RESEARCH ARTICLE

PROPOSED METHODOLOGY FOR AUTO ERROR CORRECTION AND DETECTION FOR CLOSED LOOP MANUFACTURING USING EMBEDDED SYSTEM

[1,*]Prathima, B. A., [2]Dr. Sudha, P. N. and [3]Dr. Suresh, P. M.

[1,2]Department of Electronics and Communication Engg., K.S.I.T., Bangalore, Karnataka, India
[3]Department of Mechanical Engineering, K.S.I.T., Bangalore, Karnataka, India

ARTICLE INFO	ABSTRACT
	The CNC machine tools are used to manufacture precision machined components. Generally the component profile & size to be achieved is programmed using NC Codes. Once the parts are produced, the operator will check whether the desired dimension is achieved or not. There are chances that due to the tool wear (predominantly) and other reasons like material non homogeneity, insufficient coolant supply etc. (less predominantly) the produced parts are out of specified tolerance zone. By chance if the operator miss to check and correct the wear offsets, then there are chances that the few components get rejected during series of production. Dimensional and Geometrical parameters measurement in CNC machine is primarily an open loop system. The checking is done by operator after completion of operation, which is not reliable. This is called OBQ (Operator based quality). The requirement of the industry is to switch from the OBQ to SBQ (System Based Quality). In the proposed work, an end to end solution from auto measurement to analysis using an embedded system and feedback to the CNC machine using communication protocols, thereby making Auto Inspection system for a closed loop manufacturing system will be developed.

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INTRODUCTION

Over the years, machining systems have been developed with the ability to machine high-quality parts promptly, economically and precisely. CNC systems have been around the machining systems for more than half century and they have been playing an essential role in almost all aspects of manufacturing. Fundamentally, these systems are closed loop in their architectures, rigid in their configurations and complicated in their operations. Despite the machine being closed loop within itself, all the applications around the machine has not been effectively closed loop. In the machine tool, the current programming standard is as per ISO 6983, using NC Codes. It describes merely low-level information such as machine tools actions and axis movements. The previously developed machining systems use STEP-NC file as the import for CAM modules hence CNC controllers still get only low-level information and was unidirectional. The newly developed STEP compliant NC standard ISO 14649 opened the way to transfer high-level information to CNC System.

*Corresponding author: Prathima, B.A.
Department of Electronics and Communication Engg., K.S.I.T., Bangalore, Karnataka, India.

This standard, also known as STEP-NC, can be used to describe a wide range of information such as part geometry measurement, feature placement, machining method, process parameter optimization and tool description etc. (Po *et al*., 2014). However all data can be fed in CAD level and available in the form of STEP NC through a post processor. The ever-growing capabilities of CNC controllers, especially open architecture CNC (Yu *et al*., 2009) (Yuan *et al*., 2009), makes it possible to interpret STEP-NC directly without the help of post processor. These enhanced possibilities have made On-Machine Inspection (OMI) systems which provide direct inspection in manufacturing and quality control, which was vital for automated production (Zhao *et al*., 2009).

Computer Aided Inspection Plan (CAIP) is an off line measurement system mainly developed for CMMs (Co-ordinate Measuring Machines). The concepts of CAIP are used in OMI. When compared to CMM, OMI was beneficial as the part was not disturbed from the machined location. Using STEP NC it was possible to measure parts on the machine itself using Touch Trigger Probes (Valino *et al*., 2009). But OMIs was not so much popular as the machining time was lost in measuring and machines accuracy was inferior when compared to that of CMM or any other exclusive measuring device.

The researchers intend to employ either invasive (touch type) or non-invasive (non touch type) sensors to measure feature parameters. Sensors like LVDT, Laser, Ultrasonic, LED, Photoelectric, CCD camera etc. are extensively and effectively used for such applications. A system consisting of smart sensors generally includes a direct connection of different kinds of physical sensors, and sensors that can be interfaced to a microcontroller, or a digital signal processor. Those smart sensors are adaptive and have memory of the past. Smart sensor boards include signal processing modules that are capable of amplitude transformation, linear compensation, digital reset to zero and digital filtering. Micro electro mechanical system and CMOS technologies can be integrated to provide smart sensors with better anti-interference ability (Feng *et al*., 2012).

