Journal of Materials Processing Technology 142 (2003) 374–382

Journal of Materials Processing Technology

www.elsevier.com/locate/jmatprotec

Integration of reverse engineering and rapid tooling in foundry technology

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Received 7 January 2002; accepted 11 March 2003

Abstract

The aim of this work is to present some research and development made at Institute Superior Technique (IST) of Lisbon and at Institute Polytechnic of Leiria (IPLEI) in the application of 3D-digitising and propose some practical approaches to transform by reverse engineering (RE) methods, the point cloud obtained from an object surface during digitising processes in 3D-CAD surface or solid data to manufacture rapid tooling (RT) for foundry technology. The approaches presented are also fundamental to verify prototype's geometry for tooling and for modelling/simulation by finite element analysis (FEA), to assure the metrological accuracy of tooling geometry and optimisation of foundry process parameters. Based on four case studies presented, the paper will reach some useful conclusions for the appropriate application of 3D-digitising and RE to assist product development and RT in foundry processing technology, validating the accomplishment by the integration of these new methodologies and technologies in foundry technology.

Keywords: 3D-scanning; Reverse engineering; Rapid prototyping; Rapid tooling; Foundry technology

1. Introduction

To advance technology innovation, assisted by computational manufacturing, the use of 3D-digitising, are being integrated in the chain process of some Portuguese foundries, for applications such as: reverse engineering (RE), quality control, differential inspection, direct replication, detection of inaccuracies, redesign of parts, and manufacturing tools faster.

The rapid prototyping (RP) is a stimulating new technology for users quickly creates physical models and functional prototypes directly from CAD models. The rapid tooling (RT) generally concerns the fast production of tooling using inserts. RP and RT are means to compressing time-to-market of products and, as such, are competitiveness-enhancing technologies in foundry industry.

Since 7 years research with 3D-scanning technology has been carried out at the prototype modelling laboratory (LMP) at Instituto Superior Técnico [1–11] with 3D-scanning equipments, mainly for RE and quality control purposes integrated in the development of foundry RP patterns and RT equipment.

When a part exists but not the drawing (CAD or paper drawing) the CAD model can be generated using data from 3D-digitising (non-contact range scanner system based in laser-optical triangulation) and the RE methodology. The resulting mass of data from 3D-digitising requires RE algorithms that can efficiently and reliably generate CAD models.

The methods to digitise and reconstruct the shapes of complex three-dimensional (3D) objects have evolved rapidly in recent years. The speed and accuracy of digitising technologies owe much to advances in the areas of physics and electrical engineering, including the development of lasers, CCDs, and high speed sampling and timing circuitry. Such technologies could allow taking detailed shape measurements with precision better than 1 part per 1000 at rates exceeding 1000 samples per second. To capture the complete shape of an object, many thousands, sometimes millions of data geometry points (*X*–*Y*–*Z* coordinates) must be acquired.

2. RE for RT

The 3D-digitising [12,13] and reconstruction of 3D-shapes [14] by RE has numerous applications in areas that include manufacturing, virtual simulation, science, medicine [15], and consumer marketing. This is an actual research and development field that is related to the problem of processing images acquired from accurate optical triangulation [16], and is presented as a RE methodology for surface reconstructing from sets of data known as range images [17].

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0924-0136/$ – see front matter © 2003 Elsevier Science B.V. All rights reserved.
doi:10.1016/S0924-0136(03)00601-0

The standard methods for extracting range data from optical triangulation scanners are accurate only for planar objects of uniform reflectance. Using these methods, curved surfaces, discontinuous surfaces, and surfaces of varying reflectance cause systematic distortions of the range data. When using coherent illumination such as lasers, however, the laser speckle places a fundamental limit on accuracy for both traditional and space–time triangulation [18].

The range data acquired by 3D-digitisers such as optical triangulation scanners commonly consists of depths sampled on a regular grid; a sample set known as a range image. A number of techniques have been developed for reconstructing surfaces by integrating groups of aligned range images [19,20]. A desirable set of properties for such algorithms includes: incremental updating, representation of directional uncertainty, the ability to fill gaps in the re-construction, and robustness in the presence of outliers and distortions [21]. Using these methodologies one is able to merge a large number of range images yielding seamless [22,23], to assemble high-detail models to develop RT.

2.1. Integration of RE

When solving the pattern/tool making bottleneck, through the interfacing of information technologies, with RE methodologies and with RP and RT technologies, these allows reducing the lead time of manufacturing cast parts, improving the quality of parts, and assuring a better partnership with clients. The research and development of RE methodology integrated with CAD/CAE to manufacture optimised tooling (RT) is schematised in Fig. 1.

