A 3D Printing with Feature-based Extension

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Abstract

The NC programming language is developed for effective information flow in CAD-CAM-CNC chain. The international standards for the NC languages are G-code (ISO 6983) and STEP-NC (ISO 14649). Recently, additive manufacturing (AM) becomes challenging fabrication process while the computing power of a microprocessor is dramatically enhanced. Thus, the higher-level NC language that is portable and interoperable is demanded. The feature-based extension is proposed with demonstration of its benefits. The proposed NC language interfaces CAD-CAM-CNC with a measurement device, a Camera in this case. With the proposed NC language and the mockup intelligent NC machine, a 3D cylindrical feature that its position and size are to fit the existing objects are successfully 3D printed.

Keywords-G-code, STEP-NC, 3D printer

1. Introduction

G-code, developed in the 1960s and set as an ISO standard (ISO 6983) in 1970s, is an industrial standard language to effectively interface design with manufacturing so that parts are manufactured to create precision physical models. It is also the basic language within most of Computer Numerical Control (CNC) Machines today[1]. Computer-aided manufacturing (CAM) is a programming tool that can be used to generate a Numerical Control (NC) program, normally written in G-code, that is used to operate the CNC machine. The G-code language is distinctive in machine control since it effectively defines the motion of a machine and handle coordinates during a manufacturing process. Basically, there are four types of motion in G-code: 1) rapid motion: G00 2) linear motion: G01 3) counterclockwise circular Motion: G02 and 4) clockwise circular motion: G03.

Robots are also commanded in motion language, similar to G-code, e.g., G00 is similar to Point to Point (PTP) and G01 is similar to linear interpolation in robotics. However, there is no industrial standard for robots as most vendors develop their own proprietary language. However, most robotic languages include basic motion commands that are compatible with G00, G01, G02, and G03. The difference is that travel speed in a standard unit can be defined in G-code but accuracy can be defined in the robotic language. In other words, accuracy is not well defined in G-code while travel speed in the standard unit is not well controlled in the robotics system. The robotic languages include practical computer programing in their languages such as variable, branching, time, I/O and communication.

3D printer and additive manufacturing (AM) are also used G-code to operate their machines during its fabrication process. However, additive manufacturing is more complex than subtractive manufacturing, and the supported technology is far more advanced at the age of this AM technology. Thus, RepRap G-code has improved ISO 6983 so that it is effectively capable of planning, scheduling and controlling its additive manufacturing process.

Roughly, G-code is excellent at defining and controlling the motion of a machine. However, G-code focuses on the motion of the machine with respect to the machine axes, not the task [2, 3]. The G-code program is thus machine specific and cannot be used to control the other machine directly. The G-code programs must be generated along with information including machine brand, brand's model, and detail description of tool and peripherals [1]. Most CAM software includes a tool, called "Postprocessor" that can generate G-code program for a specific machine, tool, and cutting tool. The information flow during the integrated process is one way as CAD-CAM-CNC chain.

The other concern is that the modern CNC machines normally come with extensions [6], which are upgradable, beyond the scope of the ISO 6983 G-code to enhance the manufacturing capability. The machine program that is G-code free, portable and interoperable is demanded [4] to overcome this limitation and free the machine to new possibilities.

ISO 14649, recognized as STEP-NC, is initially developed in 1999 so that machine program is portable by using the feature-based concept. This is more like a higher-level language that commands the machine processes rather than the motion of machine tools. This means that a machine may complete the process in different ways, with the recommended manufacturing strategy, to fabricate the same model. In this concept, new features and techniques can be implemented and the resulting performance may be different. Pieces of research to implement STEP-NC

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machines are proposed [4]. However, STEP-NC is not widely used in modern CNC machines.

3D printer and additive manufacturing are now using the STL file format that stores the geometry of a 3D model, to interchange the 3D model with a machine. There is a 3D slicer or similar program, inside the 3D printer working system, to automatically convert the model in STL format into the RepRap G-code during the process. In this way, the interchange file is portable and interoperable and can be used with different machines, and thus becomes commercial standard today.

In this project, a feature-based fabrication and the data flow concept in a CAD-CAM-CNC chain are proposed such that a solid feature can be 3D printed on top of the pre-fabrication object [5]. The higher-level language and the data flow between design, manufacturing, and in-process measurement is proposed to enhance the total integrated process. In this way, the fabrication command is generated not only from CAD but also from an in-process measurement of a pre-fabrication or existing object. The proposed machine understands both the legacy G-code and feature-based commands. In the experiment, silicone floor and cylindrical wall are printed on top of the tile that its pose is determined using the camera within the automated process. The proposed command language is portable and interoperable while the machine is upgradable and flexible. The machine control system is a higher intelligence that translates this command and control all its capability to fabricate a feature.

