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PICK AND PLACE ROBOTIC ACTUATOR FOR BIG AREA ADDITIVE MANUFACTURING

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Abstract

Oak Ridge National Laboratory’s Manufacturing Demonstration Facility has created a system that works in tandem with an existing large-scale additive manufacturing (AM) system to ‘pick and place’ custom components into a part as it is printed. Large-scale AM leaves a layered surface finish and is typically post-processed through 5-axis CNC machining. Each surface must be accurately recorded into a laser tracking system. This process can be simplified with the use of fiducials, small location indicators placed on the surface of a part. Additionally, the ability to monitor an AM tool via wireless sensors is advantageous to gauge part health as it is fabricated and later used. The ‘pick and place’ system allows thermocouples, fiducials, and other sensors to be accurately placed throughout the tool as it is fabricated. This solution has the potential to reduce time, labor, and cost associated with fabricating, post-processing, and using AM parts.

Introduction

Pick and place robots are traditionally used in manufacturing environments. These robots perform tasks such as loading and unloading conveyer belts, changing tooling, and simple assembly operations like inserting roller bearings on a shaft [1]. Applying this technology to more advanced manufacturing processes, such as Big Area Additive Manufacturing (BAAM), will improve current manufacturing methods as well as increase the number of applications for the BAAM system.

One primary target for BAAM is the tooling industry [2]. Oak Ridge National Laboratory’s Manufacturing Demonstration Facility is using the capabilities of pick and place robotics by integrating this into their largest BAAM system made by Cincinnati Inc. to assist with tooling development. Two specific applications have been investigated using the integration of pick and place robotics and BAAM.

The first application influences the post-processing stage of BAAM tooling. Additively manufactured parts leave a layered surface finish and are typically post-processed through 5-axis CNC machining. However, tooling requires a smooth surface finish. To accurately mill the desired surfaces, the part must be aligned and located by a CNC machine. This process is traditionally done manually by a skilled technician. In this work, pick and place robotics was used to strategically place fiducials on the surfaces of a part as it was printed. This significantly decreased the time necessary to align the part for post-processing, and in a manufacturing setting of high volume output, this is much more time and cost effective.

The second application influences the capabilities of tooling created with BAAM. In this work, pick and place robotics was used to embed sensors in strategic locations on the tooling during the printing process. This creates an opportunity to monitor the tooling process with real-time data from the sensors located inside the tool. A prototype tool was created with three thermistor sensors to monitor the tooling temperature when applying heat. This application will streamline the tooling process and potentially influence the outcome of the parts created with these tools.

Pick and Place System

The pick and place system has been implemented to function within the BAAM printer. Figure 1 shows the location of the pick and place system with respect to the extruder. Figure 2 shows the components included in the pick and place system. This system uses pneumatically driven components along with custom alignment tools to pick and place objects with high accuracy. The pneumatic components for this system were manufactured by Schunk Gripping Systems. A Schunk HLM linear slide was used to lower and raise the gripper and a Schunk MPZ T-slot gripper was used to move the custom alignment fingers horizontally to an open and closed position. The location of the system was strategically chosen so that when the linear actuator is extended, it will operate below the extruder's nozzle, and when it is retracted, it will operate above the nozzle to ensure it is out of the way during the printing process.