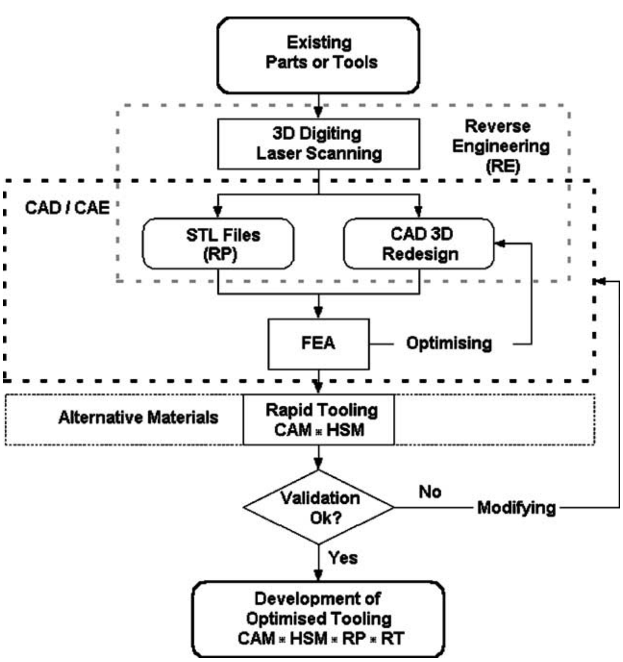

Fig. 1. Developed RE methodology integrated with CAD/CAE and FEA for optimised RT.

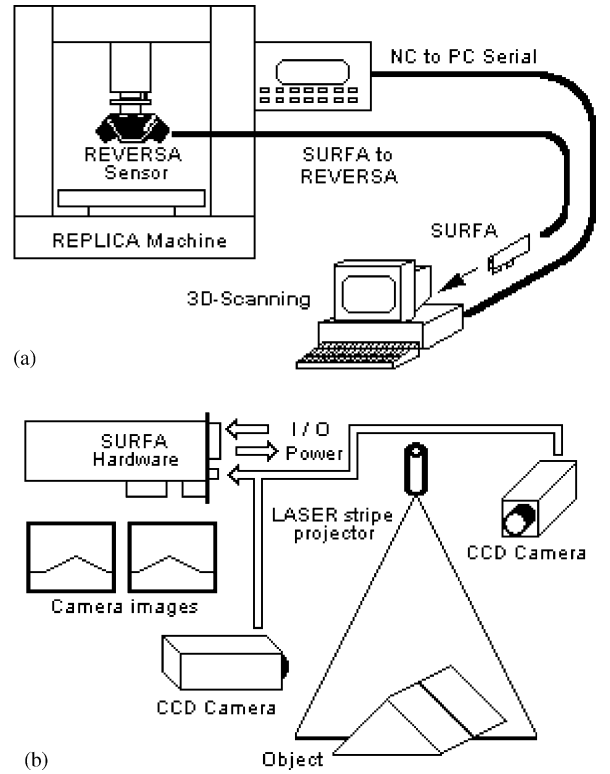

Fig. 2. (a) Scanning machine configuration (“Replica”), (b) 3D-scanning laser digitiser principle.

2.2. 3D-scanning laser digitiser principle

Laser 3D-scanning digitisers bring more automation to data gathering. These devices scan without contact by a striped laser beam the profile of a physical model and CCD cameras capture profile images that by triangulation algorithms generate digital data (Fig. 2). By exploiting the laser stripe by triangulation the “Reversa” sensor, guided by a “Replica” NC machine, measures hundreds of surface points per second, taking only a few minutes to digitise typical objects, no matter how complex their surface geometry.

This 3D-scanning system (at LMP-IST) could stripe coordinate point data at a standard scanning speed of 6000 points/min, with an accuracy on $\pm(Z) = 25\,\mu\text{m}$. Some actual limitations concerns scan surface preparation of RP prototypes that must be sprayed with matt white paint and for this reason the scanning accuracy is reduced for about $\pm 20\,\mu\text{m}$ in X–Y–Z axes.

3. Case studies

3.1. Case study 1—3D-digitising of RP-SLS for RE and FEA optimisation before casting

A preliminary set of non-optimised RP tools for sand casting have been manufactured by RP-selective laser sintering (RP-SLS) technology with powder Duraform glass-filled