Workpiece Handling System using 6-DOF Manipulator Robot for CNC Lathe Machine

Thomas Simajaya[1], Christiand[1], Anthon De Fretes[1]
[1]Mechanical Engineering Department, Atma Jaya Catholic University of Indonesia
E-mail: christiand@atmajaya.ac.id

ABSTRAK

Sistem pengumpan benda kerja berbasis robot manipulator 6-DOF bertujuan untuk meningkatkan produktivitas pada proses berbasis bubut menggunakan CNC. Sistem ini terdiri dari aktuator pneumatik, robot, control unit, dan sensor-sensor yang didedikasikan untuk mengumpan/menangani benda kerja di mesin CNC. Program yang ditanamkan kedalam sistem dapat membantu operator (manusia) dalam proses pemasangan benda kerja pada mesin CNC melalui kerja sebuah robot manipulator. Eksperimen untuk mengukur kinerja sistem dalam mengumpan benda kerja pada mesin bubut CNC telah dilakukan melalui 4 sesi eksperimen dimana pada setiap sesi diambil 100 data terkait proses pemasangan maupun pengambilan benda kerja.

***Kata Kunci**: Robot manipulator, CNC, Manufaktur, Sistem pengumpan, Electro-pneumatik.*

ABSTRACT

The workpiece handling system using 6-DOF manipulator robot is aimed to increase the productivity of turning process using CNC machine. This system consists of pneumatic actuators, robot, control units, and sensors that are dedicated to handle workpiece in CNC machine. The program installed on the system can help operator (human) in handling the workpiece by regulating the work of manipulator robot. Experiment to measure the performance of the system in handling the workpiece to CNC lathe machine has been done in 4 sessions of experiment. Each session took 100 data related to handling process of workpiece, i.e. attaching and detaching.

***Keywords:** Manipulator robot, CNC, Manufacturing, Handling system, Electro-pneumatic.*

1. INTRODUCTION

In this modern era, technology to automate the manufacturing process is getting more sophisticated and influencing many fields. One example of that technology is the use of robots in manufacturing [1]. Robots can assist or even further replace the human operator in doing tasks in manufacturing. This is particularly true when it comes to the works that require higher degree of accuracy and precision. Furthermore, robots can be very suitable for high-risk tasks where human safety becomes main concern. The use of robots in industry today is already a real thing. The wish of many robot users is to improve the efficiency, productivity, and quality but at the same time also minimize the risks of the jobs [2].

In the other side, CNC (computer numerical control) machine is also another technology advancement that gives big impact to manufacturing area [3]. CNC machine can produce products with high accuracy that reaches the level of micrometer. In a CNC-based manufacturing, an operator (human) is responsible to execute the CNC program and placing the workpiece on the CNC machine (for example: placing workpiece in spindle for turning process). The accuracy of workpiece handling by operator affects so much the quality of the final products. Therefore, regardless the high accuracy of CNC machine, human factor needs to be considered very carefully. Eventually, this brings us to the idea of using robots for workpiece handling together with CNC use for manufacturing. The idea of using robot to handle workpiece/goods is similar to previous researcher [4, 5]. Instead, the domain of application in this work is turning process in using

CNC machine.

Turning process is common process in manufacturing. Turning process is defined as a process to reduce the diameter of shaft by using turning machine (lathe machine). The workpiece should be attached or fed into the spindle where the workpiece is rigidly held. In the real case of manufacturing, human operator produces inaccuracy during the placement of workpiece. The common inaccuracy occurs in the axial direction of spindle. Generally, the tolerance of workpiece placement in axial direction ranges from 5-10 mm. To achieve the requirement of tolerance, the workpiece handling system should be improved by using robot as workpiece handler instead of human.

This paper reports the development of workpiece handling system using 6-DOF manipulator robot for CNC lathe machine. The system design is explained through the functionality of each components. The experiment has been conducted to measure the performance of the system in terms of accuracy and cycle time of attaching/detaching process.