The application on discussion requires variety of features with reference to their resolutions, linearity, measuring range, measuring cycle time, cost etc. Some efforts in the areas of measurements using above sensors are evidence in Flatness measurement using pressure sensor (Lan *et al*., 2011) and Automated Vision Inspection System for the Size Measurement of Work pieces (Lei *et al*., 2005). These efforts describe the methodology to use sensor, data collection, algorithm development to process the collected data, optimize the algorithms by comparison of the results and select the most appropriate methodology to measure the above said parameters. The techniques like edge detection, wavelet edge detection, diffuse reflective, regular reflective etc. are in practice to sense the parameter and convert them to data sets for further analysis and error detection. The algorithms enable the data collection and acquisition in such a way that the data set captured represents the net near shape of the feature parameter with minimum data loss and data deformation. Cooley–Tukey FFT Algorithm (Lan *et al*., 2011), Radix-2 Decimation-In-Time (DIT) Fast Fourier Transform (FFT), Discrete Fourier Transform (DFT), Simple Moving Average Algorithm (Lan *et al*., 2011) are commonly used algorithms for data processing.

Traditionally least squares algorithms are used for form tolerance assessment. Form tolerances like flatness, cylindricity, perpendicularity can be assessed using this algorithm. The proposed approach applies to a set of cases in order to validate the effectiveness and the robustness of the approach. The obtained results indicate that the proposed algorithm provides accurate and quick assessment (Prisco and Polini, 2010). The algorithms play a major and convenient role in the micron measurement in engineering metrology. To achieve implementation simplicity, computational efficiency and robustness of algorithms, the features like genetic algorithms, hierarchical algorithms are used.

Depending on the complexity of the profile or the surface form suitable algorithms are used. Form tolerances tends to become complex when compared to the geometrical tolerances. One or more algorithms were applied on the same parameter and an optimization technique was applied to obtain best fit result (Wen *et al*., 2006) (Zhu and Ding, 2003). The system on chip via field-programmable gate array (SoC-FPGA) technology has made the data acquisition requirements of the modern real time applications more sophisticated and affordable (Abdallah *et al*., 2011).

The data acquisition system designed based on the above concepts do not depend on the expensive general purpose computer based or microcontroller based implementations. These can be designed just enough to manage the data in the said application. The collected accurate data of error was subjected to decision tree using an embedded system to evaluate the acceptance or rejection of the parts based on the error content (Edelmoser and Anselmi, 1996) (Mou *et al*., 1994) (Peckol, 2008).

Communication Protocols to communicate the error data back to the CNC system will enable the manufacturing system to move from Operator Based Quality to System Based Quality. This is a significant step towards closed loop manufacturing system. In the present scenario the open architecture CNC machines are able to communicate using digital data (Yu *et al*., 2009) (Yuan *et al*., 2009). The communication protocols to communicate with various types of CNC systems which are predominantly assisted by PLC (Dongkai *et al*., 2012) needs to be developed which can be a generic model of data transfer to any CNC System.

Abbreviations	
CNC	Computer Numerical Control
NC	Numeric Control
OBQ	Operator Based Quality
SBQ	System Based Quality
STEP	Standard for the Exchange of Product model data
CAM	Computer Aided Manufacturing
CAIP	Computer Aided Inspection Plan
CMM	Coordinate Measuring Machine
OMI	On Machine Inspection
PPM	Parts Per Million
CCD	Charge Coupled Device
LVDT	Linear Variable Differential Transformer
LED	Light Emitting Device
FFT	Fast Fourier Transform
DIT	Decimation-In-Time
DFT	Discrete Fourier Transform
PLC	Programmable Logic Controller
SoC	System on Chip
FPGA	Field Programmable Gate Array

Need for Closed Loop Manufacturing System

In mass production environment, the critical parameter of the given operation will be identified and the same will be subjected to inspection at the end of each cycle. However, other parameters, which are more stable in the process or less critical in nature, can be subjected to inspection in a particular frequency based on the standard sampling plans. The critical parameter needs special attention.

