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Extraction of Subtractive Features of Prismatic Parts from STEP File for CAD/CAM Integration

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ABSTRACT

Automation plays an important role in the manufacturing systems to increase the productivity with high flexibility in the production process. This may leads to the requirement of an information model to control the industrial machinery and processes. The information model contains the common product data. Hence, the data extraction is mandatory to extract the product data from the product model. This paper explains the extraction of product data through feature extraction process. A simplified system is developed to extract the data from the STEP file of a product model for subtractive features of prismatic parts. Using extracted data, the controller dependent NC codes were developed. The extracted data is also useful as reference data for checking the quality of manufactured parts by comparing with the data measured by coordinate measuring machine (CMM). In this paper, the integration concept is explained with the experiments conducted to produce the prismatic parts using the generated codes.

Keywords: CAD/CAM, STEP, CMM, Feature Extraction

INTRODUCTION

The manufacturers are trying to produce products with high quality within compete price. In addition, the changes of customer needs should also to be satisfied. To achieve this, computer aided systems are used to support the entire manufacturing process easier and flexible (Abouel Nasr & Kamarani, 2006, p. 390). Further the computer aided systems like CAD, CAM and CAI should work

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together to fulfill the industrial needs (Babic et al., 2008). Each computer aided system requires the product data which may be commonly kept as information model. Hence, the product data extraction plays an important role to develop an information model for the integrated manufacturing environment (Berbinschi et al., 2014).

The CAD model contains product description data which can be used for various downstream applications such as process planning, NC code generation, assembly planning, inspection and so on (Besant, 1986; Bitla, 2017). An automatic interpretation is required to extract the data from CAD model based on features (Chang et al., 2002) Feature has different meaning at different contexts and its classifications are based on various factors (Gao et al., 2004; Ismail & Tan, 2002).

Many researchers proposed various approaches for automatic feature extraction process. These feature extraction processes are based on the internal representation of a particular CAD system and which cannot be applicable for other CAD systems (Li et al., 2010; Mamadou & Christian, 2011; Marri et al., 2017). To overcome this drawback some of the researchers convert the CAD model into standard neutral file format and extract the data from the same neutral file (Omid & Mahmoud, 2010; Sivakumar & Dhanalakshmi, 2013). This technique has the advantages of generalization and easy extraction of features since the neutral files such as STEP contains coordinate data in the form of text file. Based on the literature, it is observed that few complex systems have been developed for specific applications to address the issue of extracting the data from a CAD model (Sivakumar & Dhanalakshmi, 2013; Thivakar et al., 2016). The present work aims to eliminate the above and proposes a general and simplified approach for the feature extraction process.

In this paper, a generalized methodology is proposed to extract the product data from STEP file of a CAD model and to transfer the information to various downstream applications.

Integrated Manufacturing System

In this work, the main objective is to develop a feature extraction system to integrate the three stages of product lifecycle namely computer aided design (CAD), computer aided manufacturing (CAM) and computer aided inspection (CAI). The feature extraction method should be generalized and simplified method that is compatible with any standard CAD softwares which makes the integrated system to be as simple as possible (Wang et al., 2012). The methodology shown in figure 1 explains overall view of an integrated system which includes the generation of CAD model, Extraction of data from STEP file, Manufacturing of parts using NC code generated from the extracted data and Inspection of parts using machine vision.

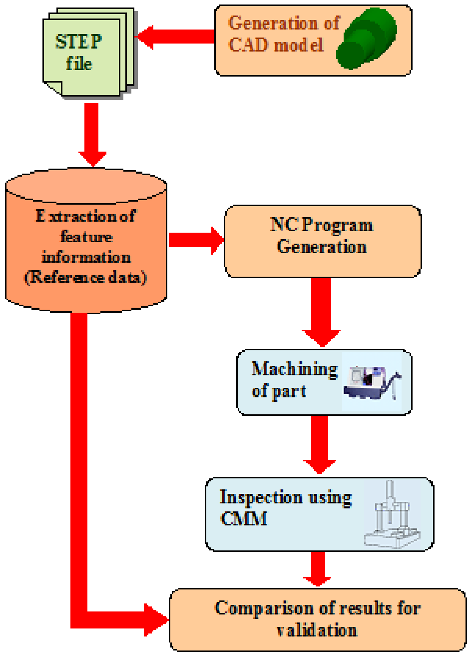


Figure 1. Proposed Methodology for integrated System

Generation of CAD model

In this work, a prismatic part is chosen as a part model. The part model is created using CAD software and it is shown in Figure 2. This part model contains three features namely slot, step and hole. The part model is converted into STEP AP203 file.