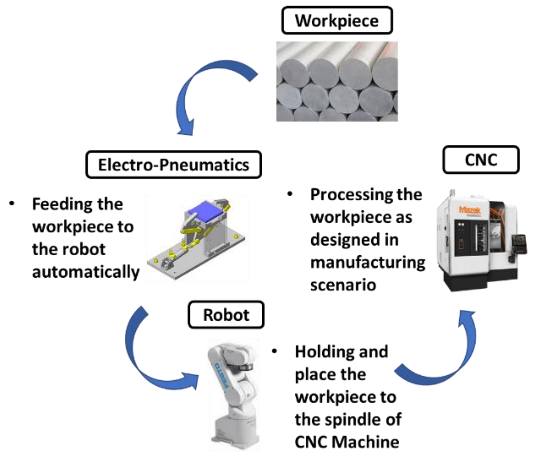

Figure 1. The steps for the workpiece to be process in CNC lathe machine

2. COMPONENTS OF SYSTEM

System consists of three components: robot, electro-pneumatics, and CNC lathe -machine. Specific role of each component can be seen in Fig.1.

Robot

The type of robot used in the design is a manipulator robot that is MELFA RV-2FB from Mitsubishi Electric. This robot is a manipulator robot with 6 joints servo motor categorized as industrial robot. The category of industrial robot confirms that this robot has the required specifications for industrial use, both in terms of performance (movement precision), and durability. In terms of specifications, this robot has a maximum carrying capacity of 2 kg, a maximum radius ranges of 504 mm and is equipped with a CR750-D type control unit [4].

The CR750-D control unit uses the MELFA-BASIC V programming language and is capable of processing 256 inputs and 256 outputs (using additional options). The specification makes it possible to use a CR750-D control unit for a fairly complex automation system when viewed from the large number of I/O supplied. The accuracy of the end-effector position is up to 0.1 mm in robot working space. This accuracy is due to the limitation of encoder in detecting the changes of motion.

Electro-Pneumatics

Pneumatic is one of the medium to transmit power by using pressurized air. In the process, the pressurized air is first dried to reduce the water content in it. Pneumatic systems commonly used in industry are powered by compressed air or inert gas. Similarly, the electro-pneumatic system itself is combination of electronics as logic and pneumatic (pressurized air) as the primary source of energy.

Electro-pneumatic system offers several advantages compared to electric-motor, such as cheaper operational cost, more safety, and flexibility. In electro-pneumatics, the solenoid is the main component used to drive the control valve. In the electro-pneumatic valve, the solenoid-generated magnetic field is used to control the metal pistons that regulate open-close airflow.

CNC Lathe Machine

The CNC lathe machine is a lathe machine that operates based on numerical code and controlled by numerical control unit. The advantages of CNC are automatically operated, more accurate, consistent, and flexible, even though for very complex manufacturing processes. The design of the product can be changed or adjusted simply by changing the instructions in numeric code. CNC lathe machine is capable to produce 1 micron (0,001 mm) accuracy. A CNC lathe machine can be used for various types of workmanship. At every turn of process, the numerical code (command) can be executed very fast. The program is stored on the computer memory on the machine. Then, the program can be called "instantly" when the process starts to be executed. In this research work, CNC lathe machine is Mazak Quick Turn Nexus 200- II MY.

3. SYSTEM DEVELOPMENT

Required Specification

In the design of workpiece handling system based on MELFA RV-2FB robot (Fig. 2), the specifications of the workpiece and the related tasks must be defined in advance. In accordance to the specified limits, the workpiece has dimensions of diameter 9,5-10 mm, length 4,7-5 mm, and made from metal material. Metallic material can be steel, aluminum, or alloys. In this research work, aluminum was chosen as the workpiece material because the aluminum material has the lowest abrasive resistance. That aluminum characteristic is suitable to conform the material of gripper and magazine. The surface hardness of workpiece should exceed the surface hardness of magazine or gripper. Otherwise, the workpiece may be worn off by magazine or gripper during contact.