2. Feature-based extension

In this work, an indirect STEP-NC programming method, as mentioned in [4], is mocked up. The program reads a STEP-NC file and then generates G-code and sends it to the 3D printer's controller. The 3D printer's controller accepts and interprets RepRap G-code and controls all the function of the printer. Noted that the program can also read image data from vision sensor and process it with the proposed feature-based extension to generate interactive G-code command.
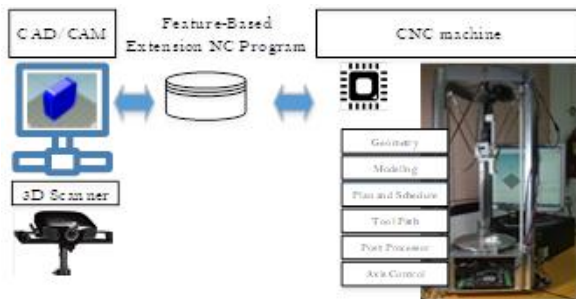

Fig 1. Feature-based NC command information flow

3. Experimental Result

3.1 A Cartesian Robot with a Silicone Head

A Cartesian robot was built with 3030 aluminum profile with feed screw and rollers. The thread of the screw is 1 mm. Each axis is driven by a two-phase stepper motor with 1/16 micro-stepping drive. This results in 1/3200 mm resolution. The workable space is $150 \times 150 \times 150$ mm^3. In this design, the payload exceeds 2 kgs. The controller board is RUMBA 3D printer control board with Repetier firmware. The maximum travel speed is up to 50 mm/s for X and Y axes and 10 mm/s for the Z axis. The head is equipped with a silicone nozzle, Logitech camera, and laser depth sensor.

The Matlab is used as a process control program that reads the proposed feature-based NC file and then generates the RepRap G-code and sends it to the 3D printer control board. In this way, we can enjoy the programming capability of Matlab, precision real-time control of the machine, and open hardware architecture to control a fabrication process.
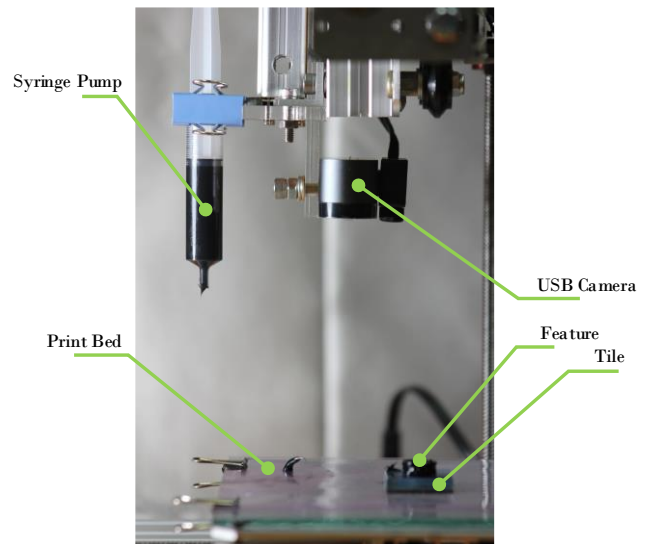

Fig 2. A Cartesian robot with a Silicone Print System

3.2 Pen Marker

The fiber-tip pen is used in a testing process. Using fiber-tip pen can reflex some performance of 3D printer as it needs a high level of accuracy to set the specific height of pen while moving it along the path. The best solution of the testing fiber-tip pen is to set the height that the tip of the pen just touches the base of the printer. If the position of the pen is too low, the pen will contact the base too much, causing friction and unsteady line. On the other hand, if the pen's position is too high, the tip will not touch

the ground and thus doesn't draw a line. The same principle applies to 3D printing nozzle as too much contact will crash the former layer, while too high tip will cause discontinuity or distorted shape.

This experiment uses probing technique to set pen's height that touches the base exactly. Probing has several advantages in advance 3D printing. It can be used to measure the base's height at any time. In this experiment that base is not a single layer plan, so the height of the second layer, or wall, can be measured before planning any printing.

Another importance of probing is to use in level revering process. In the general case, the base of the printer is not always perpendicular to the extruder. Probing can measure the difference in height and then adjust the extruder to perpendicular to the base and vice versa. If the printing continues with slant base, the might also have some distortion in printing product. In pen testing, the researchers operate the printer to probe and fill-in the square shape with circular edges on green paper with the distance between each line is 3.5 millimeter. The result is shown in Fig 5a.

Furthermore, the 3D printer can operate any available G-code command. For instance, as shown in Fig 5a, G02/G03 command, arc move, is used for making every corner of a curve edge square. Generally, the slicer program generates G01 command, linear move, at any kinds of shape because some firmware does not support G02/G03 command. However, feature-based extension NC command does not specify the movement of the 3D printer. On the other hand, when the feature-based extension commands are sent, the intelligent printer chooses and generates available and suitable movements itself. In this experiment, Matlab generates G03 at the corners. Moreover, because of this capability, the feature-based extension NC command would support any feature that will be implemented in the future.

