improved genetic algorithm," in *2008 Fourth International Conference on Natural Computation*, 2008, pp. 686–690.

[4] S. M. A. Suliman, "A sequential heuristic procedure for the two-dimensional cutting-stock problem," *Int. J. Prod. Econ.*, vol. 99, no. 1–2, pp. 177–185, Jan. 2006.

[5] Q. Yue and S. Liang, "Research on the application of genetic algorithm for the panel cutting stock," in *2011 International Conference on System Science, Engineering Design and Manufacturing Informatization*, 2011, no. 5, pp. 214–217.

[6] H. C. Lu and Y. H. Huang, "An efficient genetic algorithm with a corner space algorithm for a cutting stock problem in the TFT-LCD industry," *Eur. J. Oper. Res.*, vol. 246, no. 1, pp. 51–65, Oct. 2015.

[7] J. F. Tsai, P. L. Hsieh, and Y. H. Huang, "An optimization algorithm for cutting stock problems in the TFT-LCD industry," *Comput. Ind. Eng.*, vol. 57, no. 3, pp. 913–919, Oct. 2009.

[8] S. Sahu, S. K. Behera, and A. K. Dey, "A review of automated profile cutting machine using PLC," *Int. J. Digit. Appl. Contemp. Res.*, vol. 3, no. 10, 2015.

[9] M. S. Hossain and G. Muhammad, "Cloud-assisted Industrial Internet of Things (IIoT) - enabled framework for health monitoring," *Comput. Networks*, vol. 101, pp. 192–202, Jun. 2016.

[10] Y. Liao, E. de F. R. Loures, and F. Deschamps, "Industrial Internet of things: A systematic literature review and insights," *IEEE Internet Things J.*, pp. 1–1, 2018.

[11] B. Rainey and D. F. Gleich, "Massive graph processing on nanocomputers," in *2016 IEEE International Conference on Big Data (Big Data)*, 2016, pp. 3326–3335.

[12] S. C. Lee and L. R. Hook, "Towards the design of a nanocomputer," in *Canadian Conference on Electrical and Computer Engineering*, 2007, pp. 74–77.

[13] B. Trybus and M. Wietecha, "Low-cost multifunction controller prototype for sawmill wood processing," in *Challenges in Automation, Robotics and Measurement Technique*, Springer, Cham, 2016, pp. 309–318.

[14] P. P. Ray, "A survey on Internet of Things architectures," *Journal of King Saud University - Computer and Information Sciences*, vol. 30, no. 3, Elsevier, pp. 291–319, 01-Jul-2016.

[15] M. Çolak and T. Çetin, "Waste management in the industry of small and medium sized Turkish furniture enterprises (SMEs)," in *International Symposium on New Horizons in Forestry (ISFOR 2017)*, 2017.

[16] R. A. Peterson and W. R. Wilson, "Measuring customer satisfaction: Fact and artifact," *J. Acad. Mark. Sci.*, vol. 20, no. 1, pp. 61–71, Dec. 1992.

Mohannad Farag received his BSc. in Electronics Engineering from Damascus University in 2002 and MSc. degree in Mechatronics Engineering from International Islamic University Malaysia in 2016. After receiving his education, Mohannad worked as a technical manager with the Telecom Customer Service Centre in Damascus, Syria. Later he worked with Damascus Training Centre as a Mechatronics Technical Instructor until 2015. Currently, Mohannad is a Ph.D. candidate with Faculty of Engineering Technology at Universiti Malaysia Pahang. His research interests include robotic grasping systems, industrial control systems and computer vision-based robotic applications.

Ehsan Aboosaeedan gained his BSc. in Electronics Engineering from K. N. Toosi University of Technology, Tehran, Iran on 2006 and MSc. degree in Mechatronics Engineering from K.N. Toosi University of Technology, Tehran, Iran on 2009. He's a holder of multiple international awards in in Rescue Robot League of International RoboCup Competitions and ex-technical committee member of RoboCup federation. His field of interest is mobile robotics, embedded control systems and RPA development. He is currently the CTO of Formahero Machinery Sdn. Bhd. in Malaysia.

Eugene Ng gained his BSc. in Mechanical & Manufacturing Engineering from University of Melbourne in 2007. Currently, he is the Director and TechnoFund Project Leader with Formahero Machinery Sdn Bhd.