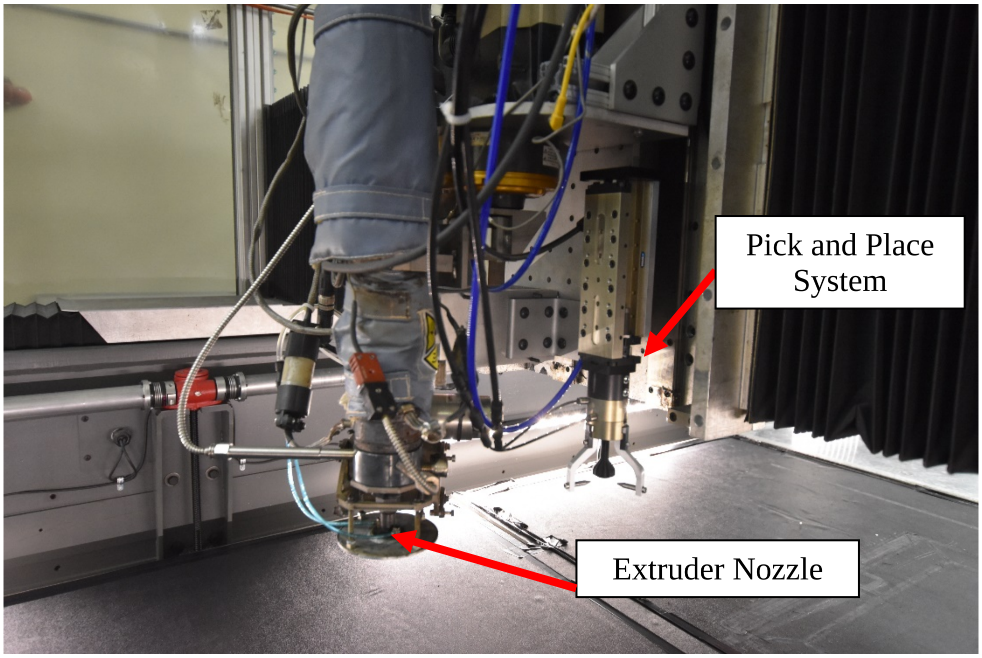

Figure 1: The location of the pick and place system with respect to the extruder nozzle.

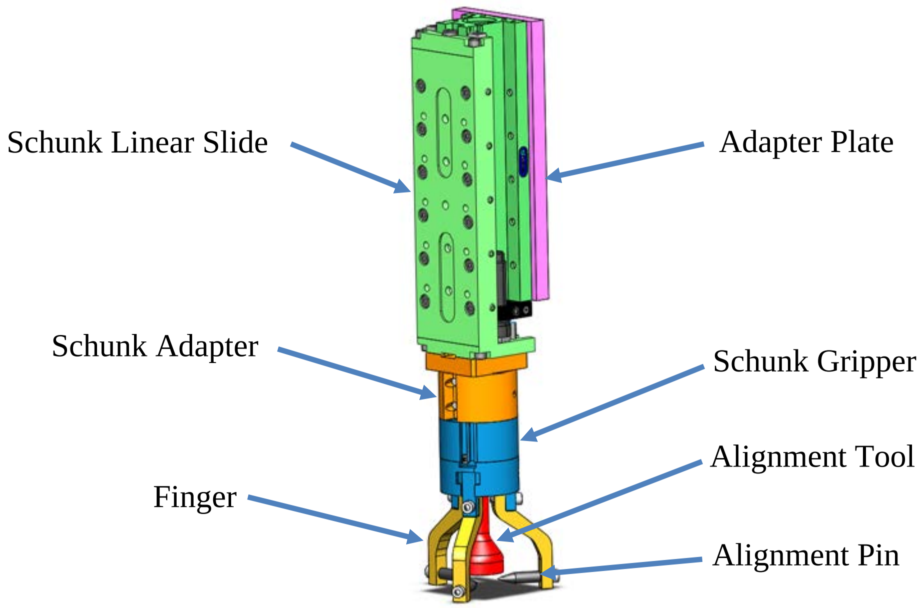

Figure 2: Pick and place CAD model with components.

Calibration of System

To ensure the system accurately places parts in the desired locations, the system was calibrated using a Faro Laser Tracking system. The offset of the pick and place system, with respect to the extruder nozzle, was measured using this Faro system. The tracker ball, used to bounce the laser back to the Faro to measure distance, was placed in the location of the tip of the nozzle and then in the location of the center of the gripper. The displacement of these locations was used for the x- and y-planes only. The z-offset was changed based on the application.

Alignment

To achieve consistent alignment, two custom components were added to the overall design. The first feature uses alignment pins that fit inside the grooves of the objects being placed. The second feature uses the alignment tool, which includes a drafted face to match the draft of the top face of the object being placed. These two features are illustrated in Figures 3 and 4. It should also be noted that the objects placed were 3D printed on an industrial 3D printer to ensure consistent and dimensionally accurate parts that can also be milled away after use if necessary.

Figure 3: Fiducial design features that ensure proper alignment.

