Stereo Vision Based Hybrid Manufacturing of Ti-6Al-4V in Component Repair Process

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Abstract

Parts or products from high performance metal are very expensive, partly due to the processing complexities during manufacturing. Recent studies have indicated that hybrid processes of additive manufacturing and machining process can be used to repair titanium parts, thus extending the service life. In order to implement these methods automatically, it is necessary to obtain the spatial geometry information of component with defects to generate the tool path. The purpose of this paper is to summarize the research on hybrid manufacturing with stereo vision function which can be applied to the component repair process. Stereo vision is adopted to detect the location and the size of the defect area which is marked by color marker. And then laser displacement sensor is applied to scan the defect area. Therefore, automated alignment, reconstruction of the defect area and tool path planning could be implemented based on the spatial geometry information. Finally, a Ti64 part repair experiment is done to verify the method. This work provides an automatic method for repairing damaged parts by hybrid manufacturing.

Introduction

Components during the service life may be subject to corrosion, impacts, variable thermal cycles and stresses, or other conditions which could cause defects or cracking. Fatigue and stress cracks are common initiators of failures that cause high-performance and high-value components to be discarded as useless.

Conventional methodologies for repairing these components entail serial labor intensive and operator skill sensitive processes. Moreover, most of them have obvious advantages. Taking the fusion welding methods as example: Electron Beam (EB) welding [1] needs a vacuum environment which is expensive and difficult to apply to larger parts; High Velocity Oxyfuel (HVOF) thermal spraying technique [2] is hard to control depth and spread of deposited material; Tungsten Inert Gas (TIG) [3] is relatively easy to apply, however, it produces a lot of heat and also cause high residual stresses, resulting in distortion and heat-related effects in the base metal.

In recent years, Hybrid Manufacturing process which combines laser deposition and CNC machining become a focus of research. Laser deposition has a small and limited heat affected zone which makes the weld less vulnerable to degradation of properties, this allows for greater repeatability and reproducibility of layer by layer deposition of material. Modern CNC technology offers high-precision, high-speed, high flexibility, effective process planning

technique, and fully dense metal part with the desired structural properties. Consequently, the effective combination of RP and CNC technologies make a great progress in repair industry.

Although the introduction of automation has advanced repair productivity, quality, and reduced costly re-work on a stepwise basis, most repair processes still rely on manual initial and final inspection. This evokes the researchers to make efforts to integrate the repair cycle (deposition/cladding, machining, scanning/inspection) into an automated process on one working platform. State of the art consists of co-locating these processes in the same manufacturing cell, or in some cases integrating them into the same machine in pairs [4,5]. Gao provides a solution to create an individual blade-oriented nominal model to achieve repair process (laser cladding/machining) and automated inspection [6]. Junghoon Hur analysis the merits and demerits of rapid prototyping process and CNC machining process, then proposed a new form of hybrid-RP system, which performs both deposition and machining in a single station, however, the cost for building this worth well considering[7]. Jason Jones developed an integrated production system which combines laser cladding, machining and in-process inspection in a single machine for flexible and lean remanufacturing, but using a touch probe for scanning the defect is still not fast and accurate enough for the repair process[8].

The absence of a fully integrated automation and adaptive repair solution still represents a significant opportunity for reducing adoption risk and barriers such as capital investment, floor space, data flow management. A new intelligence and adaptive component repair process is being implemented in Laser Aided Manufacturing Process (LAMP) Laboratory. With the adoption of Stereo vision technology and laser displacement sensor, deposition nozzle and cutting tools are navigated along the optimized working path. Accurately controlled laser deposition of Ti-6Al-4V provides the satisfactory repair quality for the cracked part. Highly integrated process performed a great reliability and suitability on current equipment.

Method and Processes

In order to achieve the repair process automatically, stereo computer vision technology is adopted to automatically detect the position of Ti64 part and the defect are. Laser displacement sensor is used to scan the geometry of the defect area before and after laser metal deposition.

