Range Finder Based Guidance of Puma Robot for the Infrared Inspection of non-Planar Materials

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Abstract - NDT (Non-destructive testing) using active infrared thermography has found numerous applications in the industry. Growing interest in the field has prompted researchers to develop inspection systems that are more and more versatile. The thermographic NDT of non-planar surfaces represents a new challenge since thermographic NDT systems must adapt to the geometry of the object to be inspected. The system developed here uses a PUMA 560 Mark II robot, onto which a JUPITER 3D sensor and a thermographic NDT unit are mounted.

1. Introduction

Proposed here is a system for the infrared non-destructive inspection of curved surfaces. This system is composed of a PUMA 560 robot onto which are mounted a Jupiter active range finder by Servo Robot, an Inframetrics 600 infrared camera and a heating unit.

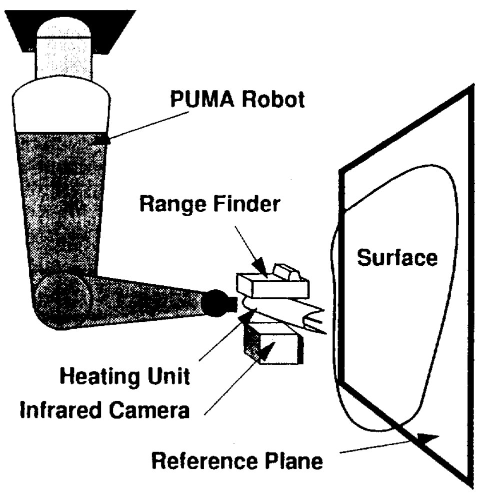

Fig. 1 *The inspection system.*

The inspection of the surface is performed in two phases: the modelling phase and the actual inspection phase. The range finder is used during the modelling phase and constitutes the actual vision system; on the one hand, it enables the robot to sense its environment and move in an intelligent manner, on the other hand, the data it returns is used to produce a model of the surface under inspection.

Once the whole surface of interest has been modelled, the infrared testing can start. The vision system can be turned off since the robot will from now on depend solely on the model built for its guidance. At this point, the surface is divided into rectangular areas that correspond to the infrared "pictures" that will be taken. Infrared thermographic inspection is performed by heating up a surface and by later taking a picture of it to observe its cooling down characteristics. Undesirable distortions are observed if two adjacent regions of this surface are inspected sequentially. Again, having a model of the whole surface under inspection is important in the sense that it enables the system to decide in what order these pictures will be taken in order to minimize these distortions.

2. The Modelling Phase

The problem we are facing here is the design of an inspection system that can adapt to the geometry of the actual object under testing. Such a system must be able to find the object, to determine the boundaries of the surface of interest, and most of all, to get the best view of that surface at all times. The use of a robot arm gives us the flexibility needed for such a task. Also needed however is a vision system for the robot. The use of an active laser range finder is interesting since we obtain distance measurements of surface points relative to the camera expressed in the camera's frame. This data can also easily be manipulated for the building of a model of the surface to be inspected.

2.1 How do we start?

In order to simplify the task at hand, the object to be inspected is placed against a planar reference surface; if we attach to this surface a reference frame with its origin at the surface's lower left corner and having its z-axis normal to it, we can impose the condition that the object can only be within the positive x-y quadrant. This reference surface gives us not only a place to start from, but enables us to work with a threshold value when we interpret the range data. Anything above the reference surface (threshold) and within the quadrant limits can be considered part of the object and hence, valid data.

2.2 Patching up work.

Since we suppose that in general the object under scrutiny is too large to be "photographed" in one set of parallel scans, we will work on what we will call "patches".

Within a patch, we keep the camera's orientation and height above the object constant. Why do we do that? Well, if we want to build in real time a useful model of the object's surface, we cannot ask the computer system to perform the calculations necessary to determine which points obtained by a group of scans are neighbors. Instead, we know that within a patch certain points are neighbors and others are not. The problem of integrating the information contained inside all of the patches can be dealt with later.

2.3 The triangular quilt.

We have said earlier that the model we are building is used in real time for robot guidance. It becomes obvious that we need some sort of information about surface orientation in order to position the system for the whole scanning process.