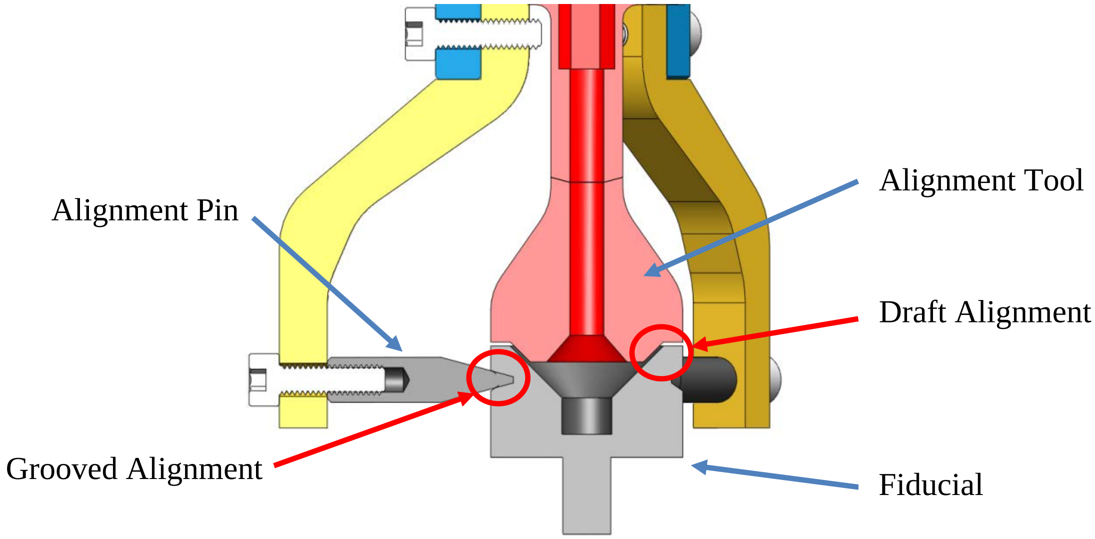

Figure 4: Section view of the pick and place CAD model. Specifically, this figure shows the alignment features located on the gripper.

Fiducial Testing

To achieve quick and efficient surface measurements, the pick and place system was used to place fiducials on the surface of the part and later tested for accuracy. First, the part was printed. Then, the fiducials were placed on the part's surface during printing. This procedure involved the pick and place system moving over to the custom fiducial magazine, shown in Figure 5, and picking up each individual fiducial. Next, the extruder nozzle moved to the location where the fiducial was placed. Then, a glob of material was extruded, and the printer moved the pick and place system directly above the glob of material and placed the fiducial. This process was repeated for the remaining fiducials. Once the printing was complete and the part was aligned for CNC machining, the 3D printed fiducials can be milled off, leaving a clean surface finish.

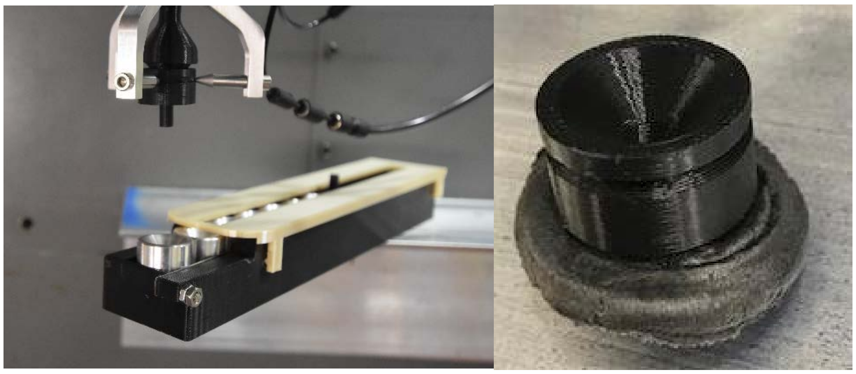

Figure 5: On the left is the custom fiducial magazine. On the right is a fiducial that has been placed in a glob of material.

The alignment process is crucial for post-processing. Once the part finished printing, the part was placed on a CNC milling platform, and a Faro Laser Tracker was used to define its alignment and placement on the milling platform. The previous method to track alignment was to use the Faro tracking ball to trace out surfaces until the part's CAD model could be aligned with the tracked surfaces captured by the Faro. This is a tedious and time-consuming process. An alternative method was created with the placement of fiducials. This method removes manual surface tracing with the tracker ball and instead uses the fiducials as aligning targets for the tracker ball to sit in. The fiducial locations were theoretically interpreted in the CAD model and then compared with the actual tracker ball locations on each fiducial, which communicates the alignment of the part much more efficiently. The elimination of surface tracing was the main goal in this application experiment. To understanding the accuracy of this new alignment method, a test piece was printed on a BAAM printer, and the fiducial locations were recorded and interpreted.

