Remanufacture Oriented Surface Inspection System with Robot

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Abstract

Remanufacture technique is on of the key techniques on our country's Sustainable Development. In this paper, a remanufacture oriented surface inspection and repair system with robot has been proposed. In this system, industrial robots have been used as the actuators. Firstly, through laser scan, 3D surface data and model of the broken part have been found quickly on the spot. Then, broken model and analyze result have been figure out. Base on the requirement of remanufacture.iency and automation level of remanufacture.

Keywords: Robot; Remanufacture; Surface Inspection

1 Introduction

Manufacturing is not only the maximal user of resources, but also one of the most maximal environmental pollute. According to statistics, manufacturing all over the world can produce 5.5 billion innocuous rubbish and 0.7 billion deleterious rubbish per year and it takes more than 70% of the total world pollute. Now, developing the green manufacture engineering technique and depressing the use of resources of manufacturing and the capacity of pollute releasing has became the important strategic direction of the country continuance developing.

Remanufacturing engineering is a general term of a series of technical measures or project activities which can be used to repair and rebuild old products that takes the product life-cycle theory as a guide and takes old products achieving Leaping Development as the goal, takes high-quality, high-efficiency, energy-conservation, materials-conservation, environmental protection as the criteria, takes advanced technology and industrial production as the means. China's assets of equipment reachs the trillion yuan and an annual of the assets of equipment which were oriented to rejecting reach ten billions. Through repairing and remanufacture to the equipment can reduce consume of resources and create huge economy benefit.

The fault of machine equipment is sometimes because of invalidation of one or two parts, but the invalidation of part is usually because of damage or distortion of the local surface. At present, the hotspot of research in our country or in other countries has been focused in the remanufacture technique of surface damage, for example, the surface of nanotechnology, Laser Rapid Prototyping Technique and so on. There are many applications which can achieve surface repairing with robot, but there are not the application which can achieve automatic repairing and programming and controlling the path. The main reason consists of two or three aspects as follows:

(1) There are not means and evidences to put up programming for machining path towards accessories which are waiting machining, and it can be only carried through artificial teaching.
(2) The controlling of robot itself is a complex issue.
(3) It needs the intercross of material, technology and controlling subject.

For this status, this article advances a surface inspection system with robot, which oriented to remanufacture. It takes industrial robot as executive machine, bases on the methods of structural light 3D surface inspection and reconstruct. And then it can obtain the 3D data of model and it can layout the path of repairing automatically according to the disrepair extent and the technical requirement of remanufacture, At last, it can finish the remanufacture and machining of accessory.

2 System Construction

The construction of the system proposed by this article is as shown in figure 1. The system chooses separate design and it has two robots, one is inspection robot which precision is very high but it's load capacity is low, the other is repair robot which load capacity is large and it can be used to carry remanufacture machining equipment. The reason why take this type of design is that: remanufacture machining equipment like electric arc spraying, plasma spraying and etc, is very weighty contrast with laser probe. It needs that robot must have larger load capacity and that the robot's precision of location will be affected and then it can't satisfy the requirement of inspection precision. The high temperature and spark and etc generated when processing also proposes a very high demand to the protection of the laser probe. Adopting separate design can avoid the problems mentioned above. The detail works process of the system as follows:

Firstly, inspection robot uses line structured laser probe to inspect 3D data for the surface of broken part and uses the robot's 6 degrees of freedom to track the surface through the adaptive path planning during the scan process. It should better keep the distance between laser probe and inspected surface as a constant. The laser incidence angle is perpendicular to the surface of the inspected point. It effectively overcomes the problem of blind spot inspection and data match on the basis of guarantee of inspection precision.

