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Optical Process Control for Additive Manufacturing

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Abstract

This project demonstrates a method that helps increase the reliability of an additive manufacturing process in the field of construction, through a stable material extrusion and automated monitoring of the printing process. In order to maintain a consistent width of the extruded filament, an optical process control system has been developed using real-time monitoring through an RGBD camera in order to regulate the speed of material extrusion by means of a PID controller. In addition, a method to observe the deviation of printed structures to the respective reference geometry is implemented to assist in defect detection (e. g. elephant's foot formation) that can lead to plastic buckling. Earliest failure detection can help prevent plastic collapse.

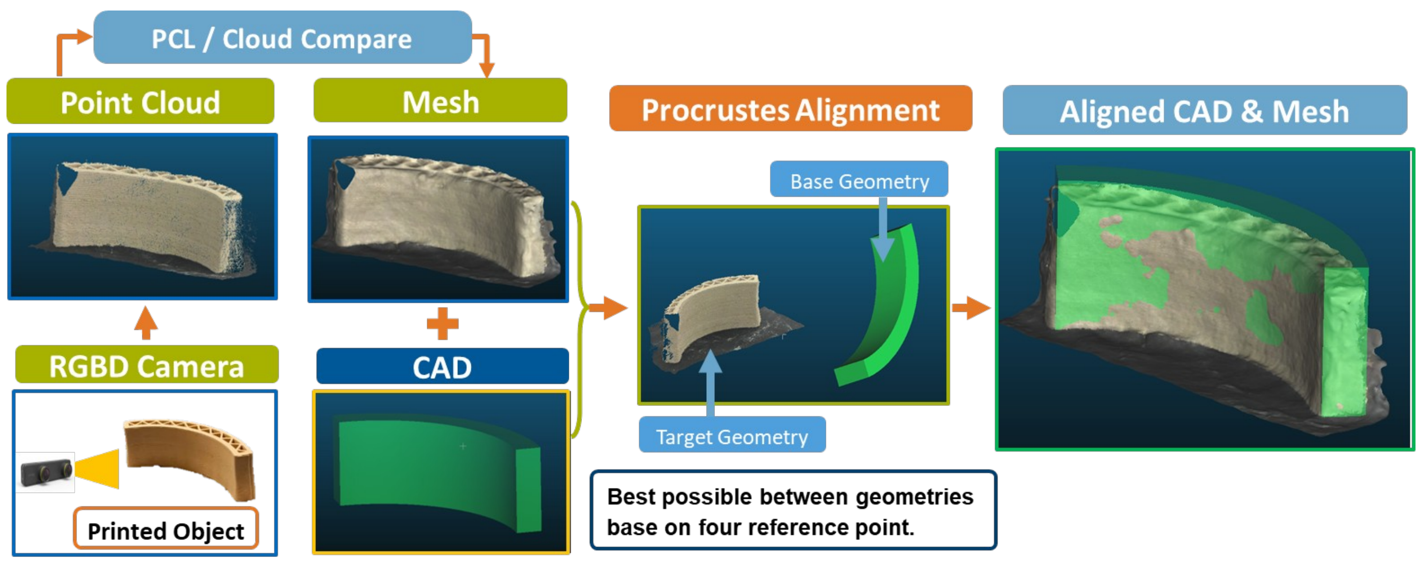
Motivation

Up to this point, the 3D printing process was controlled manually and adapted depending on the user input, which is limited in accuracy and prone to human error. In additive manufacturing, for stability and aesthetic reasons, a controlled extrusion is of high importance. Any error at the beginning of the print would be compounded as layers are printed on top. Automating this process aims to ensure consistent results.

Process Monitoring

The objective is to evaluate width of the extruded layer [2]. This is accomplished by applying adjustable color filters based on HSV (hue-saturation-value), on frames obtained from RGBD camera, this segments extruded layer from background. Calibration of pixels is done by providing pixels per mm over a fixed height, using an object of known dimension. Dynamically tracking of object is done by establishing smallest best fit rectangle over detected contour over each frame.

For comparing print with planned geometry [3], an RGBD camera placed at a fixed distance can be used to get point cloud data. which is then converted to mesh. The mesh generated from the point cloud can then be aligned with planned geometry using Procrustes alignment method.