Stereo camera to detect the defect area

Stereo camera is used to get the spatial information of the repair part for hybrid manufacturing system. Firstly, markers are put around the defect area on the Ti64 part for image processing. Secondly, after Ti64 part is fixed to the machine, stereo camera is used to take stereo image for image processing. Thirdly, image processing is done by stereo marker matching to get the 3d coordinates in camera coordinates system. And stereo camera calibration is done to provide the camera intrinsic and extrinsic parameters. Finally, the spatial information in camera coordinate system transforms to the hybrid manufacturing system.
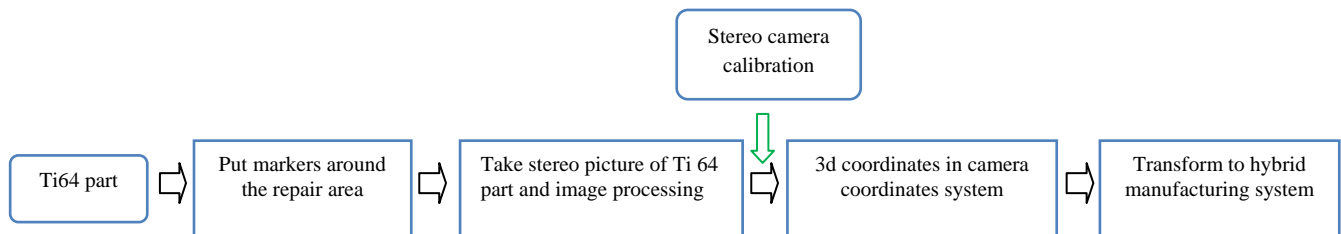
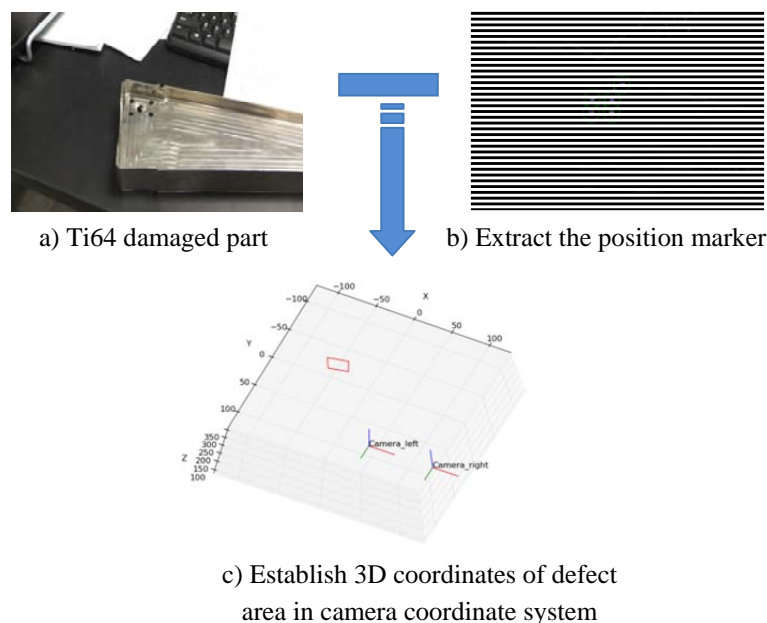Figure 1: The processes to use stereo camera to detect the damaged area

a) Ti64 damaged part   b) Extract the position marker

c) Establish 3D coordinates of defect
area in camera coordinate system

Figure 2：Automated detection of damaged region

Coordinate transformation to the CNC machine

This process is to build the relationship between CNC machine and camera coordinate system. And then the 3d coordinates of defect area on the Ti64 part in camera coordinate system is transformed to CNC machine. Eq. (1) and Eq. (2) show the method to get the transformation matrix T_{cam}^{cnc}. Four spatial positions which are not in one plane on CNC machine are used to calculate T_{cam}^{cnc}. Read each coordinate of those four positions in CNC machine and then calculate the corresponding coordinate of those four positions in camera coordinates system by stereo computer vision method.