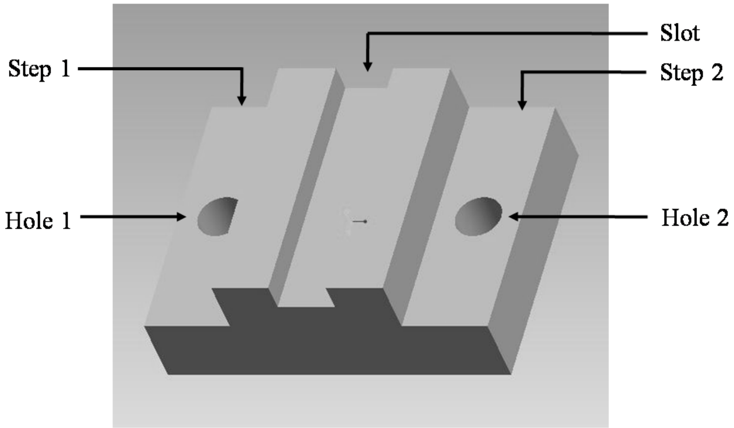


Figure 2. Part model of the sample prismatic part

Identification of Features from STEP-File

The part model is based on geometric entities such as line, circle, arc and so on. However, the information required for other computer aided systems is based on manufacturing features such as groove, chamfer and so on. Hence, it is required to convert the part information from design features to manufacturing features which is one of the major challenges in the integration process. This requires a feature extraction system for identification of features.

A feature contains the information about geometry and properties of product which includes the geometrical data and properties. In this paper, some of the subtractive features are considered and the detailed method of identification of the features is given in Table 1.