Data and Results

After comparing the alignment of the 3D printed part to the CAD model, the data was promising. The Verisurf software, used to analyze the Faro Laser Tracker data, output the offset values of the surfaces measured compared to the CAD model. Looking at Figure 6, three targets can be seen in blue, white, and red. These targets resemble the locations of the fiducials. Several surface measurements were taken to identify the accuracy of the alignment. A perfect placement would display an offset value equal to zero. The range of offset data reads as low as 0.049" to as high as 0.998". This offset range is quite large, including several outliers, which are highlighted in Figure 7.

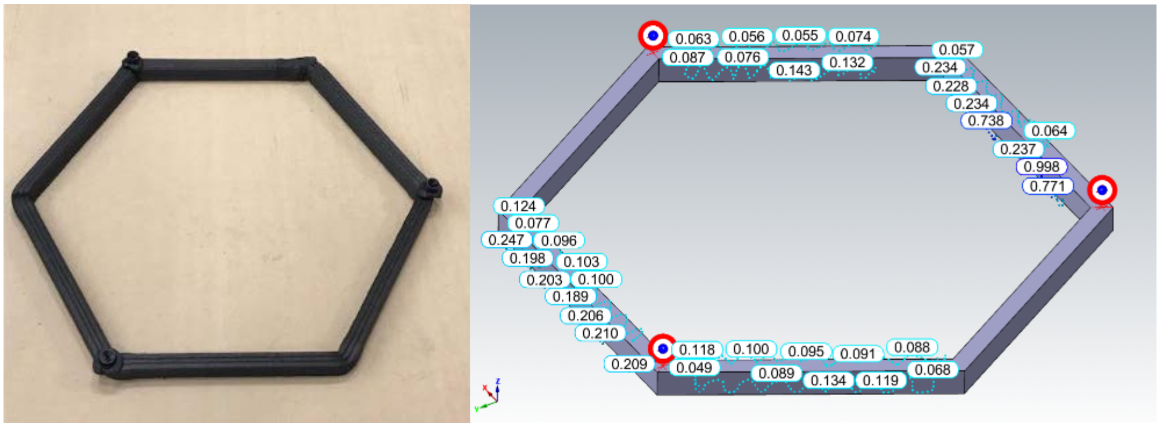

Figure 6: On the left is the 3D printed model, and on the right is the CAD model with surface offset data.

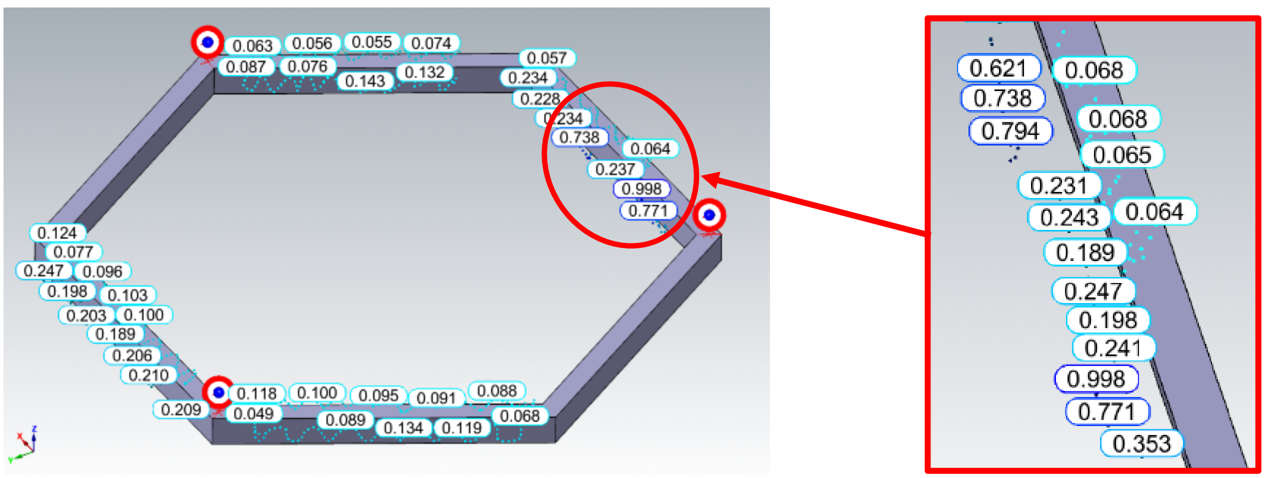

Figure 7: A closer look at the outlier data collected from the surface offset data.

