An Integrated Software System for Laser Cladding Repair of Worn-out Components

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Abstract

Recovering worn-out tools/parts could have significant economic benefits. Traditionally, only some of these worn-out components can be repaired by conventional welding processes. Laser cladding is a material depositing method by which injected powder material is melted by a laser beam and re-solidified to form a dense coating with metallurgical bonding onto a substrate. This technology can be used in the component repair to restore undersized worn-out areas. Compared to conventional welding processes, laser cladding utilizes much less heat input with much better control, which drastically reduces or even eliminates distortion, and, therefore, enables the repair of complex components that cannot be repaired using conventional welding processes.

Original CAD model does not represent the worn out component anymore and cannot be used directly for the component repair. Therefore, the first step in the laser cladding repair procedure is to extract the actual geometry of the components. Non-contact freeform surface measurement is widely used for this purpose.

We developed a unique software system for laser cladding repair of worn-out components, which integrates the non-contact freeform surface measurement, the cladding path creation and the cladding program generation seamlessly. The surface contour is measured along with the predesigned scanning paths based on its original CAD model. The measured results are filtered to remove noise, and then compared with the CAD model. Finally, the cladding path planner creates the cladding program (G-code) based on the selected laser cladding parameters. Through this integrated software, the undersized worn-out components could be repaired effectively and easily by laser cladding process.

1. Introduction

Laser cladding is a method that utilizes a focused laser beam to melt the injected powder material as well as the surface of the substrate to produce a metallurgically bonded coating. With this technology, coatings of desired properties can be produced on inexpensive materials to improve their corrosion, wear and other surface related properties. This technology has been used to repair damaged components by adding desired material onto the worn-out areas [1-4]. To increase productivity, improve quality and decrease human mistakes, the automation of repair

procedure is desirable, which may consist of several steps: (1) measuring the worn-out component, (2) creating the patch geometry model, (3) generating cladding tool path, and (4) performing laser cladding repair. Several papers have been published in this area [5-7].

The original *CAD* (Computer Aided Design) model of a component does not represent the worn-out component anymore and cannot be used directly for the repair [6]. Therefore, the first step in the repair procedure is to extract the actual geometry of the component. There are many types of sensors used to measure the geometry. Among them, laser displacement sensors have the advantages of low cost and high accuracy.

Our previous work demonstrated that, as a part of the laser cladding system, the measuring system based on a laser displacement sensor can be embedded into an existing motion control system by its predesigned input/output (I/O) communication ports. Therefore, a master-slave structure of measurement system was developed [8], as shown in Figure 1. In the system, the sensor is installed on the end plate of a Z motion axis in a 3-axis motion system and its position along the Z-direction is dynamically controlled based on available surface geometry information in such a way that the target point being measured on the component surface is always kept within the sensor's measurement range. After a scanning request (such as scanning area) is inputted through the user's interface, the measurement controller (in Master) automatically generates a measuring plan. It includes the sampling points, path and corresponding motion control commands (G-Code). The commands are sent to the motion controller (in Slave) and then to be executed automatically in Slave. The distance, Z, between the sensor and the component is acquired by the sensor at each sampling point.
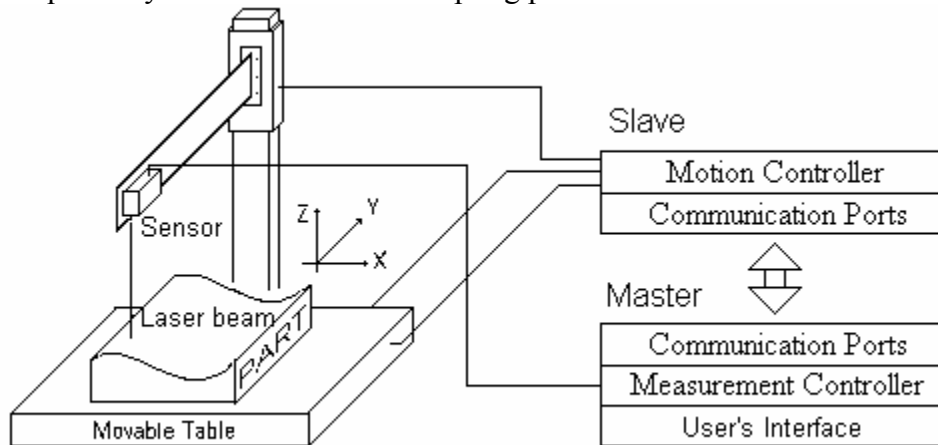