The other capability of the feature-based extension NC command is that the printer can create the feature with real-time measurement, which is helpful for users especially when a feature is printed on top of a complicated-shape object. In this experiment, the length of the different size of color paper is measured using a USB camera and image processing method. Then, these measurements are used for calculation through Matlab and then a curved edge square is printed on the paper with the relative dimension.
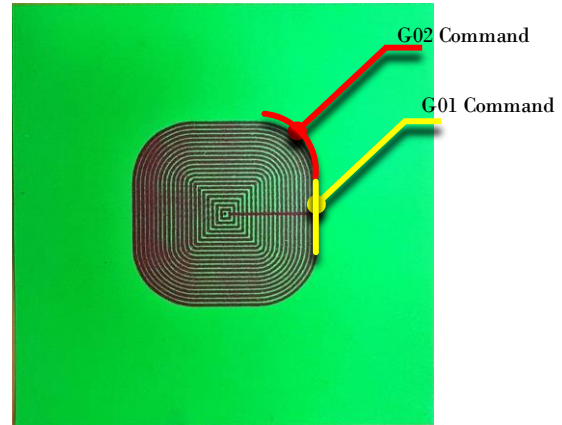
a) A round box drawn with pen

b) Interactive boxes that their sizes fit the paper

Fig 3. Pen Draw with the Proposed Technique

3.3 A Silicone 3D Printing

A silicone is used as a material for demonstrating 3D print in this experiment. To generate a perfect result, many measurement and calculation have been executed. For determining the centroid and dimension of tile, the USB camera is used for taking pictures of the tile. Matlab is used for detecting image's dimension and centroid in the pixel through image processing, using built-in color thresholder function and for finding machine reference position through mapping.

Like the pen maker, the tip height is effect on the quality of printing. The printer requires the high level of accuracy to set the specific height of the nozzle, especially for the first layer. The nozzle would drag flooded silicone if the head is set too low. In the worst case, the nozzle might hit the bed can cause damage. On the other hands, the first layer would not form if the nozzle is set too high.

As a result, the USB camera is used for determining the relative depth where the nozzle almost touches the tile since a silicone needsroom for forming the first layer. During the finding depth process, the detecting dimension process is repeated at the different height to find, on Matlab, an equation representing a relationship between the tile's dimensions in pixel and the z-axis values in millimeters.

For other layers, the high level of accuracy setting is needed as well, but the solution is simple as the height between layers is equal to the diameter of the nozzle, so silicone has enough room for laying on the former layer.

For the printing process, the ratio of the area of a syringe pump to that of the nozzle is determined so that an appropriate amount of silicone is extruded between the starting point and ending point. The printing process is divided into two parts. The first part is printing the based or the first layer which is like the printing process of the pen maker, but the syringe pump is used instead of fiber-tip pen and the 3D printer's controller also controls the extruder so that the silicone is pushed throughout the printing process. The second part is printing the wall, which only the most outer boundary of the feature is printed.
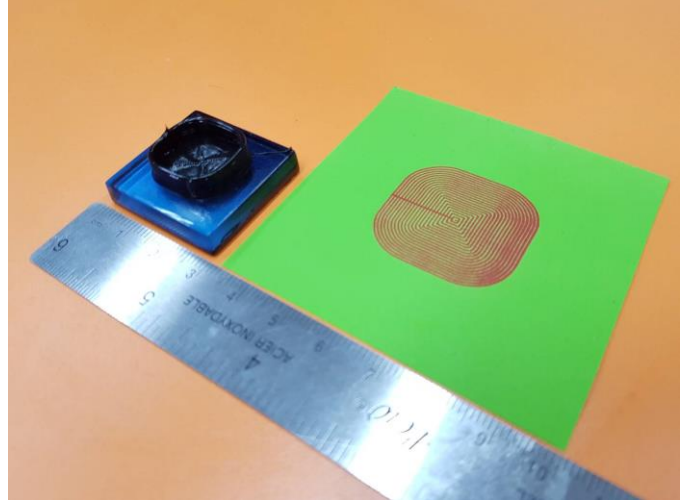
As shown in Fig. 6c, the command used for printing pen maker result is as same as that used for printing the base or the first layer of silicone 3D print model even though the print head tool is changed from fiber-tip pen to syringe pump.
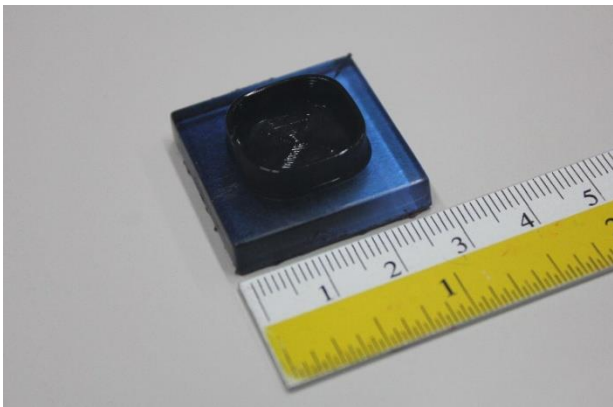
a.   A Silicone Feature 3D Printed on top of a tile
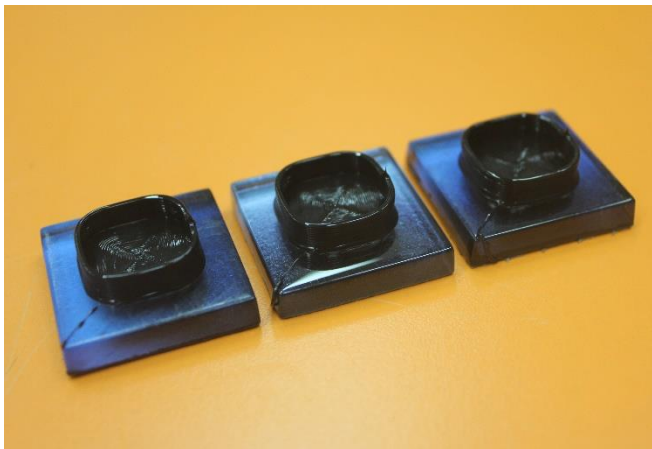
b.   Some Silicone Results