$$\begin{bmatrix} P_{1x}^{cnc} & P_{2x}^{cnc} & P_{3x}^{cnc} & P_{4x}^{cnc} \\ P_{1y}^{cnc} & P_{2y}^{cnc} & P_{3y}^{cnc} & P_{4y}^{cnc} \\ P_{1z}^{cnc} & P_{2z}^{cnc} & P_{3z}^{cnc} & P_{4z}^{cnc} \\ 1 & 1 & 1 & 1 \end{bmatrix} = T_{cam}^{cnc} * \begin{bmatrix} P_{1x}^{cam} & P_{2x}^{cam} & P_{3x}^{cam} & P_{4x}^{cam} \\ P_{1y}^{cam} & P_{2y}^{cam} & P_{3y}^{cam} & P_{4y}^{cam} \\ P_{1z}^{cam} & P_{2z}^{cam} & P_{3z}^{cam} & P_{4z}^{cam} \\ 1 & 1 & 1 & 1 \end{bmatrix} \rightarrow points^{cnc} = T_{cam}^{cnc} * points^{cam} \quad (1)$$

$$T_{cam}^{cnc} = points^{cnc} * inv(points^{cam}) \quad (2)$$
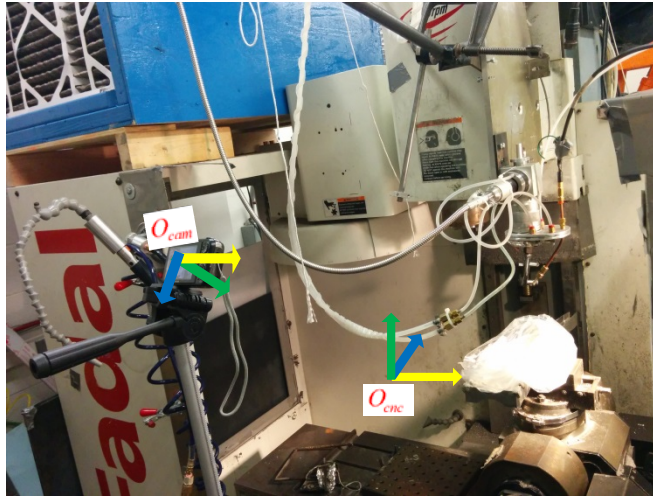

Figure 3: Coordinate Relationship between stereo camera and CNC machine

Laser displacement sensor to scan the geometry of the defect area

After stereo camera measures the position of the repair area, laser displacement sensor is adopted to scan the geometry of the defect area. Point cloud of the repair area from the laser displacement sensor is used to generate the deposition tool path. The laser displacement sensor scans the damaged area on Ti64 sample part in Fig. 4. Fig. 5 describes how to calculate the repair deposition tool path according to the point cloud. Convex hull is obtained by point cloud and then raster path generation algorithm is adopted. In the same way, laser displacement sensor is

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used to scan geometry of the repaired area then the machining tool path is generated for finishing machining.
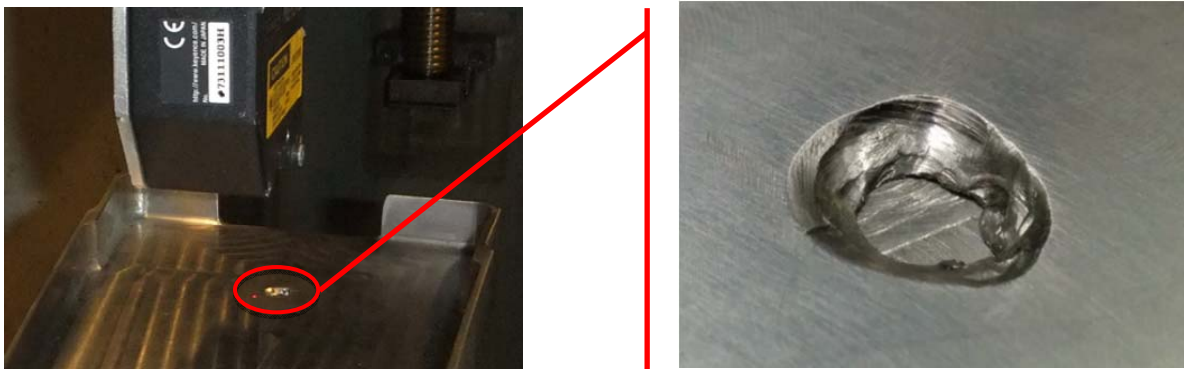