Figure 1: Improved structure of a surface contour measurement system

In this paper, we have designed and implemented an automated repair software system which integrated all repair steps seamlessly. Using the system, a NC (numerical control) program for repairing could be generated in minutes after measuring. In addition, we will also discuss one of its application cases: tooling repair.

2. Setup of the System

Component to be repaired is shown in Figure 2. The bearing surface is a belt-like area on the top of the blade which includes concave surface, convex surface and edge surface. The wear appears in somewhere on the belt. To obtain the 4-side surface contour, the simplest setup for the measurement is that introduce the forth axis (rotary) shown in Figure 3. The blade is mounted on the rotary with a fixture which allows the geometry center line of blade to be the turning center line of the rotary. The rotary is mounted on the X-Y table and the turning center line is parallel to the X axis. The sensor is mounted on the Z axis over the blade and face down. The beam is parallel to Z axis. Therefore, the beam is able to access almost all points on the bearing surface perpendicularly.
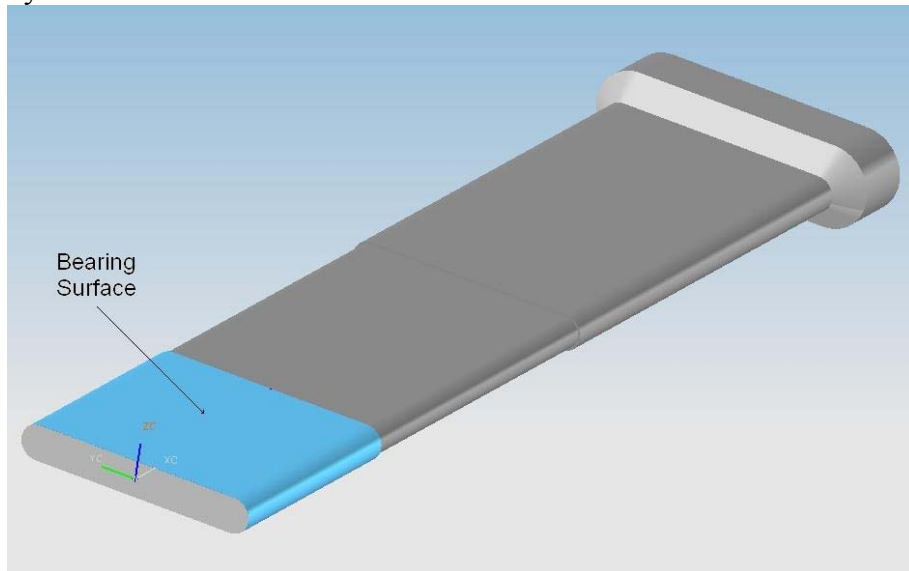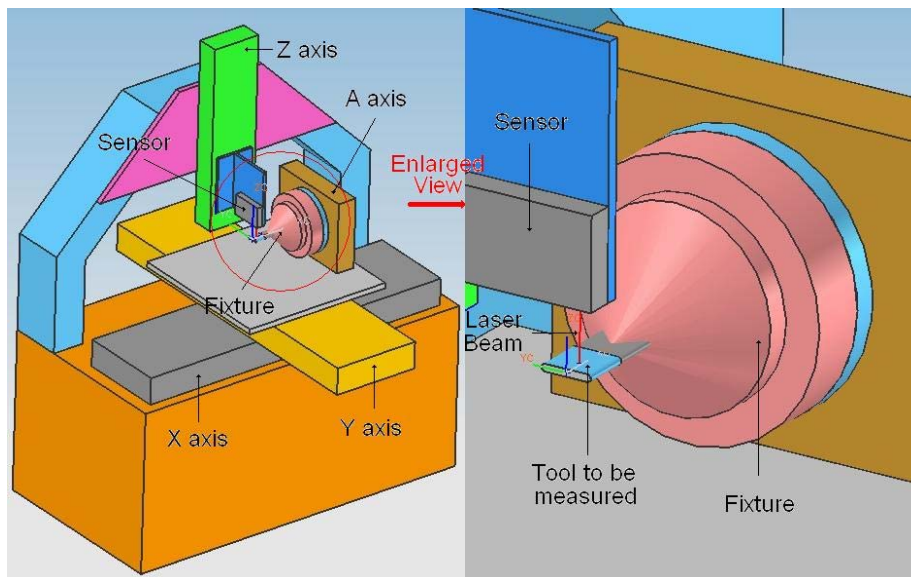
Figure 2: Blade in the study case