It will fit the scan result with initial CAD model of parts and then pick up 3D model of broken region according to fitting result. On the basis of analysis to the broken region, the repair control program

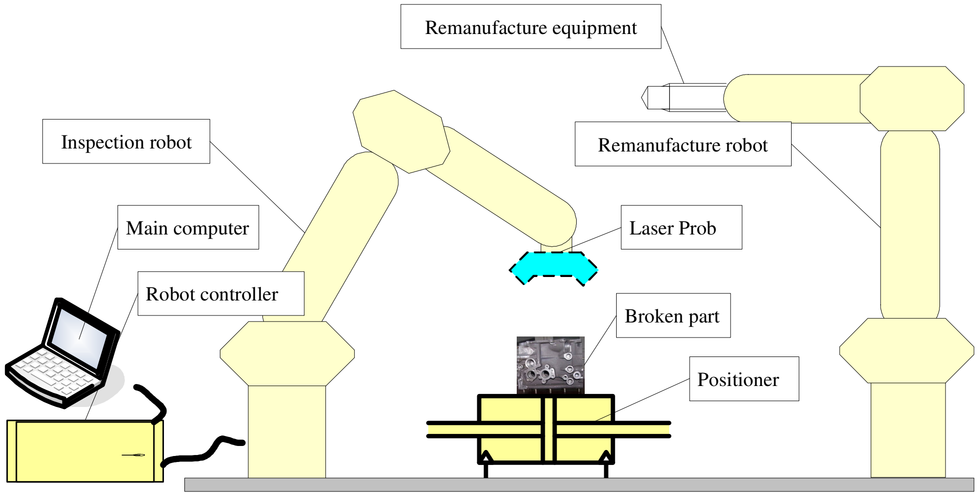

Figure 1: The constitutes of system

according to the requirement of remanufacture can generated. The control program includes the motion path of repair robot, the motion path of positioner, work parameter of machining equipment and work process control of machining equipment.

At last, download the control program to the controller of robot through communication interface and execute the program to finish the remanufacture of broken parts.

The key problems need to solve in the system include: system calibration, picking up broken region and planning of repairing path. The next paragraphs will introduce it separately.

3 System Calibration

The characteristic of this system is that the local coordinate system is multiple and it needs a large amount of coordinate transform. The coordinate system includes: laser probe coordinate system, machining tools coordinate system, wrist coordinate system W1 and W2 of two robots, base coordinate system R1 and R2 of two robots, turntable coordinate system B. The target of system calibration is to unite all of the related coordinate system to the world coordinate system based on turntable coordinate system.

3.1 Hand-eye calibration of Laser Probe and Robot

The problem will be firstly solved in this paper is the relationship between the coordinate system of laser probe and the wrist of robot.

Line structured laser probe has the following characteristic:

(1) Inspection coordinate system is a visual coordinate system built on the laser plane.

(2) It is 2D data in fact which is gained from this coordinate system.

Therefore, it is very hard to ensure the 3D relationship between inspection coordinate system and coordinate system which calibration object in through inspected data if don't import assistant inspection equipment. Aim at the problems above, this article proposes solved methods as follows:

(1) Since it is hard to determine the transform relationship before and after the motion of the sensor for inspection coordinate system on light plane through inspected data, the position of inspection coordinate system can be changed (for example, setting the position of inspection coordinate system to the Optical Center and determining the equation of light plane under the Optical Center coordinate system), so that the transform relationship can be determined easily.

(2) Can inspect the characteristic of 2D information of point in space using probe and then build hand-eye calibration equation adaptive to this system.

The detail method is to select any position of wrist as the initial position, select plane target as calibration target, and then build equation of calibration target under wrist

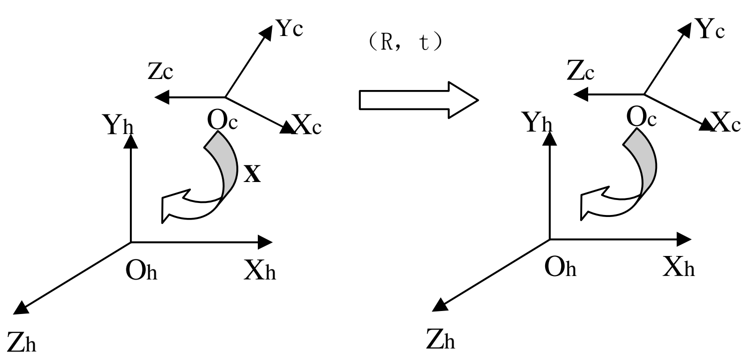

Figure 2: the hand-eye calibration of robots

coordinate system (coefficient is unknown), control the wrist move N times. We take two motions for example to explain problem, which as shown in figure 2. Setting position 1 as initial position, the equation of calibration target under wrist initial coordinate system is: $a_0 x_h + b_0 y_h + c_0 z_h + d_0 = 0$, the equation of calibration target under wrist initial coordinate system of position 2 is:

$$a_1 x_h + b_1 y_h + c_1 z_h + d_1 = 0 \qquad (1)$$

Supposing the wrist transform relationship between two positions is (R, t) (R, t) can be determined by the information of controller of robot, it is known parameter), the relationship between (a_1, b_1, c_1, d_1) and (a_0, b_0, c_0, d_0) can be determined. Control sensor will inspect calibration object separately in two positions and it receives two groups of inspection data. The relationship of this two groups of inspection data is a equation related to hand-eye matrix X and (a_0, b_0, c_0, d_0) , therefore we can build calibration equation.

Supposing wrist coordinate system in initial position is $O_{g0} - X_{g0} Y_{g0} Z_{g0}$, the equation of plane target in this coordinate system is: $n_0^T x_{g0} + b_0 = 0$.

When the wrist moves to the position J: $O_{gj} - X_{gj} Y_{gj} Z_{gj}$, the equation of this target under this coordinate system is: $n_j^T x_{gj} + b_j = 0$.

Supposing $x_{g0} = R_{0j} x_{gj} + t_{oj}$ (R_{0j}, t_{oj} can be gained from motion of wrist, it is known).

So it is able to find out that:

$$n_j^T = n_0^T R_{0j}, b_j = n_0^T t_{0j} + b_0 .$$

Supposing reading data of sensor in the position of J is x_{sj} , we can receive $n_j^T (R \cdot x_{sj} + t) + b_j = 0$ from $x_{gj} = R \cdot x_{sj} + t$, and next step we can receive the equation related to hand-eye relationship which is drove by inspection data:

$$n_0^T R_{0j} (R \cdot x_{sj} + t) + n_0^T + b_0 = 0 \qquad (2)$$

And through this equation we can find the hand-eye relationship between the laser probe and the robot.

3.2 The Transform of Coordinate System of Double Robots

As to two robots, we can adopt equation following to express the transform relationship of them:

$$RX + T = X0 \qquad (3)$$

And then, R is the rotate matrix of two robots, T is shift matrix of two robots, X, X0 delegate the coordinate in two robots of the same space point which is pointed to by calibration probe.

Stall calibration probe on the end of two robots, set the tip of calibration probe as the tool tip of robot and always make the calibration probe of two robots move to the same position in space, and then note the coordinate of this point under the coordinate system of this two robots, use a optimizing method to solve the transform relationship of coordinate. Thus, we can find out R, T through several pose transform of two robots, and then we can gain the transform matrix of two. The figure 3 is a practical scene of two robots during the calibration process.

There is a little machinery error because the industrial robots of 6 degrees of freedom adopt the mode of serial communication. So the precision of space absolute orientation is not high, especially near the odd position which is far from the joint parts of robot, the precision of absolute orientation will drop sharply(the error will larger than 10mm), and the change of error is non-linear. The precision of absolute orientation is upper relatively only near the very small region of the position of joint parts of robot. Finally we can make the precision of coordinate transform of two robots in this work region reaches 1mm through picking up large data from this region and building error model through neural networks.

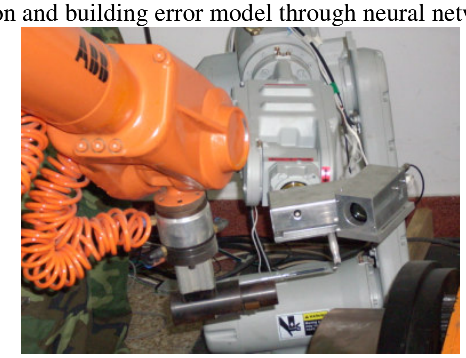

Figure 3: The calibration of two robots

3.3 Fast Calibration of the Relationship of Positioner and Robot

As the holding framework of turntable parts, the positioner needs to compute the direction and position of rotation precisely. In practical application, the position and pose of positioner may be changed a lot, so we must find out a more simple method to finish the calibration of positioner. This article adopts a club-shaped object as the calibration object and puts the calibration object on the positioner and controls the scanner robot scan the calibration object in any angle. There will appear a space ellipse after the club-shaped object is cut by the light plane of laser probe. We can receive a series of the circle center of the space ellipse through the optimizing method, and then fit a line which delegates the center of rotor of positioner through the space coordinate of a series of the circle center. Figure 4 is a practical scene of positioner and robot during the calibration process.