Figure 4: Laser sensor scans the damaged area on Ti64 sample part

a) Point cloud of damaged area

b) Convex hull of point cloud
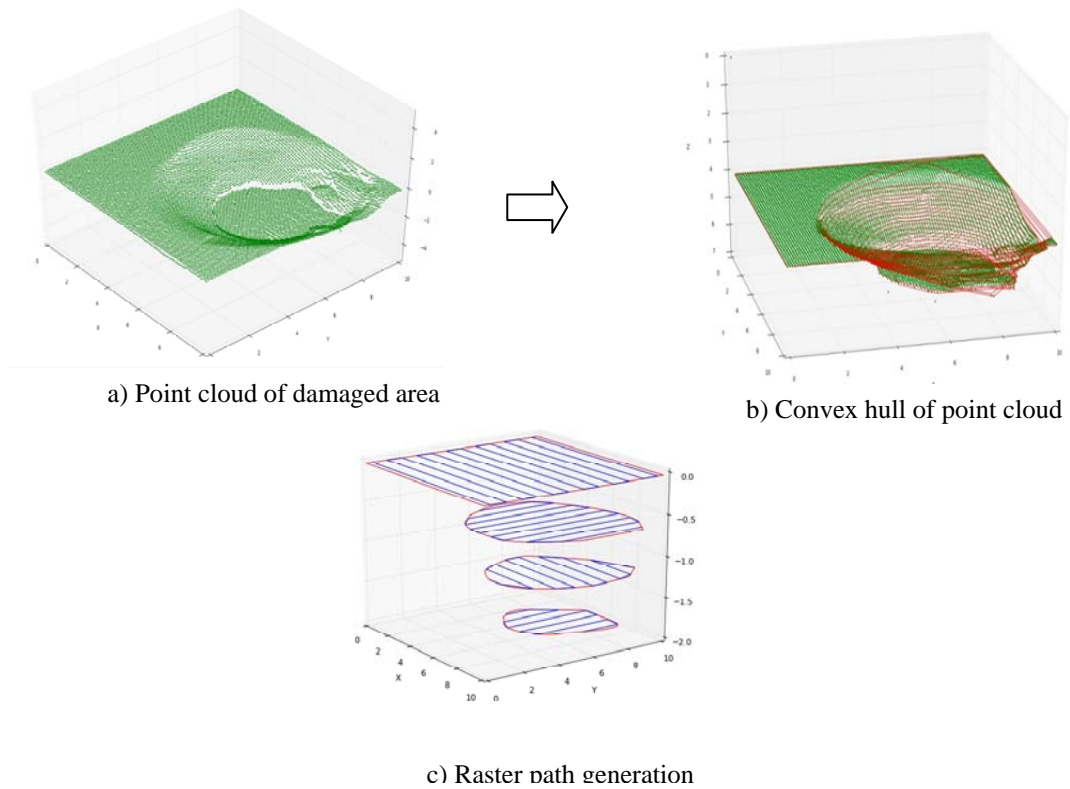
c) Raster path generation

Figure 5: Deposition tool path generation for repair

Results

Laser metal deposition and machining for repair is carried out in a hybrid manufacturing system which has been developed at the Laser Aided Manufacturing Processes (LAMP) Laboratory in Missouri University of Science and Technology[9]. It includes two major systems:

a laser deposition system (Rofin–Sinar 025) and a 5-axis CNC milling machine system (Fadal VMC-3016L). And a Fujifilm 3D digital camera and LK-H052 laser sensor are used to automatically obtain the spatial information and the geometry of the defect area of Ti64 part on CNC machine. As can be seen in Fig. 6, the defect area is well covered by the deposition material. And the machining result shows the deposition material has a good connection with the original material.

a) Ti64 part for repair

b) the defect area

c) Laser deposition result

d) Final repair result after machining

Figure 6: The result of deposition and machining for Ti64 part repair

Conclusions and Future Work

An integrated automation process of component repairing by using hybrid processes is proposed. This method combines the advantages of a one-setup process from RP and the high-accuracy offered by CNC. Stereo computer vision is used to detect the damaged area and provide the position information to the hybrid system to do deposition and machining. In addition, a test bench system has been developed to verify the proposed approach and repaired a mold part. However, the power rate of laser needs to be adjusted in the future experiments to achieve a good

density quality of the repair area. And for the next step, these processes will adopt robot arm as moving mechanism to comply repair task at more flexible and larger scale.

Acknowledgement

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