After every cycle, the operator is expected to check the component using the pre-defined checking method, and the error is assessed. If any error is observed, the value to be estimated by the operator is fed as wear offset value correction. The machine's feedback system senses the error and the error signal will be fed back with corrective action in the output. Possibilities of operator not checking the component, the parallax error while measuring, gauge repeatability & reproducibility issues, lack of knowledge of operator to feed the offset value, decimal errors while feeding the offset correction etc. could result in rejection of the components. Fig.1 illustrates the block diagram of Open Loop

Manufacturing System. The rejection would be more severe in mass production environment, as operation time is less and several components can get rejected before incorporating the corrective action. Several manual controls are in practice to check the same such as set up approval, in-process checking, final inspection, on the job training etc. However, this area has remained as open loop and predominantly dependent on operator only. The industry norms for rejection is 0 to 500 PPM (parts per million) i.e. 0 to 0.05%. Depending on the process stability and capability, the rejection levels are around 2% – 3% (20000 to 30000 PPM) which is not acceptable. The requirement of the industry is to switch from the OBQ to SBQ. Fig. 2 shows the block diagram of Closed Loop Manufacturing System. The proposed research work will significantly reduce the PPM levels to achieve the industry norms.

MATERIALS AND METHODS

The various components produced may have one or more errors in the following parameter. Some of the major errors that can occur during production process are tabulated in Table 1. Not all the parameters are critical in a given component. Many would be achieved by process and hence may not require thorough checking. However, some key functional parameter would require checking after each cycle with corrections.

Step-1: Study of existing measurement methods

Several methods of measurements are in practice in the industry. These are categorized as first principles, analog devices and digital devices.
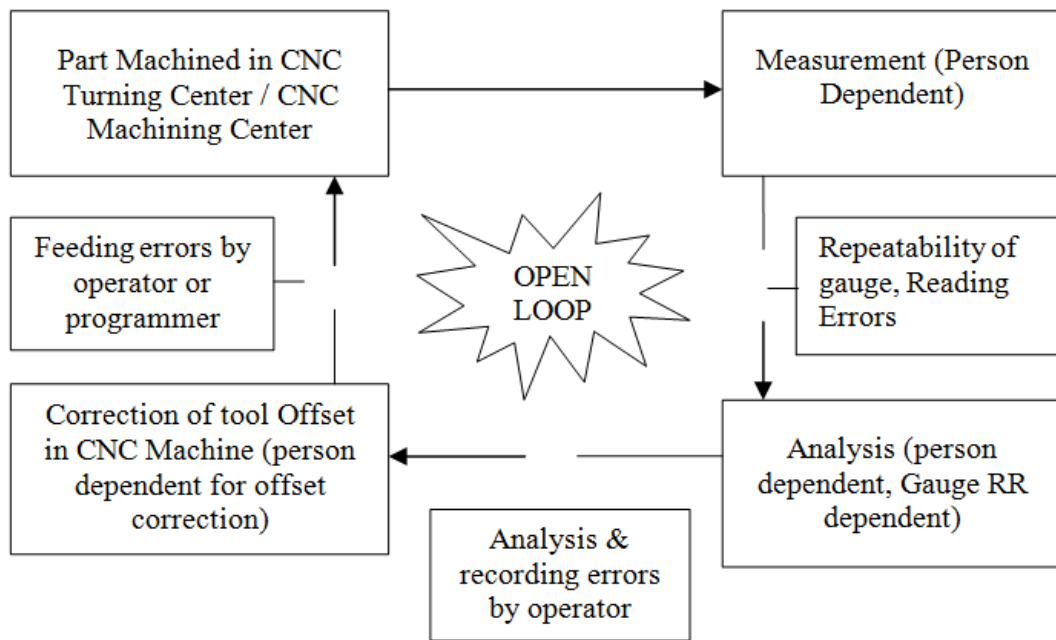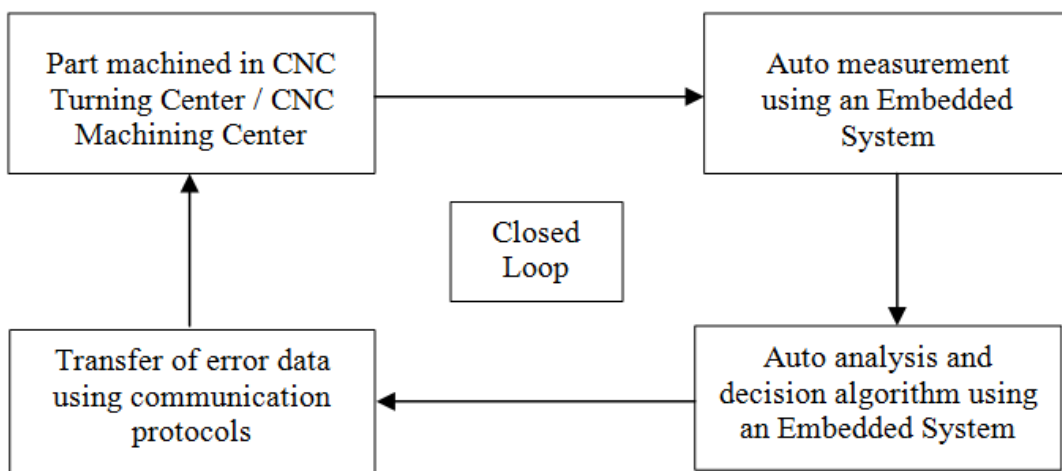