The outliers appear to be greater than the average offset from the data gathered. The outliers also appear to be concentrated in one section. Figure 8 shows that the fiducial closest to the outliers is inadequately levelled on the part. Any inconsistencies in the alignment of placed fiducials will negatively impact the alignment process, likely causing the outlier data. This misaligned placement could have been caused by the cooling process of the polymer where the fiducial moved as the polymer cooled and hardened.

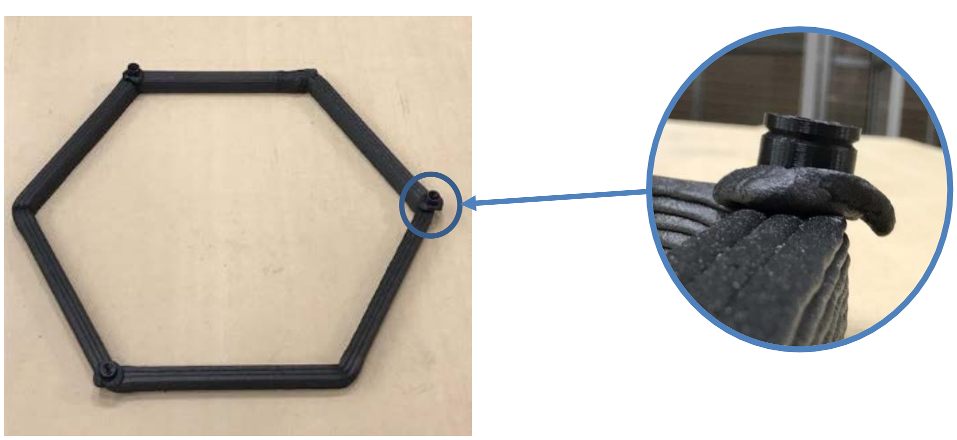

Figure 8: A closer look at the unlevel fiducial placed on the part.

Embedded Sensor Testing

The inclusion of a compliant wireless sensor platform brings a new wave of possibilities for 3D printed tooling. Embedded sensors will help tool users monitor surroundings and gauge part health as it is fabricated and later used. The sensors embedded into the tools are placed in small, 3D printed capsules as shown in Figure 9. The capsules are designed so that the main body that contains the sensor is placed inside the tool as it is printed. Attached to the main body is a magnetic lid. The lid is designed with alignment features, similar to Figure 3, and is detached from the main body once the main body has been embedded in the tool. Several of these capsules are placed into a magazine mounted inside a BAAM printer as shown in Figure 10.

Figure 9: On the left is the sensor module assembly, displaying the magnetic lid, cap, sensor, and main body respectively. On the right is the sensor module fully assembled.

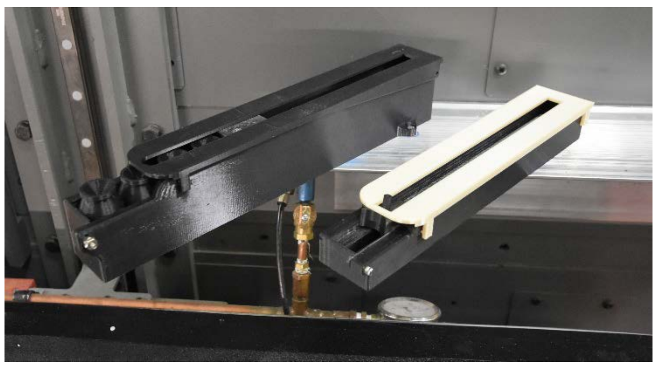

Figure 10: Sensor module magazine on the left and fiducial magazine on the right.

For this application, Tarts wireless sensors were used. Tarts is a division of the Monnit Corporation, which brings fully functioning sensors to developers incorporating their own monitoring systems using Arduino, Raspberry Pi, or BeagleBone Black platforms. Tarts offers a wide range of wireless sensors, but temperature sensors were chosen for this test as they provide useful information for tooling.