Table 1

Identification of subtractive features from STEP file

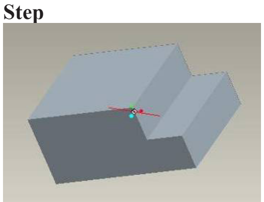
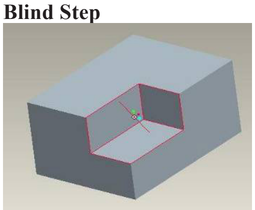
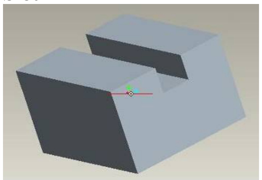
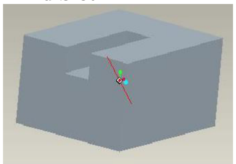
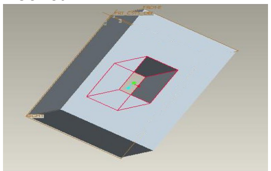
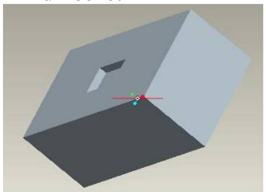
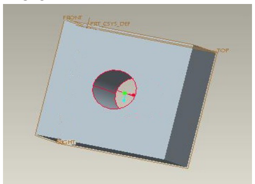
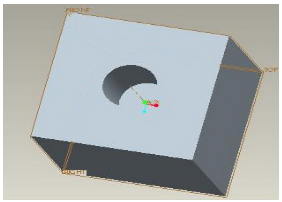
Type of feature	STEP format	Identification of feature
Step 	#1=DIRECTION('',(0.E0,1.E0,0.E0)); #5=DIRECTION('',(-1.E0,0.E0,0. E0)); #9=DIRECTION('',(0.E0,1.E0,0.E0)); #13=DIRECTION('',(-1.E0,0.E0,0. E0));	If the STEP data contains the directional sequence 'y, -x, y, -x' then the feature is identified as step. In addition, the length of the step is equal to the base cube length then the feature is called step.
Blind Step 	#1=DIRECTION('',(0.E0,1.E0,0.E0)); #5=DIRECTION('',(-1.E0,0.E0,0. E0)); #9=DIRECTION('',(0.E0,1.E0,0.E0)); #13=DIRECTION('',(-1.E0,0.E0,0. E0));	If the STEP data contains the directional sequence 'y, -x, y, -x' then the feature is identified as step. In addition, the length of the step is less than the base cube length then the feature is called blind step.
Slot 	#5=DIRECTION('',(-1.E0,0.E0,0. E0)); #9=DIRECTION('',(0.E0,-1.E0,0. E0)); #13=DIRECTION('',(-1.E0,0.E0,0. E0)); #17=DIRECTION('',(0.E0,1.E0,0. E0)); #21=DIRECTION('',(-1.E0,0.E0,0. E0));	If the STEP data contains the directional sequence '-x, -y, -x, y, -x' then the feature is identified as slot. In addition, the length of the slot is equal to the base cube length then the feature is called slot.
Blind Slot 	#5=DIRECTION('',(-1.E0,0.E0,0. E0)); #9=DIRECTION('',(0.E0,-1.E0,0. E0)); #13=DIRECTION('',(-1.E0,0.E0,0. E0)); #17=DIRECTION('',(0.E0,1.E0,0. E0)); #21=DIRECTION('',(-1.E0,0.E0,0. E0));	If the STEP data contains the directional sequence '-x, -y, -x, y, -x' then the feature is identified as slot. In addition, the length of the slot is less than the base cube length then the feature is called blind slot.

Table 1 *(Continue)*

Type of feature	STEP format	Identification of feature
Pocket 	#21=DIRECTION('',(0.E0,0.E0,1. E0)); #25=DIRECTION('',(-1.E0,0.E0,0. E0)); #29=DIRECTION('',(0.E0,0.E0,-1. E0)); #33=DIRECTION('',(1.E0,0.E0,0. E0));	If the STEP data contains the directional sequence 'z, -x, -z, x' then the feature is identified as pocket. In addition, the pocket height is equal to the base cube height then the feature is called pocket.
Blind Pocket 	#21=DIRECTION('',(0.E0,0.E0,1. E0)); #25=DIRECTION('',(-1.E0,0.E0,0. E0)); #29=DIRECTION('',(0.E0,0.E0,-1. E0)); #33=DIRECTION('',(1.E0,0.E0,0. E0));	If the STEP data contains the directional sequence 'z, -x, -z, x' then the feature is identified as pocket. In addition, the pocket height is less than the base cube height then the feature is called blind pocket.
Hole 	#136=FACE_BOUND('',#135,.F.); #135=EDGE_LOOP('',(#132,#134)); #132=ORIENTED_ EDGE('',*,*,#131,.F.); #131=EDGE_ CURVE('',#95,#96,#25,.T.); #25=CIRCLE('',#24,1.E2);	If the STEP data contains FACE_BOUND with CIRCLE then the feature is identified as hole. In addition, the hole height is equal to the base cube height then the feature is called hole.
Blind Hole 	#164=FACE_BOUND('',#163,.F.); #163=EDGE_LOOP('',(#160,#162)); #160=ORIENTED_ EDGE('',*,*,#159,.T.); #159=EDGE_ CURVE('',#99,#100,#33,.T.); #33=CIRCLE('',#32,1.E2);	If the STEP data contains FACE_BOUND with CIRCLE then the feature is identified as hole. In addition, the hole height is less than the base cube height then the feature is called blind hole.

Extraction of Data from STEP File

The geometrical information of the part features and their positions are extracted from the STEP file using feature extraction process. The feature data are extracted by a generalized program developed in C++ language. The extracted data are stored in a text file for further use. Algorithms are developed based on the identification procedure mentioned in Table 1 and the flowchart for extraction of subtractive features of prismatic part is shown in Figure 3. These extracted data can be used for all downstream activities.