To better understand how we go about this problem, let's follow our system as it goes through a scanning cycle.

Knowing where to start, our robot places the system above the lower left corner of the reference surface. It takes one scan along the x-axis and then moves a small step along the y-axis. A second scan is taken here. At this point, the two parallel set of points are used to build small triangular surface elements whose vertices are three neighboring valid points (see Figure 2 below).

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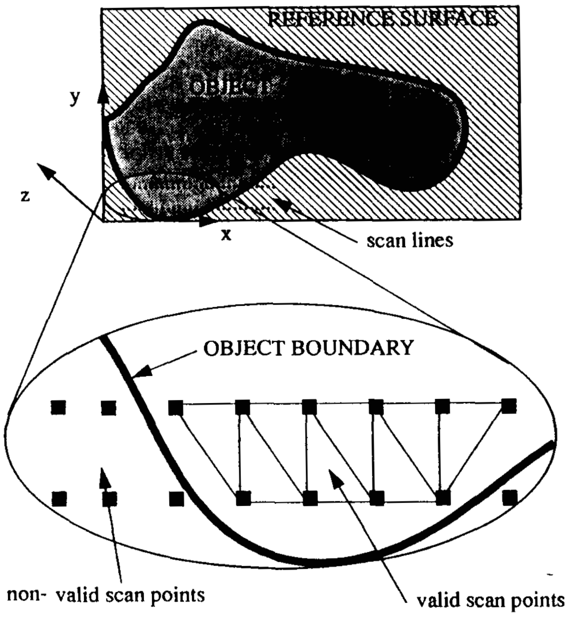

Fig. 2 *Triangulation of a pair of scans.*

The vector normal to every triangle is calculated, as is every center of gravity. An average surface orientation is then estimated and used to decide if the present camera orientation and height above the object's surface are adequate. If such is the case, the system will continue working over what we call a "patch" : another step along the y-axis is taken, another scan is taken, another triangulation is performed, and so on. If the average surface height and orientation imposes a change in the point of view, the system readjusts itself and starts another set of scans -or another patch if you prefer-. Thus, if the surface under inspection is fairly smooth, the whole object could be modelled by integrating over just a few patches.

2.4 *Melting pot.*

After the whole object has been covered, we need to integrate the data into the model we seek. This we can do by using a planar parametric grid onto which each triangle obtained previously can be projected.

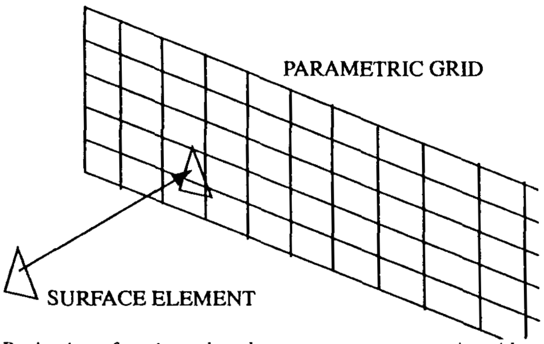

Fig. 3 *Projection of a triangular element onto a parametric grid.*

The only assumption we have to make about the object we are interested in is that all of the points on the surface to be modelled must be visible from that grid. Otherwise such a grid would be useless. We orient this grid parallel to our reference plane against which the object is resting. In general the patches obtained during the scanning process will overlap and some areas of the object's surface will be represented in possibly many patches. This redundancy can be removed by the use of the parametric grid.

