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Automated Weld Tracking

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Abstract

In this paper we will present a robust approach to the problem of weld following. The task is particularly useful in the creation of automated weld inspection robots, but the technique could also be used to follow other contours in the image plane.

The technique uses the image intensity along a circular contour to determine the symmetry patterns which feature across real contours such as welds. The ability to follow a complex contour such as a weld without any smoothing significantly reduces the computational load. The algorithm also provides a means of searching for the weld in the case of the system "getting lost" due to outside disturbance.

1 Introduction

Many welds are under conditions that make them difficult or impossible to inspect regularly. The risk of weld failure cannot be overlooked, and a system to automatically inspect these welds is important. This paper takes one step towards this goal by suggesting a robust technique for automated weld tracking. Although the algorithms are presented in this context, they could easily be adapted for other contour-following tasks.

Following welds might appear a simple task with the advent of fast and effective contour tracking techniques such as the B-spline snake. However, the complex intensity profile of real welds makes the task very difficult. Figure 1 shows a 3D plot of a typical weld intensity profile, from which it might appear that smoothing would be necessary to some degree.

We shall show, however, that it is possible to base a weld following routine simply on the assumption that the intensity profile forms a symmetrical pattern either side of the weld. The algorithm will use this information to direct a robot to follow the weld. The technique is based on a circular search region around the image centroid, along which a new intensity profile is established. This is then used to "balance out" the intensity around the circle, and determine the direction of the weld.

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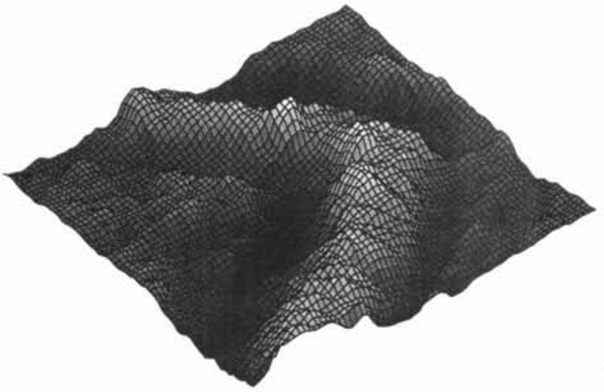

Figure 1: The 3-D plot of the weld image intensity shows how the contour lacks a well-defined structure, which makes it difficult to track. There is a large-scale symmetry across the weld which can be exploited in weld tracking algorithms.

2 Theory

2.1 Contour Tracking using Radial Intensity Moments

By defining a polar coordinate system, (r, θ), centred in the image, the image intensity function can be express as $I(r, \theta)$. If we now consider the intensity profile along a circular contour of radius a, the function will be seen to have local maxima at the points of intersection of the contour and the weld (the assumption that the weld does actually cross the contour is considered later).

Using a mechanical analogy, the circular contour can be imagined as a continuous ring having a changing elemental thickness of $I(a, \theta)$ for constant a. If the ring is allowed to hang from its centre, the area with largest density (or maximum intensity in the image plane) will be pulled to the lowest point under gravity. This analogy shows that to determine the point of maximum intensity (or the area where the weld crosses the circular contour), specified by the angle α from some datum, the total summed "mass" either side must be equal:

$$\int_{\alpha}^{\pi+\alpha} I(a,\theta)d\theta = \int_{\pi+\alpha}^{2\pi+\alpha} I(a,\theta)d\theta \ . \quad (1)$$

Note that this is only true if the weld crosses the contour at just **one** position, which will also be considered later.

Expanding the integrals and defining the intensity integral

$$J(\gamma) = \int_{0}^{\gamma} I(a,\theta)d\theta \ , \quad (2)$$

we find that the contour direction, α, is given by

$$J(\pi+\alpha) - J(\alpha) = \frac{1}{2}J(2\pi) \ . \quad (3)$$

It might appear from this analysis that the technique relies on a low background intensity relative to the intensity of the weld. However, by considering the mechanical analogy described above, it can be seen that the technique works based on the symmetry of the intensity profile, rather than specific intensity values.

As mentioned above, if the weld closes the circular contour at two radially symmetric positions, equation (3) has no single solution. To solve this problem, one of the high intensity peaks along the integration contour must be ignored. This is done by "windowing" the intensity profile:

$$I'(a,\theta) = w(\theta)I(a,\theta) \quad (4)$$

where $w(\theta) = 1$ for some range of θ and zero elsewhere. If the approximate direction of the weld is known, the window can be set to extend either side of this direction. The range must be chosen according to the following criteria:

- If the range is too large, the solution to equation (3) will be meaningless for the case where the weld crosses the circular contour at two radially symmetric positions.
- If the windowed range is too small, there is the risk that a sudden change in weld direction will cause the intersection of the weld and the circular search contour to be outside the windowed area.

Figure 2 shows different situations of the weld position relative to the camera.