The platform chosen for this project is an Arduino Uno board with a special Tarts Gateway attached. LabView was used to record the data from the sensors and displays real-time data in a user interface. Both the microcontroller and LabView interface are displayed in Figure 11. A custom interface allowed for the user to input the ID of each sensor used, save the data from that sensor, and display it. The sensors communicate with an Arduino board where the Arduino code automatically detects new sensors and relays the information to LabVIEW.

Figure 11: Arduino/ Tarts Gateway microcontroller with data capturing through LabVIEW.

When designing the tool in a CAD software, a "cup" must be included for every sensor capsule. These cups are placed inside the tool cavity as shown in Figure 12. The "cup" is designed to securely hold the sensor. Once the printer has completed the top layer of the cup, the print is paused while the Pick and Place system inserts a sensor capsule into it and discards the lid. The printer then resumes printing the next layer. The tool printed was designed with a circular opening on one end to hold a heater. The heater blew hot air through the inside of the tool and past the three successive temperature sensors.

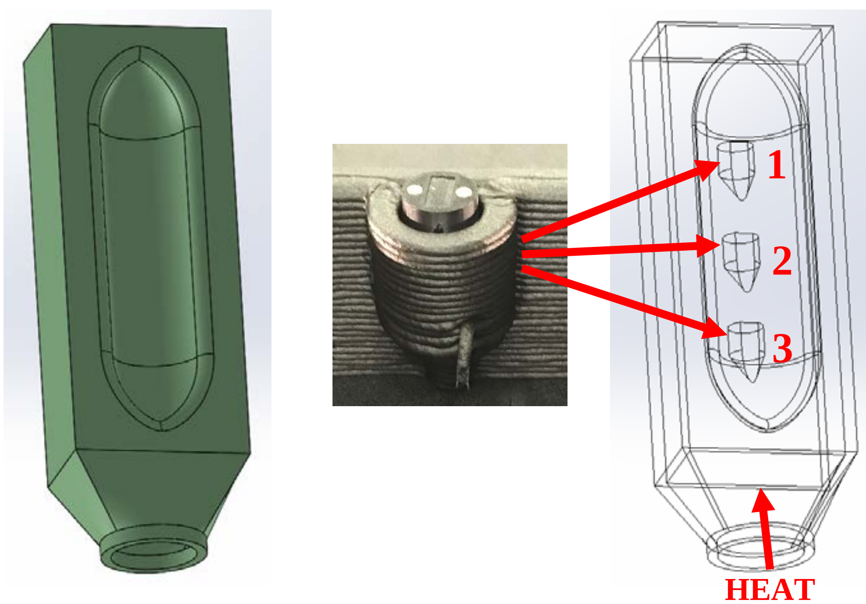

Figure 10: CAD of tooling with sensor module cup locations.
Sensor 1 is furthest from heat source, and sensor 3 is closest.

Data and Results

A test was conducted to determine the viability of using embedded temperature sensors in a heated tool. Shown in Figure 13, hot air was pumped through the internal cavity of the tool, which contained three embedded temperature sensors. The temperature across the sequential sensors was expected to decrease as they became further away from the hot air source.

The data in Figure 14 represents the temperatures of each individual sensor with respect to time. The