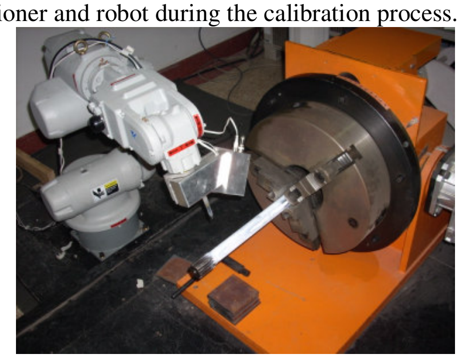

Figure 4: Calibration of positioner and robot

4 Analysis of Broken Region and Planning of Repairing Path

For inspection and analysis to the broken region, firstly, we should divide the data into pieces and pick up the fine region and broken region from 3D data. We are mainly based on two strategies to divide the region: 1.the edge and depth of broken region is anomaly; 2. building expert knowledge normal library according to broken reason. And then we must deal with broken region which appears overlapped in space separately, it can avoid making the inspection of broken region not full because of overlapped projection and influence to the effect of remanufacture and repairing. On the basis of divided region, we can make the ICP arithmetic as core, use CAD model of parts been scanned and the coordinate information during scanning to determine the initial value of fitting. It achieves fitting fast and high precise between inspection model and CAD model. ICP arithmetic can satisfy the precision requirement of data for alignment basically, but the efficiency of the arithmetic itself is low and the time for computing is too long. Through analysis, we find the time for computing is mainly spent on the computing to the nearest point. Hence, we will use CAD model information and KDTree data structure to compute the nearest point of point cloud, this method can promote the computing speed of fitting arithmetic greatly.

After the fitting of scan data and initial CAD model, we can achieve extraction to the broken region through setting the inspection error threshold and cluster of data points. As the figure 5 shows, we adopt macro-underside cube to fit the broken region and compute the volume of broken part through statistics for volume of cube. When the bottom surface of cube is as small as possible, the computed error of broken volume is no larger than 2 cubic millimeters.

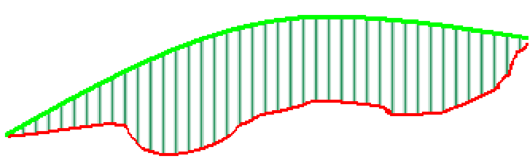

Figure 5: The fitting of broken region

Figure 6: single turning path

The plan of repairing path is mainly basis for repairing technology and it will finish layered for broken region. And then we can determine the machining path and machining parameter of repairing robot according to the shape of every layer. According to the requirement of remanufacture technology, we have designed several planning methods of repairing path, which includes rotating path, spiral path, multilayer path and etc. we can set the height of layer, space between rows, rotating speed of turntable, acceleration of turntable and a series of control parameters. It achieves the repairing for the accessories of axisymmetric body under the cooperation with MIG welding machine and dimensional arc plasma spray equipment. The figure 6 is the sketch map of single layer turning path, the figure 7 is sketch map of layered path.

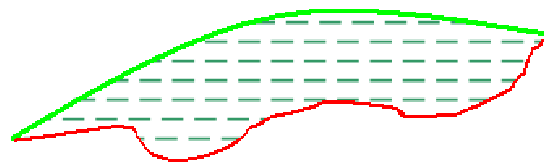

Figure 7: The achieving of layered path

5 Experiment Result and Conclusion

Repairing experiment to a Type of Axle Parts and adopt MIG welding machine as repairing technology, the whole running instance of system is shown as figure 8:

The time for system from scanning to finishing repair is 15 minutes, but if we don't use this system we will need more than 2 hours. In the aspect of technology, arc striking or arc extinguishing of welding machine will be controlled more precise and the efficiency of repairing is better than the artificial planning evidently.