Figure 3: Setup for measuring

The setup of a cladding system is similar to the measuring system: replace the measuring sensor by a cladding head shown in Figure 4. Using the same (or similar) setup in the cladding system and the measuring system can simplify the creation of the NC programs because the coordinate system communication is omitted. Furthermore, if the measuring sensor is integrated into a cladding head forming a multiple function head, the measurement and repair in only one component installation can save more processing time.
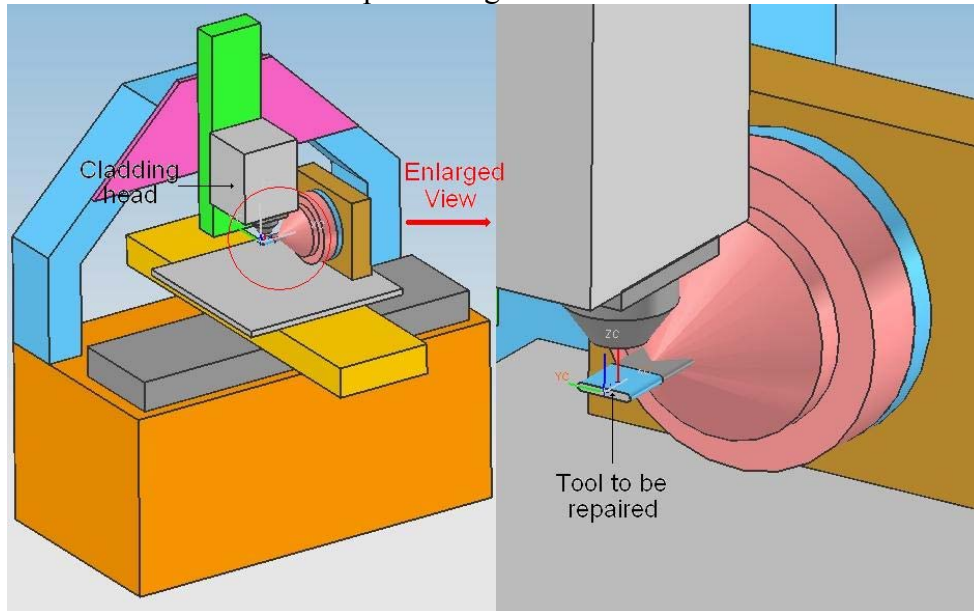

Figure 4: Setup for cladding

However, in this study case, two motion control systems are used for measuring and cladding the components respectively.

3. Software system structure

In order to integrate the repair procedure seamlessly, a software package is designed and developed. Its function structure is shown in Figure 5. The software is designed under Unigraphics platform. The modeling module (CAD) of unigraphics is used to design the scanning paths (curves/lines) based on an original CAD model of the component and measuring parameters such as range and stepover (distance between two adjacent paths). From our experience, if the stepover is the same as the cladding requirement, a lot processing time of scanning results could be saved. The manufacturing module (CAM) is used to indicate the scanning speed, direction and so on. A Matlab scanning program can be generated by the post-processor module for scanning.