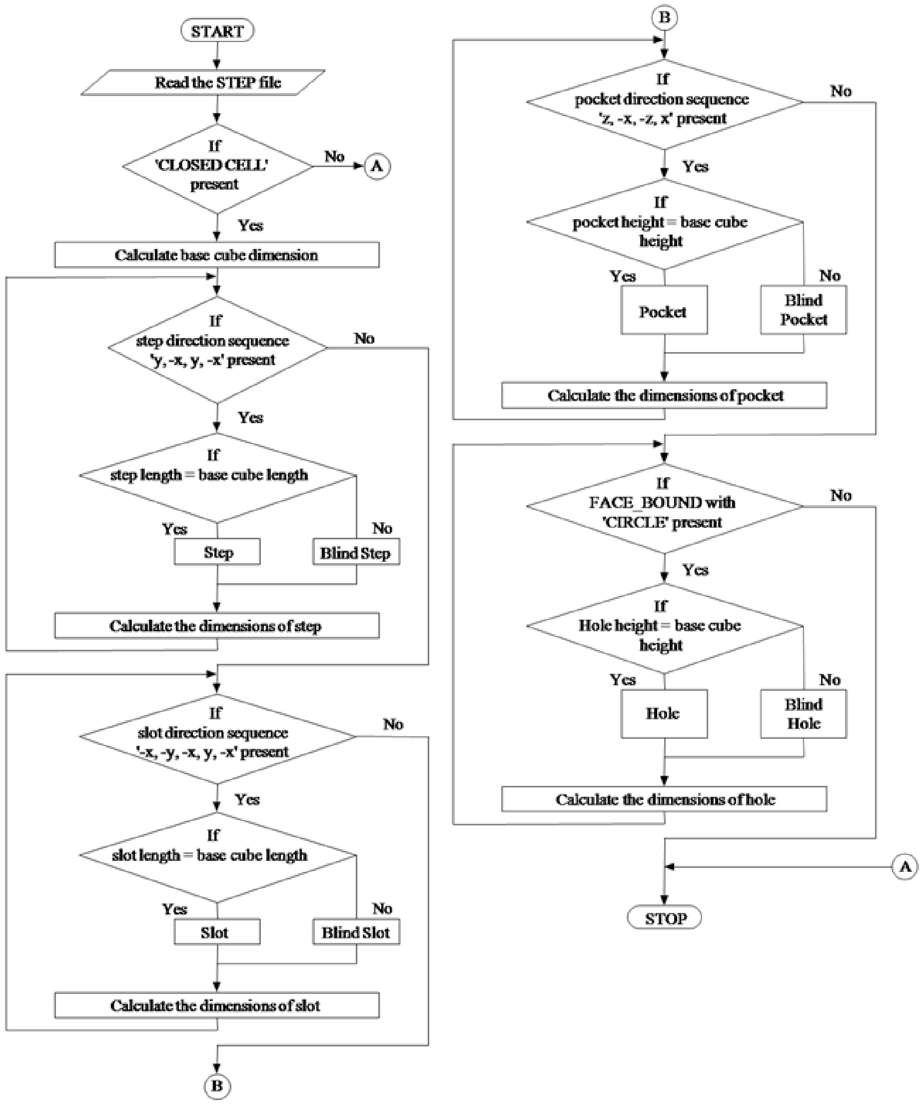


Figure 3. Flow chart for feature extraction of prismatic subtractive features

The extracted data from STEP file is shown in Table 2. In this work, the features are considered from the left end of the part, since machining is carried out from the left end of the part.