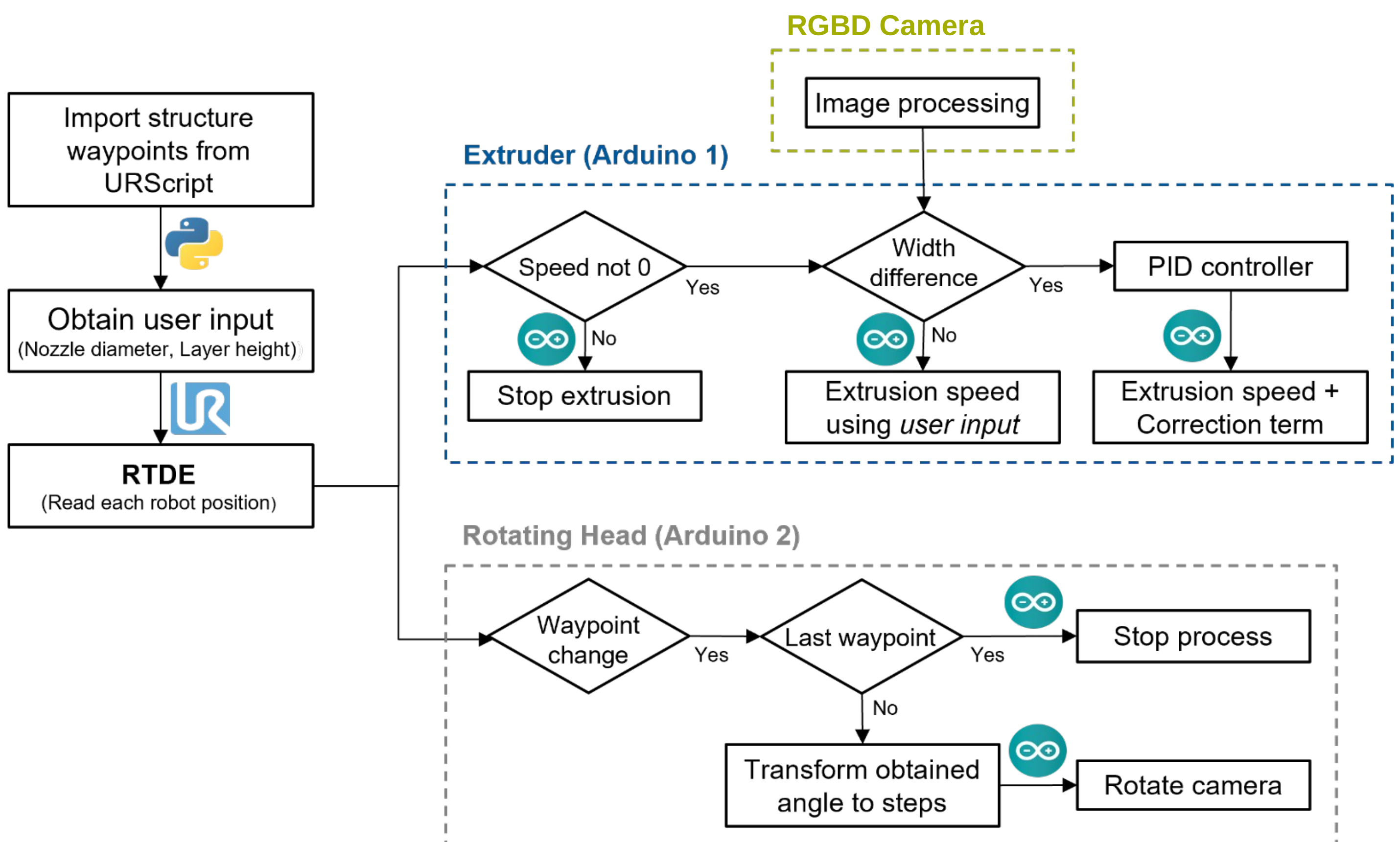


Process Flow to Compare Planned Model with Printed Geometry

Process Control

Once a print path is executed on the UR10e robot controller, the *Process Control Logic* algorithm obtains input from the robot through RTDE (Real Time Data Exchange) [1]. In parallel, *Image Processing* gives feedback to the main loop. When a camera width is detected, the PID controller starts its internal process.

The PID controller compares the error between both inputs and provides a correction term that is added to the extruder speed. The obtained extruder speed is sent to the *Arduino 1* and keeps executing until a different value is detected



Process Control Logic

For curvatures, the camera head needs to rotate according to the waypoints in order to be able to capture the extruded filament. The necessary angle of rotation is calculated using the slope between two waypoint lines. The obtained angle is sent to the *Arduino 2* including the direction of the rotation and the number of steps necessary to reach this position. The process is terminated once the final waypoint is detected.

Conclusion

The outcome of the project provides a solution for a stabilized control of the printed filament width. The PID controller ensures a consistent print based on the optically evaluated width. Finally, the obtained structure can be compared with the target geometry using an RGBD camera.

Future Improvements

- Implementing the method around a high-resolution sensor, such as a laser line profiler can provide sufficient image resolution to resolve depth on a mm scale.
- Redesign the camera head to reduce the offset between the printing nozzle and the camera view.
- Determine the UR10e robot movements through RTDE to ensure a time-accurate waypoint.

References

[1] UR10e - RTDE - https://www.universal-robots.com/articles/ur/interface-communication/real-time-data-exchange-rtde-guide/
[2] A. Kazemian, X. Yuan, O. Davtalab, B. Khoshnevis, Computer vision for real-time extrusion quality monitoring and control in robotic construction, Automation in Construction 101 (2019) 92–98
[3] Wolfs, R.J.M., Bos, F.P., van Strien, E.C.F., Salet, T.A.M. (2018). A Real-Time Height Measurement and Feedback System for 3D Concrete Printing. In: Hordijk, D., Luković, M. (eds) High Tech Concrete: Where Technology and Engineering Meet. Springer, Cham