The scanning program is run in Master in the measuring system within Matlab environment and a simple NC program (interpret and execute commands from Master) is run in Slave. These two programs complete the measurement cooperatively. The scanning results are saved and proceed to filtering in Master. The details of the filter will be discussed in Section 4.

We have two ways to generate a NC cladding program. One is through the CAM in Unigraphics. Another one is from the measuring results directly. The former is flexible but complex and time-consuming. The later is simple and fast but lower flexible. The details about generating NC cladding program will be discussed in Section 6.

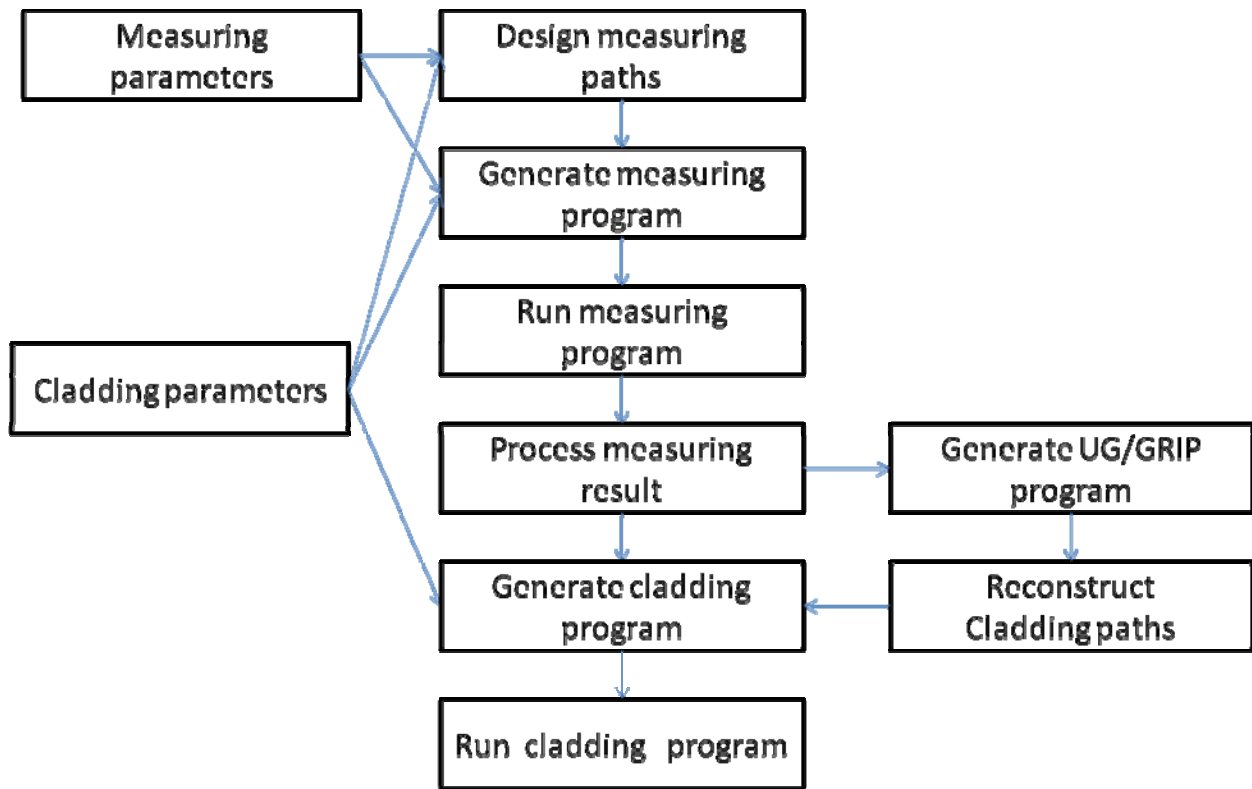The repair of the component could be realized by running the NC cladding program in the cladding system.