At present, remanufacture technology is in the phase of whole developing all over the world. It will become a new growth point of our national economical developing accompanied by that the effect of it in the stratagem of continuance developing in our country become standing out day by day. In the field of remanufacture in our country, the annual market volume has reached as high as tens billions yuan, but because of the limit of remanufacture machining efficiency, the practical exploitation amount is lack than one tenth. Through further perfect to the research fruit of this article, we can make the efficiency of existing remanufacture machining gain an improvement of about one order of magnitude, and promote the machining precision, reduce the working intensity of workers, improve the ability of producing, bring considerable economic efficiency and social efficiency. Otherwise, it can also assist us to continue our research to the remanufacture technology, develop new technology and improve the competition power of remanufacture industry in our country.

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References

[1] Xu Binshi, Liu Shishen, Shi Peijing. Contribution of Remanufacturing Engineering and Surface Engineering to Cycle Economy, China Surface Engineering, volume 19, pp 1-6. (2006)

[2] Daniel V R, Guide J. "Production planning and control for re-manufacturing: industry practice and research needs", Journal of Operations Management, volume 18, pp. 467-483. (2000)

[3] Xu Binshi, Remanufacturing Engineering and Nano Surface Engineering, Heat Treatment of Metals， volume S1, pp 1-6. (2006)

[4] Xu Binshi, Liu Shishen, Wang Haidou. Industry of developing Remanufacture, Journal of QiuShi, volume 12, pp46-47. (2005)

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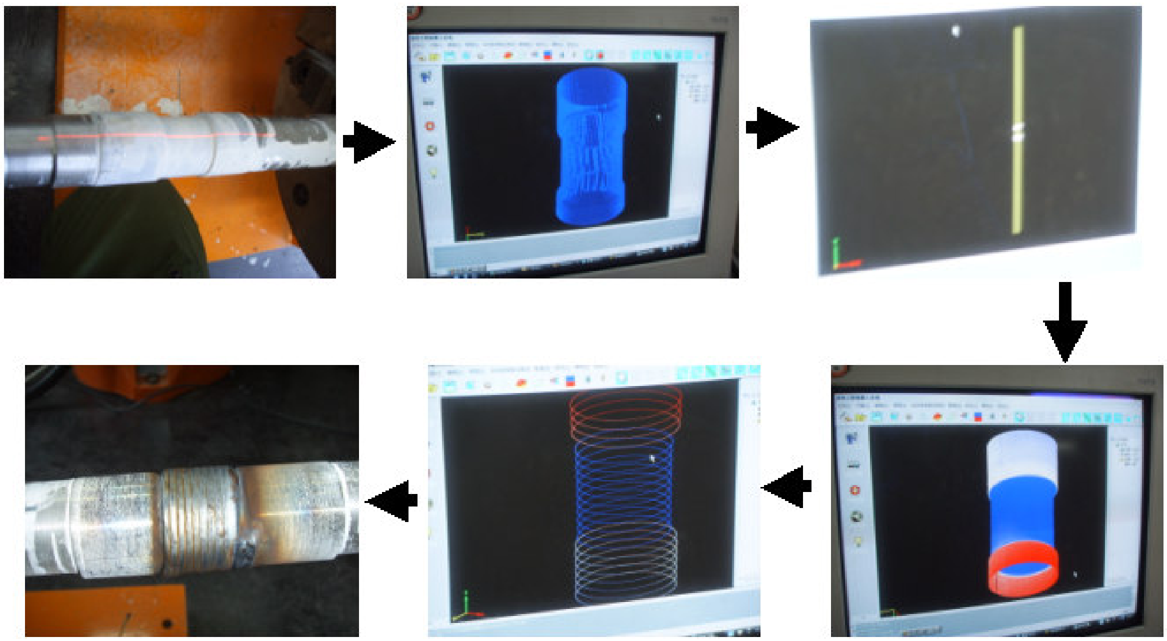

Figure 8: Practical applications