Machine Learning for Additive Manufacturing

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Additive manufacturing (AM) is the name given to a family of manufacturing processes where materials are joined to make parts from 3D modelling data, generally in a layer-upon-layer manner. AM is rapidly increasing in industrial adoption for the manufacture of end-use parts, which is therefore pushing for the maturation of design, process, and production techniques. Machine learning (ML) is a branch of artificial intelligence concerned with training programs to self-improve and has applications in a wide range of areas, such as computer vision, prediction, and information retrieval. Many of the problems facing AM can be categorised into one or more of these application areas. Studies have shown ML techniques to be effective in improving AM design, process, and production but there are limited industrial case studies to support further development of these techniques.

machine learning | supervised learning | unsupervised learning | reinforcement learning | additive manufacturing | design for additive manufacturing | additive manufacturing process | additive manufacturing monitoring

Additive manufacturing (AM) is the name given to a family of manufacturing processes where materials are directly joined to make parts from 3D modelling data [1]. This is generally done in discrete planar layers, but non-planar processes also exist [2]. AM enables various advantages, particularly when compared with traditional manufacturing techniques, the enablement of mass part customisation and greater part complexity on the macro-, meso-, and micro-scales [3]. Other advantages include not requiring any hard tooling and enablement of on-demand manufacturing [4]. Despite these benefits, drawbacks include a lack of inherent repeatability [5] which has led to difficulty in gaining certification in some sectors [3]. Another drawback is the lack of widespread design knowledge and tools tailored specifically for AM and the above-mentioned benefits that are enabled [3].

While, to some extent, applicable to all major industries, AM development has been largely driven by the aerospace, automotive and medical sectors [4]. The major driver in the aerospace and automotive sectors is to reduce component mass whilst not hindering performance [4]. A wider range of motivations is seen for medical applications of AM, although patient customisation, improved biocompatibility and performance is a common theme [4]. AM is also often used in consumer products, with mass customisation and light-weighting both being common motivations [4]. Machine learning (ML) is a branch of artificial intelligence concerned with training programs to automatically improve their performance. With this broad definition in mind, there are different types of ML which may be classified as supervised, unsupervised, semi-supervised, or reinforcement learning [6]. Shinde and Shah identified five key application domains for ML [7]:

- Computer vision.

- Prediction.
- Semantic analysis.
- Natural language processing.
- Information retrieval.

Of these five domains, computer vision, prediction, and information retrieval have applications in AM. More varied exploration into these areas has been enabled by recent advances in graphics hardware which have allowed for faster optimisation of ML algorithms on large training sets [7]. These advances have allowed for the implementation of ML solutions within AM environments.

Across design, production, and process, improvements to current practices in AM require significant expertise in operators and designers [8]. To leverage the benefits of AM, the design, process, and production become significantly more complex [8]. In design, mass customisation requires deep knowledge of the links between the variables being changed as well as the requirements of the part. Similarly, increasing part complexity, either to lighten the weight or deliver improved performance, greatly increases the difficulty in designing suitable part topologies. As a result, these goals often come with large time and/or computation trade-offs.

There is little orthogonalisation in AM parameters: for example, in material extrusion, increasing extrusion temperature may improve layer adhesion but may also increase stringing. As a result, optimising process parameters for specific parts or new materials can be a time consuming and costly procedure [9]. Furthermore, part consistency is essential in sectors where AM adoption is most likely, such as aerospace, but variation in part quality both between and within machines and builds presents a barrier to more widespread adoption. Variations can include inconsistent part geometries, porosity, and functional performance. These issues encompass the management and interpretation of large amounts of data and knowledge. Such problems may be eased through the proper application of ML methods by reducing the amount of human or computational effort required to deliver satisfactory results.

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