Figure 5: Function structure

4. Scanning results process

Shrink measuring results

The scanning is achieved by a relevant motion between the sensor and the motion table. For given reasonable step length (the distance between two adjacent sampling points), the measuring speed (the amount of measured points per second) can be calculated by motion speed/step length. The motion speed of the table is limited by the mechanical conditions of motion system such as load, power of motors and so on. Therefore the measuring speed is limited by the mechanical conditions of the system. On the other hand, the sensor's sampling speed is much higher than the measuring speed. This potential capability can be used for improving measuring accuracy. For example, supposing the sampling step length is 0.001". The relevant motion speed is 0.1 inch/second. 100 points per second must be obtained. However, the sensor's sampling speed is 1000 points/second, which is 10 times higher than the measuring speed (100 points/second). That is, only 1/10 acquired point is used to reconstruct the curve profile. To realize the sampling rate

convert, the simplest way is pick one point up from every ten points. But this method can't remove the measuring noise. We take the local average of ten points as one point described in formula:

Assume $z_1, z_2, ..., z_n$ to be initial data acquired from the sensor.

If n is the integral multiple of 10,

$$Z_i = \frac{z_{10*i-9} + z_{10*i-8} + \cdots + z_{10*i}}{10} \quad (i=1, 2, ..., k)$$

where $k=\text{int}(n/10)=n/10$. Otherwise,

$$Z_i = \begin{cases} \dfrac{z_{10*i-9} + z_{10*i-8} + \cdots + z_{10*i}}{10} & i \leq k = \text{int}(\dfrac{n}{10}) \\ \dfrac{z_{n-m+1} + z_{n-m+2} + \cdots + z_n}{10} & i = k+1, m = n - 10*k \end{cases}$$

The benefit of this method is that the measuring noise is reduced which could be illustrated by an example: take 50000 given random numbers between -0.001 and +0.001. The RMS (Root Mean Square) of the output data of various methods and their CPU (Central Processing Unit) processing time are displayed in Table 1.

Method	Function	RMS (X10^{-3})	CPU Time (Second)
Initial data		0.5797	N/A
A:Take first point every 10 points	Reduce sampling rate	0.5785	~0
B: Take average of every 10 points	Reduce sampling rate and measuring noise	0.5105	0.2031
C: Moving Average (10 points)	Reduce measuring noise	0.5105	1.8281

Table 1: Comparison of RMS and CPU time in various methods

The method A is the simplest and fastest way. But it can hardly reduce the measuring noise (higher RMS). The method C can reduce the noise. But it is not able to convert the sampling rate. Meanwhile, the time cost to reduce the noise is much higher than the method B.

Filter without profile distortion

Traditional filters such as Moving Average (MA) are effective method to remove the measuring noise. However, the features such as sharp steps on the profile may also be removed while the noise is erased because these kinds of filters are low pass filter. We designed a band stop filter based on a MA filter. It is able to remove the measuring noise efficiently and keep all sharp geometry feathers. In this algorithm, two filter parameters have to be preset: (1) the point number of MA which related to the low frequency. The large the number is, the lower the low frequency of the filter is. (2) The threshold of the amplitude of the profile which related to the high frequency. The larger the threshold is, the higher the high frequency of the filter is.

