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ADD_IN

TEST PLAN

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TABLE OF CONTENTS

1. INTRODUCTION

The ADD_IN team is developing a new format of 3D printer which can produce 3D printed parts enclosing off the shelf hardware (COTS) components to increase structural and functional performance. The printer being developed uses a mass produced FDM type printer modified with a custom nozzle which can extrude filament at an angle while continuously rotating. Custom software enables the printer to pause operation at predetermined print locations to allow an operator to insert a COTS item.

The following test plan outlines some of the key functional tests which will be performed to verify the correct operation of the ADD_IN printer and its subsystems

2. LOGISTICS

Tests have been designed to demonstrate system functionality while requiring a minimum amount of test time, equipment, and personal. With the exception of the SVE tests, all tests will be performed within the MRSD lab by select team members, without requiring additional tooling or fixtures. Some tests however will require the design and generation of custom .stl and/or g-code files which will be produced by team members in the days prior to test.

The spring validation experiment will require the use of a tensile testing machine. Preliminary arrangements have been made with the CMU material science department to gain machine access. In the event that a tensile testing machine is unavailable, provisions can be made using tooling available within the RI machine shop and readily available force scales which are within the team's budget.

3. TEST SCHEDULE

MILESTONE	DATE	TEST ID	TEST
PR 8	10-Feb	1 2	- Motor Synchronization Test - Consistent Filament Extrusion During Rotation Test
PR 9	24-Feb	3 4 5	- Software Collision Checking - Motor Current Test - R Axis Homing Switch Repeatability
PR 10	16-March	6 7	- Locating Feature Accuracy And Repeatability Test - COTS Item Adhesion Test
PR 11	30-March	8	-Software Web Pipeline Test
PR 12	11-April		(Preparation for SVE)
SVE	20-April	SVE.1 SVE.2 SVE.3	-Bending Stiffness Test -Fastener Pullout Strength Test -Integrated Sensor/Electronics Test
SVE ENCORE	27-April		-Bending Stiffness Test -Fastener Pullout Strength Test -Integrated Sensor/Electronics Test

4. TESTS

4.1 Motor Synchronization Test

Objective:

The objective of this test is to ensure that all axes including the R-axis move simultaneously with each other

Elements:

Firmware and Hollow Stepper Motor

Location:

MRSD Lab

Equipment:

MakerGear M2, Hollow Stepper Motor, Pen and Paper

Personnel:

Nikhil Baheti

Procedure:

The modified firmware will be uploaded to the ATMega2560 on the RAMBo board. A pen will be mounted on to the hollow stepper motor and a paper will be placed on the printer bed. A planar test pattern that includes G-codes G0 – G3 will be used. A G-code file will be generated containing the commands and then using will be sent to the RAMBo board using Pronterface. The following are the subtests:

1. Then the test will be repeated for same patterns to test repeatability
2. Different patterns like "ADD_IN" will be drawn to test generality.
3. To test synchronicity of motors, a test at reduced speeds of the motors for various G-code commands will be performed.
4. The final test will be to check if the printer can draw a point while the x-axis and y-axis are moving along the circumference of a circle with radius equal to the r-axis offset and the r-axis must point to the center of the circle.

Verification Criteria

The test will be considered as pass if the following points are successful:

- The test repeated with same patterns must overwrite on the previous pattern.
- The test for different patterns must produce the expected pattern
- Synchronicity will be a visual check and will be successful if all the motors stop at the same time at the end of a G-code.
- The pen must draw only a point for the final test.

4.2 Consistent Filament Extrusion during Rotation Test

Objective:
The objective of this test is to ensure that the rotational joint can extrude filament consistently while rotating.

Elements:
Rotary joint, extruder and hot end.

Location:
MRSD Lab

Equipment:
MakerGear M2 with rotary joint

Personnel:
Ihsane Debbache

Procedure:
Upon integration of our hardware, we will use this test to make sure the rotary joint can extrude filament consistently. To achieve that, we will send a G-code to the printer that makes the rotary joint rotate while extruding. The G-code describes a cylinder, with the R axis rotating and the X & Y axes fixed.

Verification Criteria
The test will be considered as pass if the following points are successful:

- The rotary joint rotates at constant speed, without
- The extruder and hot end do not jam
- The extruder and hot end do not leak
- The filament does not break due to kinks

4.3 Software Collision Check Test

Objective:
To ensure that the generated G-Code does not allow the extruder to collide with the inserted COTS parts

Elements:
The key element to be tested is the software subsystem.