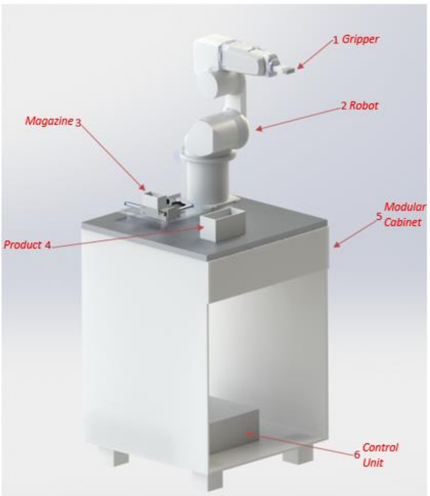

Figure 2. Workpiece handling system

In term of designed tasks, the handling system should be able to assist human operator to perform two activities, i.e. material sorting and feeding. To achieve that goal, supporting actuators were developed. For the clarity, these supporting actuators were named gripper and magazine (Fig. 3). These supporting actuators can provide the best result in terms of performance (accuracy and speed), durability, and design simplicity. The collaboration between supporting actuators and robot produce the high quality of handling task (i.e. feeding and sorting workpiece)

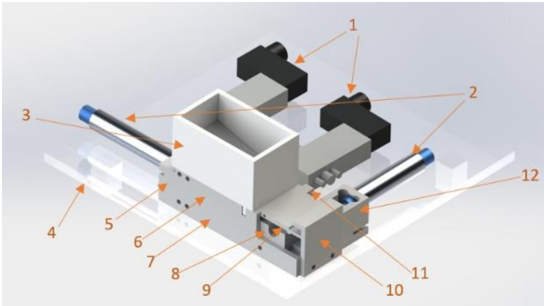

Figure 3. Additional actuators design (magazine)

To plan the working scenario of handling system, the environment is layout-ed using CAD models of robot, supporting sub-systems, workpiece, and other objects in working space. This layout becomes the reference for path planning of the robot and design of feeding motion. Layout of the environment can be seen in Fig. 4.

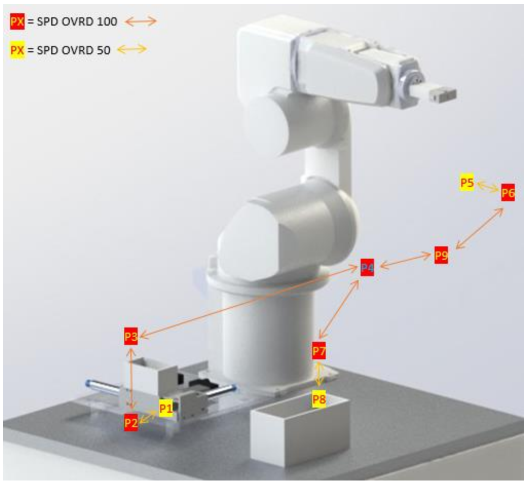

Figure 4. Path of robot end-effector

Programming the System

The motion of the robot is programmed through CIROS® Software created by Festo. The programming language is Melfa Basic V which is one of the programming languages of Industrial Robot Language (IRL). The robot is programmed by PTP (Position To Position) concept where the end-effector is the controlled point. To define the working scenario of the handling system, two information are required, i.e. program data and positions list. While the positions list shows the positions of end-effector, the program data dictates the logic of handling system (e.g. sequence of task).

Each desired end-effector coordinate is stored in the table of positions list and given simple naming rule such as P1, P2, etc. Each position reflects the location of the end-effector of the robot in working space as depicted in Fig. 3. The values of robot joints from Inverse Kinematics are calculated automatically by the software. The joint control is also performed by software and its integrated module. In addition, the available I/O in the module can be managed and programmed using software. I/O itself can be integrated to create robot motions or logic of the handling system by control commands. Marking the end-effector is performed by Teach-In process. The accuracy of the end-effector position is up to 0,1 mm in robot working space.

As the part of algorithm design, the definition of each task is necessary since the task involves human and handling system (robot, actuators, and module). Therefore, both task definition and task sequence should be well prepared, as seen in Table 1. However, due to limitation of system, there some processes are still handled fully by human.

