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Experimental Workflow Implementation for Automatic Detection of Filament Deviation in 3D Robotic Printing Process

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1 Introduction

3D-Concrete Printing (3DCP) is a form of Additive Manufacturing (AM) using cementitious materials specifically for the fabrication of construction components or urban furniture, it reduces construction time while increasing the complexity of the building. As a multidisciplinary field, the print quality can be affected by different factors, including material mixing proportion, environmental conditions and printing system parameters, thus, the cooperation between different parts of 3DCP remains a challenge. Moreover, when the print job is performed in uncontrolled environment with perturbations (e.g. outdoors), the parameters determined in a controlled environment through a calibration procedure can not be ensured to match the material state sufficiently to maintain print quality because the behavior of the material changes during the printing process due to environmental changes and internal chemical reactions, as it is in transient status. Fig. 1 demonstrates a typical process of 3DCP, including three steps : tool path generation, material preparation and material deposition (printing). Conventional 3DCP workflow requires an inspector to monitor the print quality and intervene in printing parameters when filament size deviates during printing. To address this limitation, an automatic filament deformation detection method is needed to automate the printing process. In

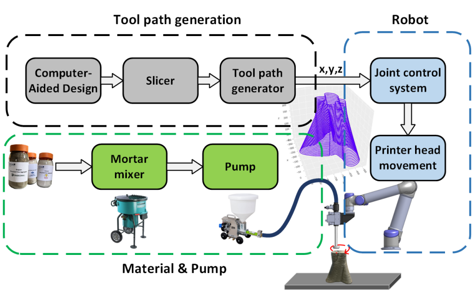

FIG. 1 – The process of 3DCP

this paper, an integrated workflow of robotic 3DCP is proposed, focusing on the detection of deviations in printed filaments. A print quality monitoring process is integrated into the conventional 3DCP workflow, this process includes a vision system that automatically detects deviations in filament width with parametric uncertainties. The filament width deviation detection is realized by two steps : firstly, a filament width estimation algorithm based on Deep Learning and morphology is developed to estimate the width of printed filaments in real time. Secondly, residual signal and adaptive threshold are generated to detect filament width deviation. The residual signal is derived from geometric relationships that reflect the deposition state of the material, and adaptive thresholds with consideration of parametric uncertainty helps to detect deviation and avoid false alarm in the monitoring of the printing process. The output of the quality monitoring part helps to determine the operation status of the printing process. If filament width deviation is detected, the printing system can be reconfigured to compensate by adjusting the nozzle movement speed [1] or the pumping speed. By considering multiple parameters, this workflow improves the detection of printed filament deformation and contributes to future development of compensation strategy.

2 Workflow for automatic detection of filament deviation

2.1 Printing system equipped with multiple sensors

A printing system, as shown in Fig.2 with multiple sensors including flow rate sensor and cameras were deployed to facilitate the online monitoring of the printing process and perform deviation detection.

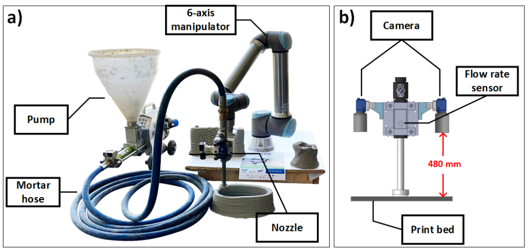

FIG. 2 – 3D Concrete Printing System. a) Overall view of printing system. b) Nozzle equipped with multiple sensors.

2.2 Vision based estimation of filament width

A vision-based filament width estimation method was developed by using a Deep Learning instance segmentation model, namely Mask RCNN. The estimated value of width in millimeter is given by this method.

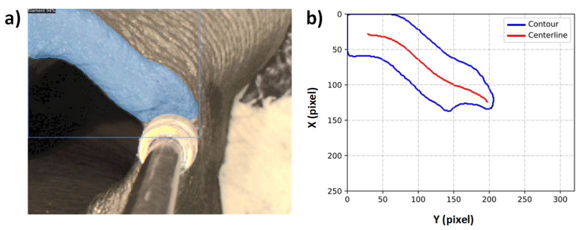

FIG. 3 – a) Output of Mask RCNN. b) Contour and center line of filament reconstructed in image frame.

2.3 Automatic filament width deviation detection

The method is based on the following geometric model of material deposition filament illustrated in Fig.4. According to the geometric model, the following relation can be established :

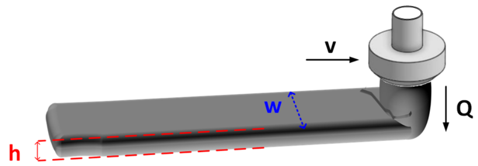

FIG. 4 – Geometric model of material deposit filament during a printing process. h is the filament height, w is the filament width, v is the nozzle travel speed and Q is the volumetric flow rate of material deposit. h is considered identical to the designed layer height.

$$Q = whv \tag{1}$$

The following equations were derived from equation 1 by considering the parametric uncertainties, which consist of two parts : 1) a nominal part r called residual for describing the model and 2) the uncertain part a which is used for the generation of adaptive thresholds during normal operation of the system

$$\begin{cases} r = Q - w_n h_n v \\ a = |w_n h_n \delta_h v| + |w_n \delta_w h_n v| + |w_n h_n v \delta_h \delta_w| \end{cases} \tag{2}$$

2.4 The integrated workflow

The proposed workflow of filament deviation detection during a printing process combines the steps depicted above and integrate them into a traditional 3DCP workflow. The workflow monitors the quality of filament in term of width and detects filament deviation. Once deviation is detected, an adaptive speed compensation step is applied to compensate for the deviation. The detailed compensation quantity is reported in [1].

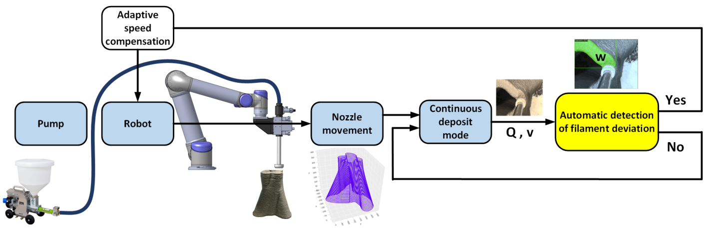

FIG. 5 – The integrated workflow of automatic filament deviation detection in a 3DCP process.

3 Conclusions et perspectives

In this paper, an integrated workflow of filament deviation detection in a 3DCP process is developed. The integrated workflow improves the robotic 3DCP process by providing solution to online print quality monitoring. When deviation occurs, a compensation step will be applied by updating the nozzle speed, future works will focus on improving the reconfiguration of printing parameters during robotic 3DCP process.

Références

[1] X. Yang, O. Lakhal, A. Belarouci, & R. Merzouki (2022). Adaptive deposit compensation of construction materials in a 3d printing process *2022 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)*. IEEE, 2022, pp. 658–663.