2.2 Iterative Determination of the Search Radius

Figure 2 demonstrates an important feature of this contour following technique: if the contour is outside the radius of search, a direction of travel cannot be determined. Detecting this case is easy, and can be done in one of a number of ways:

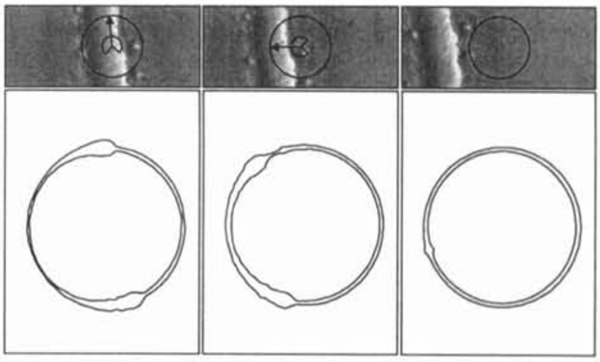

Figure 2: *Left*: the weld can be seen to cross the integration contour at two radially symmetric positions. In order to find the direction of the weld, the intensity profile around the circular path must be windowed (see text). *Centre*: The weld is slightly offset from the camera centroid, and therefore the intensity moment directs the camera in the correct direction. *Right*: If the weld does not cross the integration path, the system enters a "lost" state, which is discussed in section 2.2.

- If the integral $J(2\pi)$ falls below a threshold, the "lost" state can be triggered. This method does require a threshold to be specified, and therefore, although it is simple, it was not recommended. Further, if the camera enters a region of uniform high intensity, the results will be indeterminate.
- Counting the number of pixels on the search circle which are higher than a threshold provides a method of detecting the lost state. Once again, this does require a threshold to be specified.
- The weld is characterised by a sharp intensity gradient on either side of the contour. Therefore by searching for large gradients in the intensity contour, $I(a,\theta)$, the presence of a weld can be detected. As the size of the intensity field has been significantly reduced, it is quite feasible to smooth the intensity along the contour in order to reduce the effect of noise.

If the camera is found to be lost, the radius of search, a, can simply be increased until the weld is located. As soon as the circle search contour passes over the weld, the moment calculations will provide a vector towards the weld (see figure 3).

3 Algorithm

The experiments were performed using an uncalibrated CCD camera held in the grippers of the manipulating arm of a Scorbot ER-7 robot arm. All processing is performed in real-time on a single Sun SPARCstation 20. A test weld was arc-welded onto

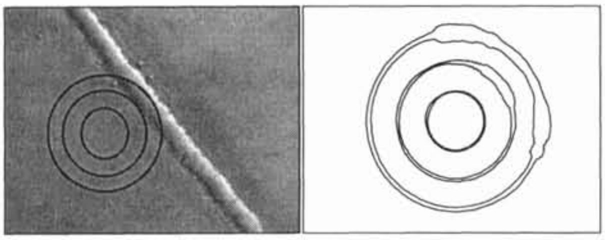

Figure 3: In the "lost" state, the radius is increased until the weld is found. This is detected be searching for areas of high intensity around the search region.

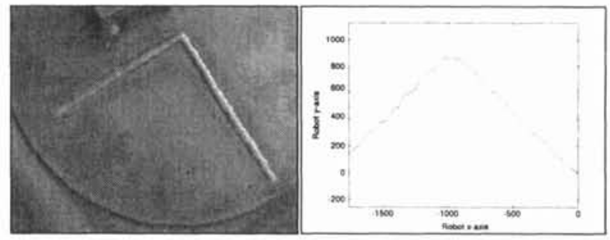

Figure 4: Following the weld in the image above and monitoring the position of the robot allows a map of the weld to be created.

a metal base, and consisted of two straight lines of 25cm in length joined at a right-angle.

1. The system is initiated with the weld near to the centre of the image, and the initial search radius is set to a relatively large starting value, typically $a = 150$ pixels.
2. The intensity values around the circle of radius a are sampled, and the integral $J(\gamma)$ is calculated from equation (2).
3. The intensity circle is searched to determine whether the system should be in the "lost" state as described in section 2.2. If the weld is not within the search area, a is increase by approximately 20% and the step is repeated. If the weld is within the search radius, the radius can be slowly reduced, typically down to about $a = 40$ pixels.
4. The intensity moments are used to determine the direction of the weld according to equation (3). The intensity profile is windowed up to 70 degrees either side of the expected weld direction (i.e. the direction of the weld on the previous iteration).
5. The robot can now be moved in the direction of the weld and the algorithm repeated.

4 Results

Figure 4 shows how the algorithm can be used to create a "map" of the weld. The position of a robot arm is monitored as the algorithm is executed, and this can then be used to produce an approximate profile of the weld shape. The inspection task is left for future work.

5 Conclusions

In this paper, we have presented a very simple technique for tracking weld contours. By avoiding smoothing and looking simply at the natural large-scale symmetry across the weld, the computational load of the algorithm is very low. Further, it has been shown how the "lost" state can be detected and resolved, by increasing the area of search in the image plane.

Acknowledgments

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