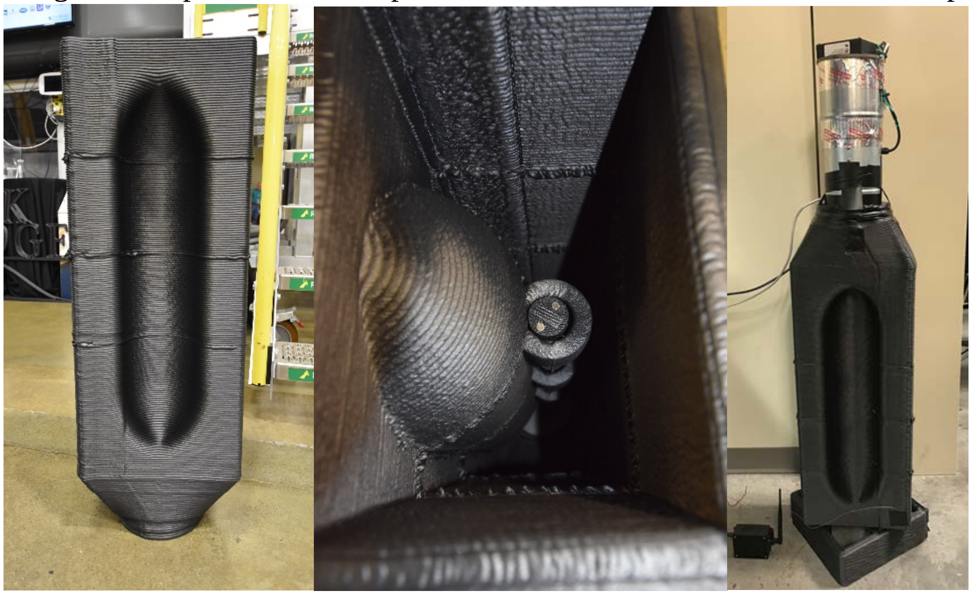

Figure 11: Printed tool on left with sensor modules inserted. Internal cavity of tool in the middle. Sensor module test rig with heater on right.

internal cavity of the tool started at 24°C. Hot air, at 40°C, was blown through the cavity for over an hour. Sensor 1, furthest from the heat source, proved to sense the lowest temperature, and Sensor 3 sensed the highest temperature. This proves that the sensors are, in fact, reading predictable data that can be calibrated to read the outer surface temperature of the tool. Note that Sensor 2 lost communication half way through the test. This problem will need to be further investigated, but it was most likely caused by the coiled-up antenna on the temperature sensor. The antenna will need to be uncoiled in the tool to improve communication. Overall, the data proved to be promising.

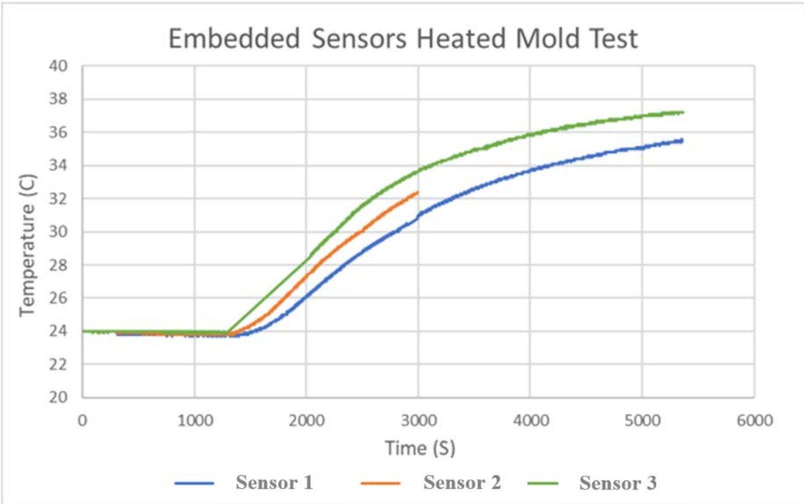

Figure 12: Test results of sensor module in 3D printed tooling.

Conclusion

Two applications were tested using a pick and place system integrated on Cincinnati's BAAM system. The first application used fiducials to help accelerate the alignment of parts during the post-processing procedure. This proved to reduce the number of steps required in the alignment process but displayed some error with accuracy. The second application used the pick and place system to embed temperature sensors inside tooling. The sensors were successfully embedded throughout the tool and continuously monitored the temperature of the mold as a heat source was added. One of the sensors lost communication half way through the test, but overall the test was a success.

Future work for the fiducial application may require a modification of the pick and place procedure. The shape and amount of material that is laid down for fiducial placement will need to be adjusted. This adjustment will create a better seat for the fiducial so that it will remain flat once the material dries. Future work for the embedded sensor application should focus on an improved communication system. The sensors had trouble connecting with the microcontroller prior to testing. To maintain signal strength, the antenna may require adjustment prior to placement in the cup.

The possibilities that come with pick and place technology in an additive manufacturing setting will continue to grow. The two applications tested represent a fraction of the possibilities for this technology. The overall goals are to thoroughly integrate the process into slicer software and to scale up the technology so larger reinforcements can be added during the printing process. The work presented provides a foundation for future work with pick and place technology and the advancement of manufacturing techniques.

References

1. Angeles, J.: Fundamentals of robotic mechanical systems, 3 edn. Springer (2007)
2. Post, Brian K. et al, "Big Area Additive Manufacturing Applications in Wind Turbine Molds." *Solid Freeform Fabrication Symposium* (2017).