Equipment:
Necessary equipment includes

- Laptop with MATLAB running on it

Personnel:
Members of the software team, namely Dan and Astha

Procedure:
1. Run the ADDIN GUI
2. Select a .STL file
3. Enter COTS item dimensions
4. Enter insertion layer height
5. Generate 4 axis G-Code
6. Run the collision check function that will check for collisions between the nozzle and COTS item at every printer state
7. Visualize toolpath generated by G-Code

Verification Criteria:
The test will be considered a success if

- The collision check function does not return collisions for any of the printer states
- The toolpath visualization does not suggest collisions

4.4 Motor Current and Heating Test

Objective:

The objective of this test is to ensure that the R-axis stepper motor does not heat up while operation

Elements:

Firmware and Hollow Stepper Motor

Location:

MRSD Lab

Equipment:

MakerGear M2, Hollow Stepper Motor, Ammeter (Multimeter)

Personnel:

Nikhil Baheti

Procedure:

The modified firmware will be uploaded to the ATMega2560 on the RAMBo board. An ammeter will be connected in between the E1 port and the one of the coils of the stepper motor being driven by it. The digipot settings will be varied to vary the current applied to the coils. The current in the ammeter will be recorded with the corresponding digipot settings

Verification Criteria:

The test will be considered as pass if current does not exceed 0.8A as suggested by the stepper motors datasheet.

4.5 R Axis Homing Switch Repeatability Test

Objective:
The objective of this test is to ensure that the rotational joint homes with enough precision and repeatability.

Elements:
Rotary joint, Endpoint sensor and Firmware

Location:
MRSD Lab

Equipment:
MakerGear M2 with rotary joint

Personnel:
Ihsane Debbache

Procedure:
A simple script will be uploaded to the firmware in order to test our homing system, which will be an encoder wheel with only one slot attached to the stepper shaft and an infrared slot sensor. The script will be used to do the following:

1. Home the stepper initially, by running the stepper forward at normal speed until the slot sensors detects the slot, run back a few steps then forward again with the slowest speed, to improve precision.
2. Stop and set that position as the zero angle.
3. Rotate the motor a certain number of steps, in one direction, then rotate back the other direction slowly until the end stop is set, and record the position at which that happens.
4. Repeat those steps 3 times in each direction.

Verification Criteria:
The test will be considered as pass if the following points are successful:

- The recorded positions at which the end stop gets set, after the initial homing, is always zero, or within one full step of zero.

4.6 Locating Feature Accuracy and Repeatability Test

Objective:
The objective of this test is to ensure we are able to precisely position the COTS item on the part.

Elements:
Software, Extruder, COTS item.

Location:
MRSD Lab

Equipment:
MakerGear M2 with rotary joint, COTS items

Personnel:
Ihsane Debbache

Procedure:
For this test we will print a rectangular part containing locating features for rectangular and cylindrical COTS items, and then we will place the COTS item and measure its position by moving the printer nozzle until nearly contacting it.

Verification Criteria:
The test will be considered a success if the COTS items are consistently localized within 0.1 as visually verified by proximity the to printer nozzle at a known location

4.7 Adhesion Test

Objective:

The objective of this test is to find out to which COTS item materials the filament adheres

Elements:

Rotary joint, extruder and hot end.

Location:

MRSD Lab

Equipment:

MakerGear M2 with rotary joint, COTS items made of various materials

Personnel:

Ihsane Debbache

Procedure:

After integrating our system and starting printing around COTS items, we will conduct this test by printing on top of simple rectangular shaped COTS items of a set surface made of aluminum, steel, copper and FR-4 glass epoxy(PCB substrate). Then we will measure the maximum normal force and shear force for each material using a tensile testing machine available in the MSE department. We will then repeat the test by varying the bed temperature and extrusion temperature, and compare it with the adhesion forces of the filament with the glass print bed.

Verification Criteria:

After the test we will record the sheer and normal forces data along with temperatures. And the test will be considered a success if at least two of the four materials mentioned have adhesion forces equal to, or greater than the adhesion forces of the glass print bed, which will ensure enough adhesion for reliable printing on that surface.

4.8 End-to-End Web Based Software Test

Objective:
To verify that the web pipeline for G-Code generation runs smoothly

Elements:
The key element to be tested is the software subsystem

Equipment:
Necessary Equipment includes:

- Laptop with internet connection

Personnel:
Members of the software team, namely Dan and Astha

Procedure:
1. Go to ADDIN's software application website
2. Upload .STL file
3. Feed in COTS item dimensions
4. Enter insertion layer height
5. Generate 4 Axis G-Code
6. Run the collision check function that will check for collisions between the nozzle and COTS item at every printer state
7. Visualize toolpath generated by G-Code
8. Download G-Code

Verification Criteria:
The test will be considered a success if

- The web interface allows the user to perform the procedure smoothly
- The toolpath visualization does not suggest collisions
- The user does not require MATLAB to generate the 4 axis G-Code

5. SVE

5.1 Bending Stiffness Test

Objective:

To demonstrate an increase in bending stiffness by incorporating stiffeners within a 3D printed part.