Table 2

Extracted data from STEP file of the sample part

Step1			Step2			Slot			Hole 1	Hole 2
Length (mm)	Width (mm)	Height (mm)	Length (mm)	Width (mm)	Height (mm)	Length (mm)	Width (mm)	Height (mm)	Diameter (mm)	Diameter (mm)
45	15	10	45	15	10	45	10	5	5	5

Machining of Parts in CNC Machine

The above extracted data can be used for other manufacturing activities. For example, in the computer aided manufacturing systems, the above feature data can be directly used to machine the parts. Here, a software program is developed to generate the NC code from the extracted feature data. For the machining process, some additional information is required. These additional information are given as input to the program which includes raw material, raw material size and machining parameters like depth of cut, speed and feed. The dimensional information of features is taken from the feature data text file. The NC codes were generated to machine the features individually from left end of the prismatic part. Figure 4 shows the flowchart for the procedure of NC codes generation.

The generated NC codes are to be feed into the CNC machines to produce the parts. In this work, ISEL CNC vertical milling machine is taken for machining process. The milling machine has three linear and one rotary axes movement that can be automatically controlled. For checking the consistency of the overall system, three similar parts are machined using the same NC codes. The machined part is shown in Figure 5.

Validation using CMM

Normally the parts produced in CNC machines are accurate and having good surface finish. To validate the accuracy of machining process, the machined parts are to be inspected using standard metrological equipment. In this work, the machined parts are inspected using coordinate measuring machine. The measurement results are tabulated in Table 3.

In addition, the quality related decisions may be taken according to the constraints based on the tolerance requirements of the parts. To do this, a system is developed to compare the CMM measured data and the extracted feature data (reference data). The flow diagram of the quality control system to accept or reject the part is shown in Figure 6.

RESULTS AND DISCUSSION

In this work, samples of three similar prismatic parts were machined using the generated NC program. All the dimensions of the parts were measured using CMM. The measurement data obtained from the CMM was having appreciable deviations from the reference data