The algorithm can be described by the flow chart in Figure 6, where positive integer n is the point number of MA filter (filter's parameter 1); the δ is the threshold (filter's parameter 2); $Z(i)$, $Z^*(i)$ are the input and output data respectively; m is the length of input(output) data.
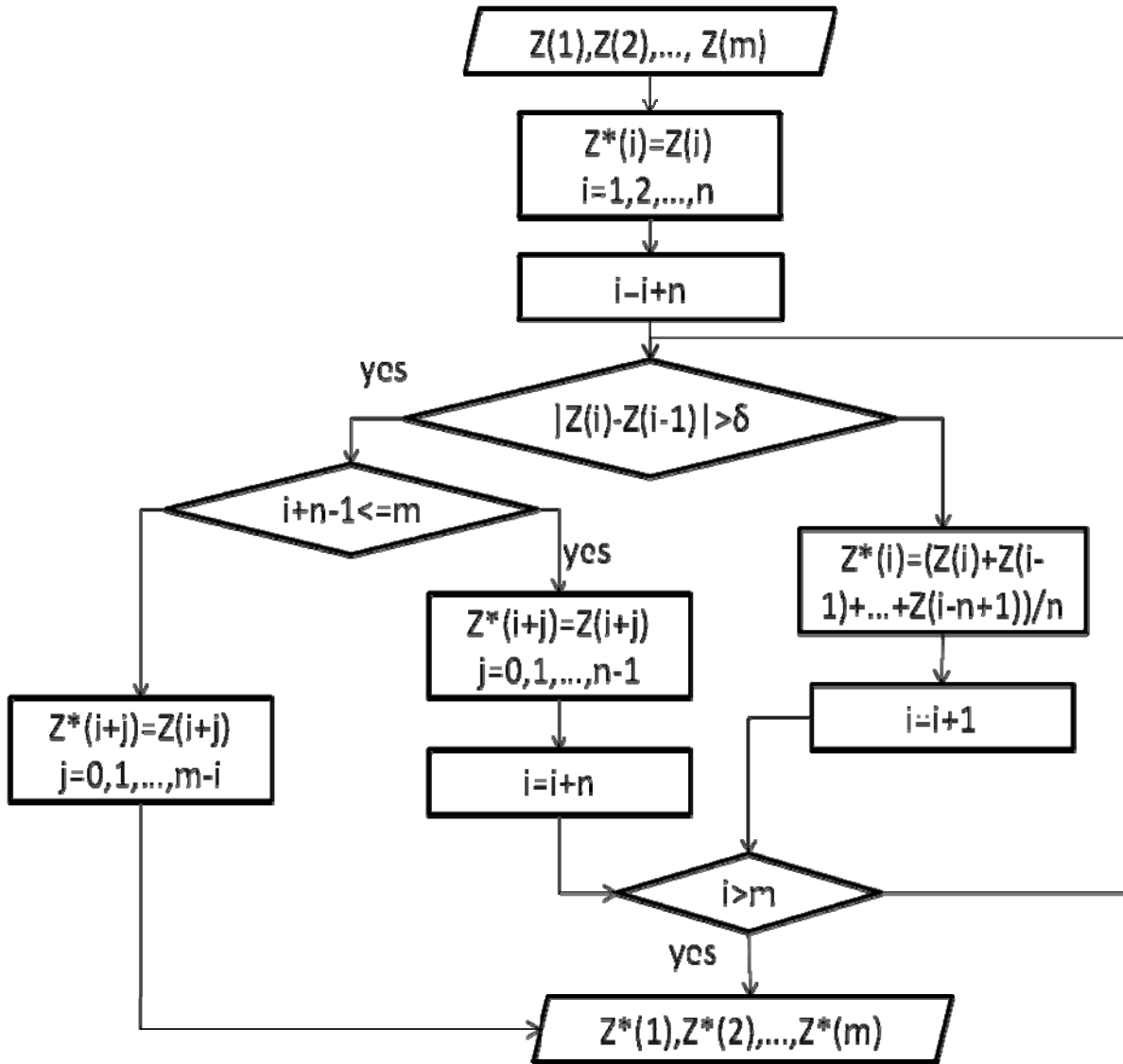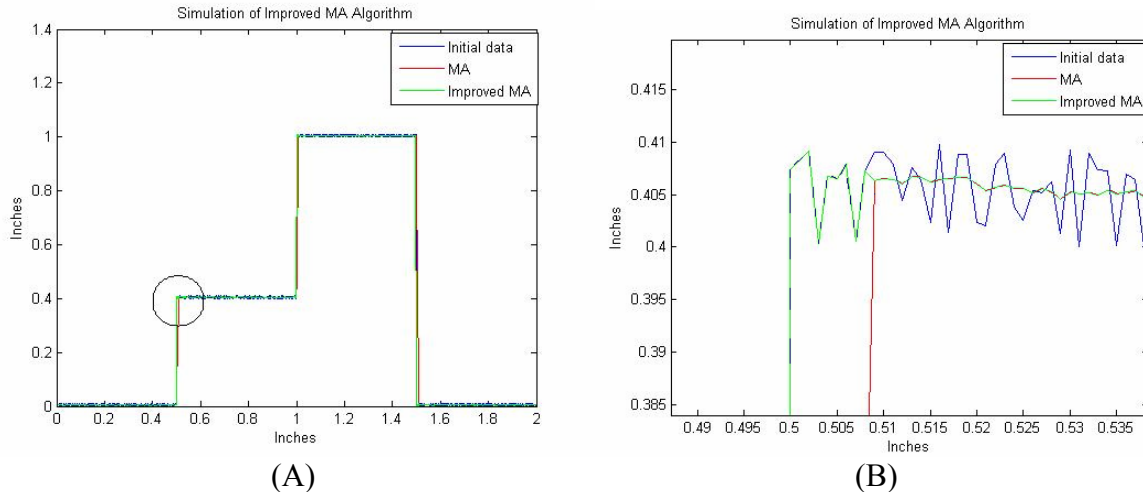