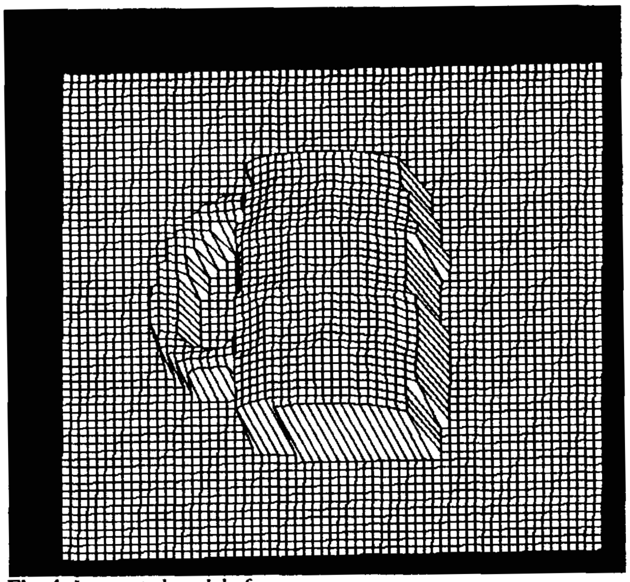

Fig. 4 *Integrated model of a mug.*

3. THE INSPECTION PHASE.

3.1 *Slicing up the cake.*

Now that we have a model of the object to work with, we can move on to the actual inspection. What we have to do here is to divide the whole region of interest into smaller regions and to take an infrared "snapshot" of each one. The way this "slicing up" is performed depends on the object's geometry and on how much interest we put over a certain region. One thing is for sure, we have to make sure that the different snapshots overlap at least a little bit to insure that the whole object is inspected.

3.2 *Bake for a few seconds and let cool down.*

The infrared thermography apparatus includes a heating unit turned on for a few seconds in order to raise the surface temperature of a few degrees. We let the thermal wave propagate through the material and after a period of time depending on how deep under the surface we want to look for defects, we take a snapshot of the surface with the IR camera.

3.3 *Playing ladders and snakes.*

Once we have decided how our surface of interest is to be divided for inspection, we need to find a way to avoid heating up neighboring regions sequentially. We probably need to play "Ladders and snakes" and move over the surface in such a way that we put as much time as possible between the inspection of two neighbors.

This is because of the fact that if we heat up a region for thermographic inspection, the thermal front will certainly propagate beyond the region's boundary; if we try next to work over a neighboring region, some distortion is induced where the surface temperature had been affected by the heating of the previous region.

3.4 Smoothing out the wrinkles.

Because of the non-planar nature of the surface of interest, the infrared pictures we have taken cannot be interpreted directly. We have to compensate for the fact that the thermal wave did not propagate through a planar material. The model we have worked so hard to build can be used again just for that purpose since we still possess the information about the surface height and orientation.

4. Interfacing

The different parts of our system need to work together in harmony by exchanging information one way or another. Let's see how our system is set up.

As we have said earlier, we are using a PUMA 560 robot arm for our purposes. In fact, it has been stripped of its original controller and is now driven by a Sparc engine connected to our computer network. This work has been done on it to improve its performance and to allow for direct software control through a special server program. This has enabled us to write direct and inverse kinematic control routines adapted to our specific needs.

The Jupiter range finder's controller has also been modified. It is now possible to communicate with it through a parallel port as well as through its standard serial port. Originally PC driven, the controller has been interfaced to a Sun Sparc station and a server program has been developed.

The infrared camera sends its data to a PC through a frame grabber. Again here, an interface between the PC and a Sun workstation has been developed.

The main program, running on a Sun work station, can control the whole system through all these interfaces. It must receive and save the data sent by the range finder. All this data must be expressed relative to a global reference frame; to do so, the program needs to know at all time the position of the camera head relative to that global frame. Conversely, the program decides where the robot should go next and sends its orders to it. This is why we have written direct and inverse kinematic control routines that work closely together to insure smooth running of the system.

Conclusion

We have presented a robotized version of the standard non-destructive infrared thermographic inspection system. In its present form, such a system could prove useful for the inspection of laminate materials that present fairly smooth curves. One cannot help but think of the aeronautic industry where planar parts are sparse.

Our system obviously has certain limits imposed by the material used. One big limit being that the infrared camera is nitrogen-cooled and must be kept fairly straight up in order to avoid coolant leakage.

The performance of the inspection system could be improved if the model building and the infrared scanning could be performed in one operation but on the other hand, separating these two processes gives us the ability to model an object once and then to use that model to inspect similar objects. The system is flexible enough to allow one to model objects only in order to build a bank of part models, or to perform the whole process if desired.

Acknowledgements

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