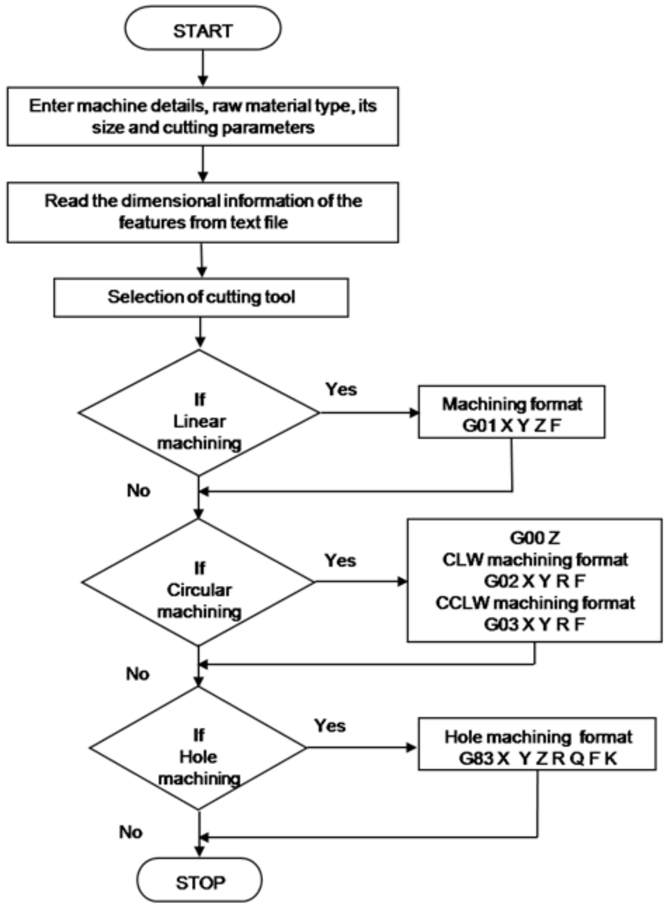


Figure 4. Flowchart for NC codes generation

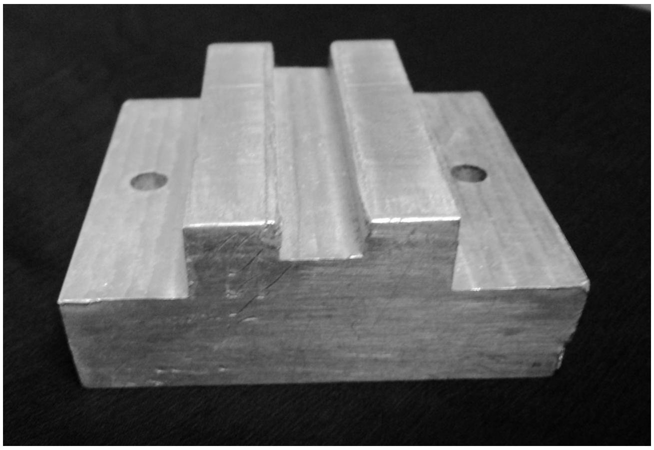


Figure 5. Image of the machined prismatic part

Table 3
Measurement details of prismatic parts using CMM

S. No.	Feature	Parameter	Measurements obtained from CMM (mm)			Percentage of deviation (CMM with Reference Data)		
			Part 1	Part 2	Part 3	Part 1	Part 2	Part 3
1.	Step 1	Length	44.93	44.86	44.89	0.156	0.311	0.244
		Width	14.87	15.12	15.08	0.867	-0.800	-0.533
		Height	9.86	9.94	9.89	1.400	0.600	1.100
2.	Step 2	Length	44.88	44.87	45.05	0.267	0.289	-0.111
		Width	15.16	15.08	15.12	-1.067	-0.533	-0.800
		Height	9.88	10.05	9.93	1.200	-0.500	0.700
3.	Slot	Length	44.84	45.01	45.08	0.356	**-0.022**	-0.178
		Width	10.12	10.05	10.18	-1.200	-0.500	-1.800
		Height	4.90	4.94	4.96	2.000	1.200	0.800
4.	Hole 1	Diameter	5.06	5.10	5.13	-1.200	-2.000	**-2.600**
5.	Hole 2	Diameter	4.91	4.94	4.96	1.800	1.200	0.800

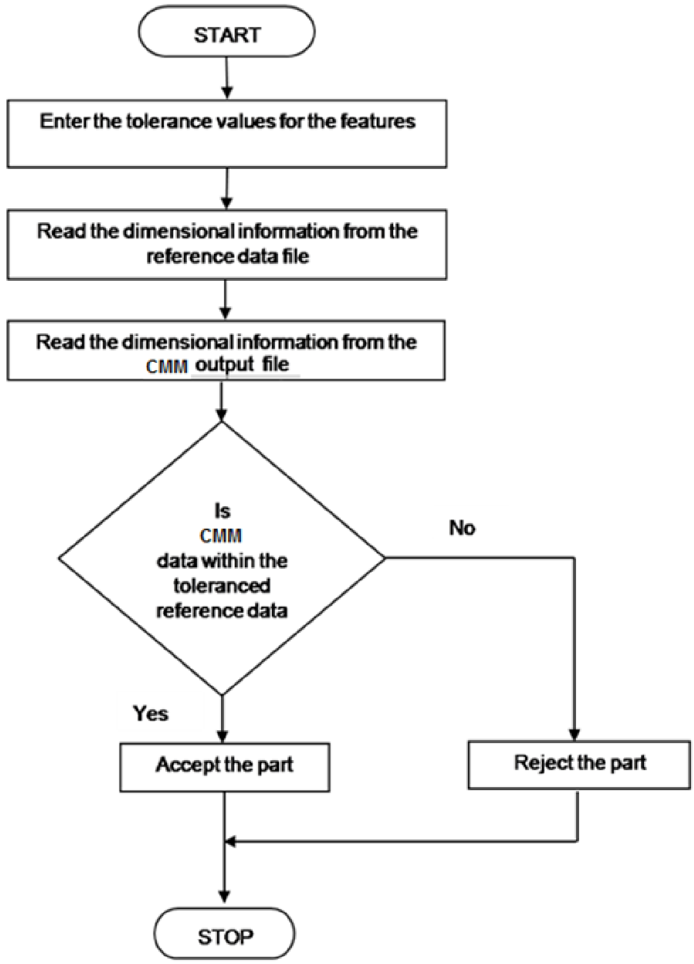


Figure 6. Flow diagram of the quality control system

extracted from the STEP file. Figures 7 shows the comparison of the CMM measurement with Reference data for various features.