Table 1. Comparison of Conventional and Proposed System

Process	Conventional	Proposed
Door Open	Human	Human
Wp. Attach	Human	System
Wp. Dettach	Human	System
Chuck	Human	Human
Turning	Human	Human

* Wp = Workpiece

During the attaching-process of workpiece, the system takes the role of the human operator in placing the workpiece on the spindle, 40 mm in the axial direction. In conventional method, the human operators manually place the workpiece by their hand. Upper body of the operator enters the CNC area to access the spindle area. In proposed handling system, the robot motions replace the hand movements of the operator in placing the workpiece. Half of the robot enters the CNC work area to access the spindle area.

The concept of role replacement in detaching-process of workpiece is exactly same as in attaching-process of workpiece, except that the sequence of motions is the backward sequence of attaching sequence.

The operator in the flow diagram of Figure 5 starts the process by assigning input to the system and press the key button to run the sequence of the program.

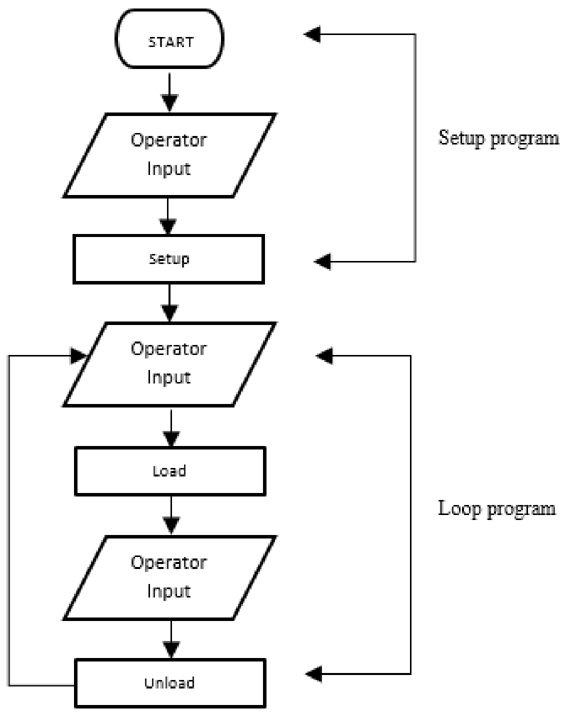

Figure 5. Flowchart of System Procedures

4. EXPERIMENT AND RESULT

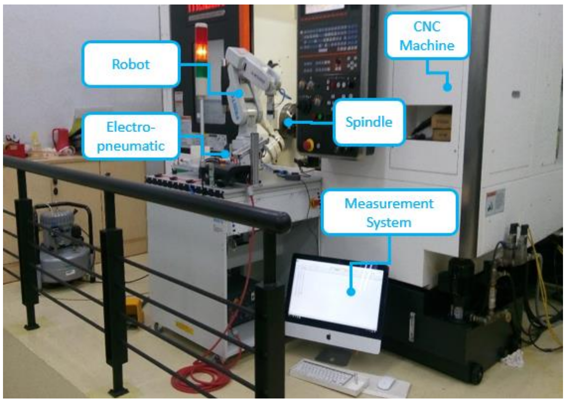

Figure 6. Experiment layout

The experiment collected 100 data samples from 4 sessions. A digital dial gauge was used to measure the deviation of workpiece position with respect to the reference position. The reading of measurement is automatically saved into the computer.

Data collection of 100 samples also represents the durability of supporting actuators. During the experiment, the data was taken repeatedly without intermediate stop between the process as long as there are no failure or emergency conditions. 6 hours experiment was performed without termination of the program. Overall, the durability of the supporting actuators was concluded to be good since it has never failed during the operation.

The experiment was divided into 4 sessions of experiment to reduce the possibility of measurement error due to possible shifted position of dial gauge. This may happen since the dial gauge holder was a magnetic block that can suffer of sliding motion caused by uncounted external forces or vibrations. For every session, the dial gauge position was re-calibrated.

