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Build Time Estimation Models in Thermal Extrusion Additive Manufacturing Processes

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Abstract

In this study, two build time estimation models (analytical and empirical) for the Material Extrusion (ME) - Fused Deposition Modelling (FDM) Additive Manufacturing (AM) process have been developed. Both models have been validated through a set of experimental case studies. The inputs required for the models include the G-Code, the volume of the part and experimentally defined coefficients related to the AM equipment. Both models are fast to run, simple in their use and provide very accurate results, since the acceleration and deceleration of the machine head is also taken into account, the effect of which play an important role in the final time estimation. The results retrieved from the analytical models are the most accurate. The outcomes of the current study are expected to assist in better production planning and energy efficiency issues related to FDM – AM processes.

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Keywords: Additive Manufacturing; Build Time Estimation; Fused Deposition Modelling;

1. Introduction

Additive Manufacturing (AM) is defined as "the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies, such as traditional machining"[1]. Bikas et.al. [2] stated that AM offers many advantages, the most important of which are near zero material waste and design freedom, allowing for the manufacturing of parts with complex geometry without any extra cost. According to Berman [3], AM makes possible the manufacturing of customized parts at a much lower cost, because it eliminates the need for auxiliary equipment, like molds.

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Table 1 Nomenclature

Nomenclature	
a	*Head Acceleration*
k	*Number of times the head accelerates/decelerates*
l	*Line length*
T	*Build time*
t_1	*Time the machine head accelerates/decelerates*
t_r	*Time needed for rapid movement*
t_u	*Constant velocity deposition time*
u	*Constant Velocity of deposition*
V_r	*Rapid movement velocity*
x_1	*Distance in which accelerating movement takes place*
x_2	*Distance in which head's velocity is constant*
w_{coef}	*Distance Coefficient*
a_{coef}	*Acceleration Coefficient*

There is a wide range of materials that can be used in the different AM processes (Bikas et.al. [2]). One of the most common AM processes is the Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF). In this process, a moving extrusion head deposits in a layer-by layer fashion thermoplastic material (ABS, PLA, Nylon, Composites etc.), after it has been heated to a temperature close to its melting point (Chryssolouris [4]).

Some of the factors that determine part quality are surface roughness, dimensional accuracy and mechanical properties. Several attempts have been made towards optimization of the AM processes by the optimization of those Key Performance Indicators (KPIs), utilizing modelling and simulation. However, according to Danforth and Safari [5], one of the most important drawbacks of AM is the low productivity of the process, which is directly connected to the Build Time (BT). On the issue of low productivity, Han et.al. [6] conducted a build time analysis of the process parameters for improving it. Gibson et.al. [7] defined the BT as the time needed for the manufacturing of a part, without taking into account design time, conversion of the CAD file to STL or the development of the G-Code. Jin et.al. [8] investigated the different impact of path generation concerning different process parameters and stated the importance of time estimation in a wide range of scientific and industrial applications. More specifically, Zhang et.al. [9] developed an adaptive estimation BT model and state that BT estimation is essential for layered manufacturing, as it affects the production process planning. Chryssolouris [4] pointed out that the cost of the final part heavily depends on the machine's operation time. Ahsan et.al. [10] studied a large amount of input data concerning part features, machine setup and production requirements that are necessary for the development of an effective BT estimation model, which are are accuracy, low simulation times and simple input data need. However, according to Jin et.al. [8], it is difficult to meet all these requirements simultaneously. Bikas et.al. [2] classified BT estimation models in three main categories: analytical, numerical and empirical. Thrimurthulu et.al. [11] studied the optimum part deposition orientation in FDM process in order to achieve better part quality or minimum built time, utilizing a numerical BT model. BT estimation models for AM have been presented in several other studies, some of which can be adapted to the FDM process [12]-[15].

The parameters that affect the BT of a part can be divided in three main categories i) The volume and mass of the part, ii) The configuration of the printer and iii) The kinematic characteristics of the printer (acceleration, deceleration, printing speed, rapid movement speed) (Table 2). However, most of the existing BT estimators do not take into account the acceleration and deceleration of the printing head, neither the rapid movements, resulting in less accurate estimations, particularly for parts with complex geometry. The models that are presented in this study take into account acceleration, deceleration and rapid movements of the printer head, resulting in estimations of higher accuracy. More specifically, in this study two models for the calculation of the kinematic characteristics (head velocity and acceleration) of the FDM AM process are presented: an analytical and an empirical one. The empirical build time model requires less input data, while the analytical is more accurate and both require low computational time.