The percentage of deviations are calculated and mentioned in the Table 3.

The calculation for the percentage of deviation is as follows:

Consider the diameter of hole 1 for part 3

Measurement obtained from CMM : 5.13 mm

Reference Data from STEP file : 5.00 mm

$$\text{Percentage of deviation} = \frac{(\text{Actual value} - \text{Observed value}) \times 100}{\text{Actual value}}$$

Since reference data is the standard required value, the reference data is taken as actual value and measurement obtained from CMM is taken as observed value.

$$\text{Percentage of deviation} = \frac{(5.00 - 5.13) \times 100}{5.00}$$

$$= -2.600\ \%$$

Similarly, the percentage of deviation for all the dimensions is calculated and is given in Table 3.

From the Table 3, it is observed that the percentage of deviation falls between -2.600% to +2.000%. The maximum deviation occurs, while measuring smaller dimensions. In this work, while measuring the diameter of hole, the maximum deviations occur.

The data from the table clearly shows that the CMM measurement has a minimum error of -0.022% and maximum error of -2.600% from the reference data. The deviation occurs in both positive and negative direction. This deviation may be due to errors in the machining process and can be reduced by proper selection of machine tool and cutting conditions.

In this work, the CAD is integrated with the CAM through the generation of NC codes from the product data extracted from the STEP file of the CAD model. In similar way, CMM measured data is compared with product data extracted from STEP file of CAD model for taking quality related decisions. Thus, this work may provide a generalized and simplified method for the integration of CAD, CAM and CAI.