The experiment result shows the variation of distance between real and reference workpiece position. The largest range can be seen from data session No. 1, that is 0,207 mm with a variance of 0,062 mm. From the result, it can be concluded that the proposed handling system can achieve maximum inaccuracy of feeding operation as big as 0,2 mm. The proposed system can outperform the conventional method that requires human operator to set a clearance distance about 0,5 mm before turning process begins. The 0,5mm clearance distance is the traditional guideline without further technical analysis that operators “guess” to produce safe operation during attaching process. 0,5mm is believed to be convenient enough for operator to see the clearance by naked eyes. The result gives hope for improvement of feeding process efficiency since the clearance distance is reduced by 0,3 mm. The clearance distance is the safe position where the tool (insert) starts the feeding process without collision to the workpiece. However, bigger clearance distance means that unnecessary feeding motion occurs before the tool gives the real work on the workpiece. This unnecessary feeding motion can be actually reduced by lowering the clearance distance. However, one cannot arbitrarily set the clearance distance since the clearance distance itself represent the uncertainty (accuracy) of placing the workpiece in the spindle. Lowering the clearance distance without paying attention to the accuracy of placing the workpiece on the spindle will result the chance of tool-workpiece collision. Result shows that robot performed better than human in placing the workpiece on spindle.

Experiment also shows the cycle time of attaching and detaching of workpiece. The cycle time was measured by using stopwatch. For the process of attaching, the start point of time is when the workpiece on magazine is gripped by the robot. The end point of time is when the workpiece has been placed in spindle and the gripper releases the workpiece. For the process of detaching, the start point of time is when the workpiece on spindle is gripped by the robot. The end point of time is when the workpiece has been placed back to magazine and the gripper releases the workpiece. The average cycle time for attaching workpiece is 1,729 seconds, and detaching workpiece is 2,902 seconds. The average time for system to prepare the workpiece (in magazine) is 10,519 seconds.

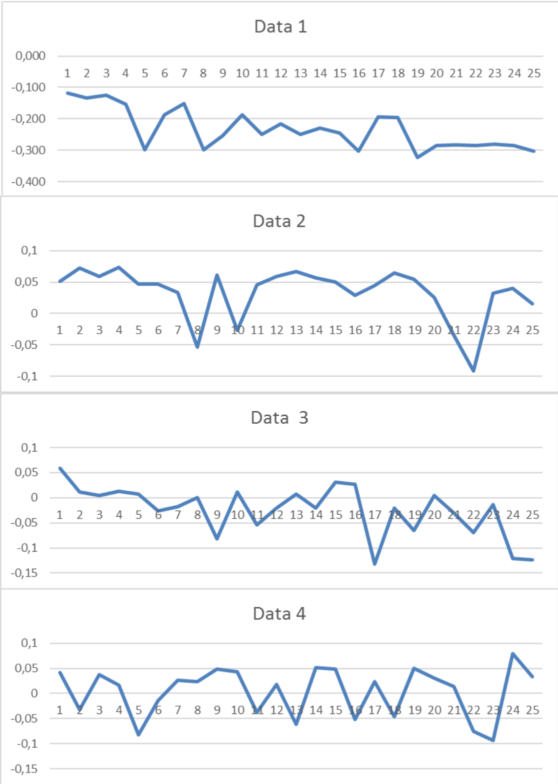

Figure 7. Experiment Result

5. CONCLUSION

The proposed handling system gives promising result to assist human operator to place the workpiece on spindle for turning process. The system based on manipulator robot MELFA RV-2FB has been successfully developed and tested in real feeding process of workpiece. From the experiment result (Fig. 7), it is shown that the maximum deviation of workpiece location is 0,207 mm with a variance of 0,062 mm. This result shows that the system outperforms the human accuracy in placing the workpiece. Furthermore, the clearance distance for feeding motion can be reduced by using the system. Finally, the proposed system is feasible to be used to assist of human operator to place the workpiece on the CNC machine.

REFERENCES

[1] Siciliano, B., and O. Khatib, *Handbook of Robotics*. Springer-Heidelberg, 2008.

[2] Brogardh, T., *Present and Future Robot Control Development - An Industrial Perspective*, Annual Reviews in Control, 2007. **31**.

[3] Newman, S. T., *et. al*, *Strategic Advantages of Interopability for Global Manufacuturing using CNC Technology*, Robotics and Computer-Integrated Manufacturing, 2008. **24**.

[4] ---, *Mitsubishi Electric Industrial Robot - MELFA F Series*, Mitsubishi Electric, Japan, 2012.