Fig. 1. Open Loop Manufacturing System

Fig. 2. Closed Loop Manufacturing System

Table 1. Dimensional and Geometrical Parameters

Dimensional Parameters	Geometrical Parameters
Outer Diameter	Flatness of the surface
Inner Diameter	Parallelism between 2 planes
Thickness	Perpendicularity between 2 planes
Depth from a surface	Run out with reference to another axis
Centre Distance	Cylindricity
Profile like Radius, Chamfer, etc.	Circularity

A fair understanding of the usage of various devices and their resolutions, hysteresis, parallax error possibilities are to be identified. The feature parameters could be dimensional or geometric in nature. Different methodologies are adopted to measure individual parameters.

Step-2: Selection of sensors

Based on the existing measurement methods, the most suitable replacement methodology to be selected using appropriate sensors. The sensor could be invasive or non invasive depending on the application. Measuring range, sensing object, resolution, linearity etc have to be important selection criteria to provide a similar feel of operation with better precision.

Step-3: Algorithm development

Based on the complexity of the measurement feature and the behavioural pattern on the sensor's output, suitable algorithms will be developed to have most optimum results which can be scalable to a range of objects for measuring similar feature parameters. The results of the developed algorithms will be calibrated with the master value stored in an embedded system to validate and finalize the algorithm.

Step-4: Error detection

The measured value shall be compared with the mean value and the variation with reference to the total tolerance band will be detected. The decision algorithm will be devised to detect the errors and decide on the parts acceptance, rework and rejection using an embedded system.

Step-5: Auto Correction of error

The communication protocols will be developed to communicate with the CNC systems architecture. Many old generation CNC systems are with RS232 ports. However the latest CNC systems are with open architecture and are compatible with USB ports. The communication protocol should be able to feed the error back to the to the CNC system to make the whole system closed loop.

Conclusion

In an OBQ, the complete process is depending on the operator, which is not reliable and the rejection would be more severe. The requirement of the industry is to switch from the OBQ to SBQ. In the proposed work, a set of modern sensors are selected based on their capability to measure microns in various applications. The measurement algorithm will be developed to detect the error in its precise form.

An embedded system will acquire the error content, process and analyse with reference to the mean value. The detected error is communicated to the end machine using communication protocols. The proposed methodology helps in significantly reducing the rejection (PPM level) towards industry norms, hence minimizing the wastage of resources.

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