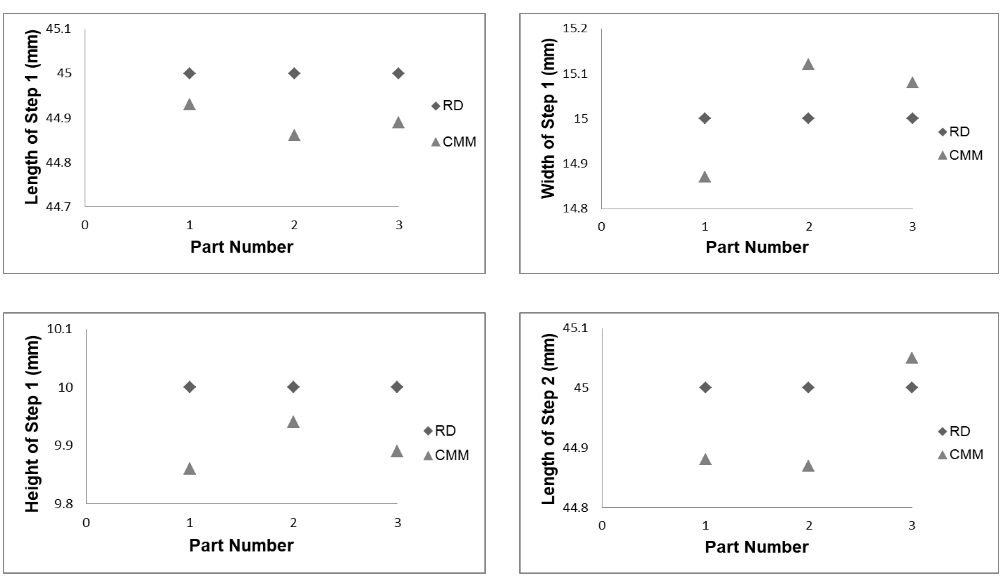


Figure 7. Comparison of measurement of different parameters of sample parts

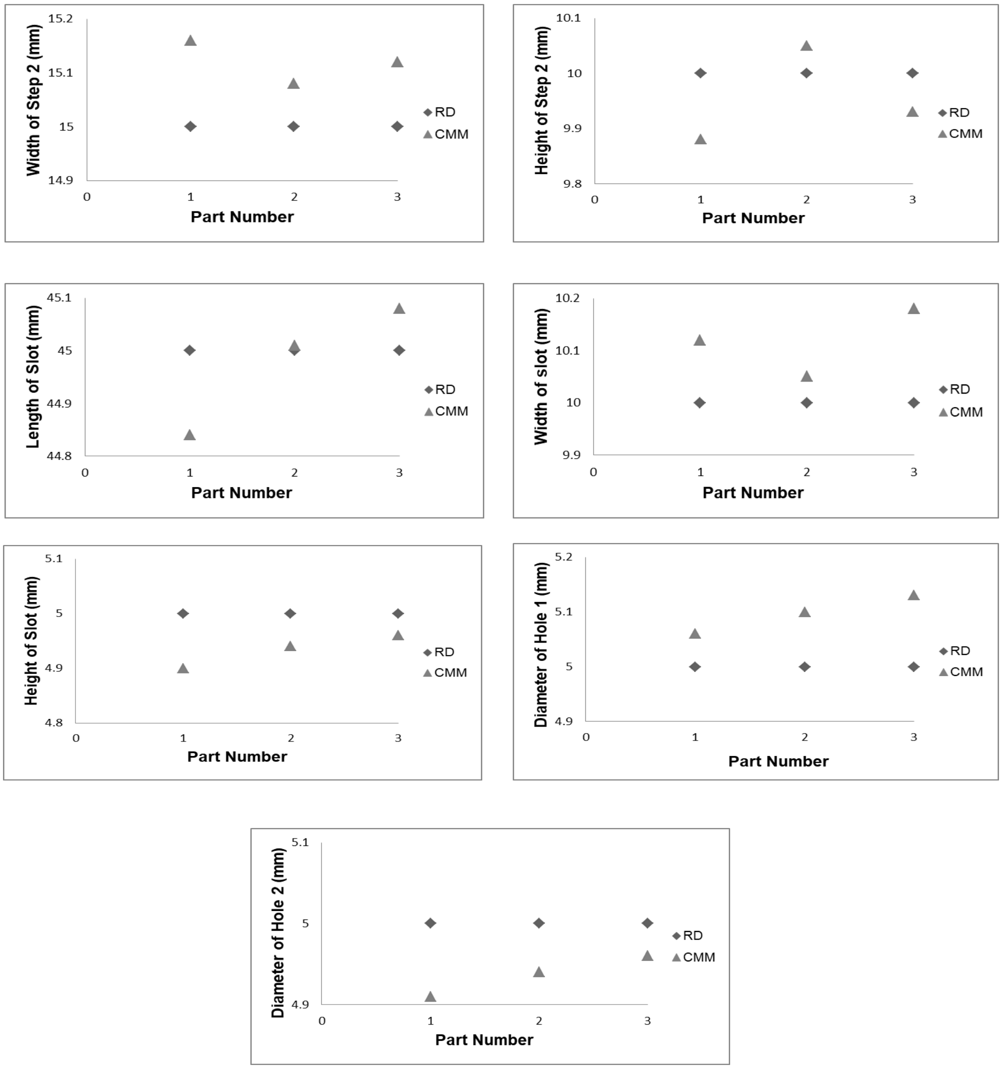


Figure 7. Continue

CONCLUSION

This work mainly concentrates on the integration of CAD and CAM systems, based on the extracted machining features from STEP AP203 file. A prototype system was developed in conjunction with a standard CAD and CAM system, to demonstrate the integration of CAD and CAM for prismatic parts. In the developed system, once the subtractive features are recognized from the STEP file of the CAD model, created using standard modeling package, the NC program can be automatically generated which minimize the necessity of user interventions. In this work, only simple features are considered and the generated codes were controller dependent unlike STEP NC. This work may be considered as a basis for achieving fully integrated manufacturing system. In addition, the work may be extended to integrate the other stages of product lifecycle such as inspection, assembly, packing and so on.

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