Figure 6: Flow chart of the filter

Figure 7: (A) Comparison of moving average filter and proposed filter;
(B) Zoom out of the circled area of (A)

The Figure 7 shows simulation results of the filter. Assuming the profile is a two-step stairs (see left portion). The initial measuring results with noise are shown in blue line. The red line is the filtering result by 10-point moving average algorithm. The green line is the filtering result from proposed algorithm.

5. Reconstruction of profiles

GRIP (Graphics Interactive Programming) is a Fortran-like programming language that allows you to automate most operations in Unigraphics NX and its associated modules. Almost any operation that can be performed interactively can be performed by using a GRIP program. These commands are available to create new objects or modify existing objects, control system parameters, perform file management function and interact with a GRIP program while it is running. There are four major steps involved in using GRIP: Create, Compile, link and Execute.

In proposed software, the filtered measuring results are used to generate an error-free GRIP program automatically. The surface profiles are reconstructed by executing the program in Unigraphics GRIP module. The reconstructed profiles could be used for comparing to that in original CAD model so that the degree of worn-out and position can be figured out and displayed clearly.

6. Create cladding program based on the scanning results

We have two ways to generate a NC cladding program. One is through the manufacturing module and post-process module in Unigraphics. It is similar to generating a scanning program. The difference is that the scanning program is a Matlab program for measurement which will be run in measuring system but the cladding program is a G-code program for repair which will be run in laser cladding system. Another one is generating the G-code cladding program directly from the measuring system based on the measuring results, original profiles and cladding parameters. The former (indirective method) is flexible but complex and time-consume. The later (directive method) is simple and fast but lower flexible.

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Generally speaking, a cladding program consists of three parts: head, foot and body. The head and foot are designed for controlling laser equipment. The body is designed for controlling tool path with specific position and speed. In this study case, the head and foot consist of following commands:

        M14   ; laser Remote control ON

        G70   ; Inch dimension programming mode

        G90   ; Absolute dimension programming mode

        G94   ; Feed per minute programming mode

        Z2 F25 ; laser head moves up

        A0 E3   ; Turn rotary to initial position

        M15   ; Laser Remote Control Off

        M2   ; End of Program

In the body portion, the laser head moves to the start point (position and orientation) of a cladding path (tool path) with a specific distance (focus). Beam shutter is opened. In the same time the part is moved along cladding paths with specific travel speed until the end point is reached. During cladding, the laser beam is always perpendicular to the surface. At the end point, the shutter is closed. This procedure could be repeated until the paths covered entire surface.

7. Conclusions

- A repair software package integrated surface measurement, reconstruction of CAD model, and tool path generation was successfully developed.
- The software package was successfully passed testing through the repair of a tooling.
- The developed software can minimize human errors in programming due to the integration and automation.
- The integrated software can significantly shorten programming time.

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