Elements:

A part produced using the ADD_IN printer will be tested. This will verify the basic functionality entire ADD_IN printer system (including software).

Location:

The printing process will occur in the MRSD lab. The bending stiffness will take place at the location of a suitable tensile testing machine

Equipment:

Hardware:

1. ADD_IN 3D Printer with associated computer, cables, and power supply
2. Tensile testing machine and fixture
3. Consumables (3D Print filament, stiffeners)

Software

4. ADD_IN Software Package
5. G-Code file for test part (T)
6. G-Code file for control part (C)

Personnel:

ADD_IN Team

Procedure:

1. The ADD_IN team will manufacture the test and control parts using the ADD_IN printer. The test part is a 3D printed part containing internal stiffener elements and designed to be compatible with the test apparatus. The control part is of identical external dimensions, but features additional infill material instead of internal stiffeners
2. Both the test and control part will be subjected to a bending stiffness test using a tensile testing machine. The maximum applied force and failure mode will be noted.

Verification Criteria:

Part Quality Verification

Prior to destructive testing, the test and control parts will be visually examined and determined if they are of similar print quality

Pull Out Strength

The pull out strength of the test part should be notably higher than the control part.

5.2 Threaded fastener pullout Test

Objective:

The objective of this test is to demonstrate and quantify the ability of the ADD_IN 3D printer to produce parts which can withstand greater fastener stresses than parts produced with a standard FDM process.

Elements:

ADD_IN printer integration and operation

Location:

MRSD Lab. MSE Lab

Equipment:

Hardware:

1. ADD_IN 3D Printer with associated computer, cables, and power supply
2. Tensile testing machine and fixture
3. Consumables (3D Print filament, #10-32 threaded inserts, #10-32 cap screws)
4. Drill press
5. #10-32 Tap and handle
6. #21 drill bit

Software

7. ADD_IN Software Package
8. G-Code file for test part (T)
9. G-Code file for control part (C)

Personnel:

ADD_IN Team

Procedure:

1. The ADD_IN team will manufacture the test and control parts using the ADD_IN printer. The test part is a 3D printed part containing one threaded insert feature and designed to be compatible with the test apparatus. The control part is of identical external

dimensions, but features a tapped 10-32 hole instead of an integrated threaded insert. The engagement length of the tapped hole is the same as the threaded insert.

2. Both the test and control part will be subjected to a pull-out strength test using a tensile testing machine. The maximum pull out force and failure mode will be noted.

Verification Criteria:

Part Quality Verification

Prior to destructive testing, the test and control parts will be visually examined and determined if they are of similar print quality

Pull Out Strength

The pull out strength of the test part should be notably higher than the control part.

5.3 Circuit Integration Test

Objective:

The objective of this test is to validate that electronic parts integrated as a part of an ADD_IN printed part are functional.

Elements:

ADD_IN printer integration and operation

Location:

MRSD Lab

Equipment:

ADD_IN, sensor/electronics, power supply for circuit, wires, connectors and other equipment as required for testing the operation of sensor

Personnel:

ADD_IN Team

Procedure:

Error! Reference source not found. shows the part intended to be designed. It is a force sensor embedded in a plastic casing with connection pins. This may be mounted on robots grippers or be used as a weighing machine to read the forces acting on it. The procedure to perform this test is as follows:

1. Use the web interface to load the .stl file

2. Select insertion layer and print configuration
3. Generate the *.gcode* file
4. Visualize resulting G-Code and ensure everything is as expected
5. Send *.gcode* file to printer
6. Start print
7. Insert sensor/electronics item when printer pauses at the insertion layer
8. Resume and finish printing
9. Connect the sensor to the RAMBo board analog extension port pins, the pin details and code is provided in 'ILR01 – nub.'
10. Run the program and see the readings on the serial monitor of the arduino.
11. Place your hand on the sensor and notice the changes in the readings.

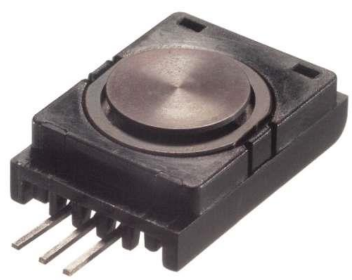

Figure 1 Part to be printed. It contains a force sensor, resistor and connection pins

Verification Criteria:

The test will be considered as pass if the force sensor shows changes in readings when we apply force with our hand. For this test it is assumed that the user has the knowledge of designing the assembly appropriately such that it does affect the sensor performance mechanically.