c.   Interactive Print

Fig 4. Print Results

This result demonstrates one capability of feature-based extension NC command. While G-code program, generated by slicer program, is specific to the machine, meaning that it needs to be regenerated every time after the 3D printer has been changed or modified, feature-based NC command is flexible so that the printer successfully works with the same command despite different tools such as a print head.

3.4 The proposed NC program

The proposed NC program is the G-code program with feature-based extension.

```
01 G28 ; HOME
02 VAR POS#01 // INITIALIZE VARIABLE
03 TAKE PICTURE
04 FEATURE EXTRACTION('VAR', POS#01)
05 PROBE('VAR', POS#01, 'PATTERN', 'CORNER')
06 FLOOR('VAR', POS#01, 'PATTERN', 'Default')
07 WALL('VAR', POS#01, 'HEIGHT', 20)
08 G28
```

The example reveals the proposed NC program that is used in the example experiment. The legacy G-code command is still valid. The first line in the example is G28 to command the machine to go to its home position. It is noted that the home position of each machine is different. The second line, 'VAR POS#01', is to define the variable or memory that can be utilized in the later command. The type of this variable is the homogeneous transform [10] or POSITION which defines position and orientation of a point. This type of variable is the basic type in robotics application since frame concept is often used. The 'TAKE PICTURE' command demonstrates that the modern

machine is capable of interfacing withnot only simple I/O, but also an intelligence sensor or actuator, the Logitech camera in this case. The NC program should be able to cope with this. The 'FEATURE EXTRACTION' command demonstrates that not only simple arithmetic, but also complex analysis is preferred in the highly complex process. The 'PROBE' command is the higher-level motion command that will determine the bed or part's positions (Z) at the given (X, Y) positions where 'CORNER'(s) are desired in the example case. This is like "manufacturing strategy" in the STEP-NC program. This command will coordinate the machine motion to determine the result and thus it is the feature-based command. This higher level 'PROBE' command may issue some RepRap G-code G30 commands which is the probe command at a current (X, Y) position. The 'FLOOR' and 'WALL' commands are the extensions of the G-code that are in features-based command.In this investigation, the 3D printer's control board is loaded with the latest '*Repetier firmware*' where G02 and G03 are available, thus the process control program translates the NC program into the G-code low-level program that includes these circular motion commands. The looping and timing programming concepts are implemented within the process control program.

This example demonstrates that the intelligent CNC machine is essential for a higher-level language, but new capability and methodology can be utilized. This machine accepts both the legacy G-code (and M-code as well) and portable feature-based commands. To interpret and process these commands require most of the programming capabilities as stated earlier and thus computing power embedded within the CNC machine. The proposed NC language and programming power can free the NC machine to new performance and capability.

4. CONCLUSIONS

A 3D cylindrical feature that its position and size are to fit the existing object is successfully 3D printed. In the proposed workflow, the data flow in the CAD-Measurement-CAM-CNC chain and the NC language are developed. The portable and interoperable NC language demands a higher intelligent NC controller but leads to a new technique of how we build a 3D object. The feature-based NC language will free a machine for new fabrication techniques.

Acknowledgement

5. REFERENCES

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