

Figure 11 Two consecutive images and their splines

Below are shown pictures taken from the metallic pieces used as samples and the splines corresponding to each image processed.

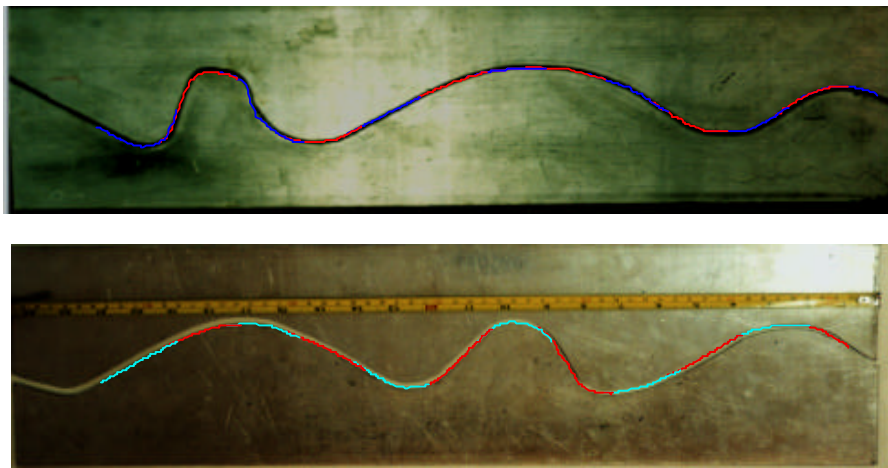


Figure 12 Metallic samples and their splines

6. Conclusions and Future Work

What was achieved so far is a good evidence that the automation of the welding cell with computer vision is possible with the use of transputers.

Possibly the acquisition times can be reduced by the development of new drives for the frame-grabber directed to the needs of this particular system, resulting in lower processing times, what would allow the robot to move faster.

7. References

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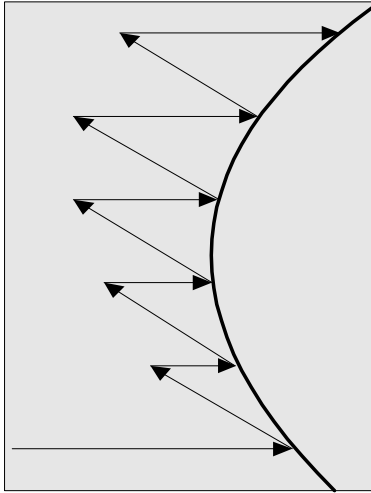


Figure 9 Triangular Search

Once the border of the piece on the left was detected, the junction is scanned to obtain the coordinates of the other border. The values stored as the junction's coordinates are the mean value of the junction and the number of the line where this search took place.

4.2 Splines

The set of coordinates of an image is interpolated using natural cubic splines. The reason why splines are used is because the resulting expression has a smooth first derivative and a continuous second derivative both in the interval and on its borders. In the case of the natural cubic spline, its second derivative is zero. In terms of robot motion it means that inside the image and in the transition between images there are no sudden changes on the motion what would cause discontinuities on the robot movement.

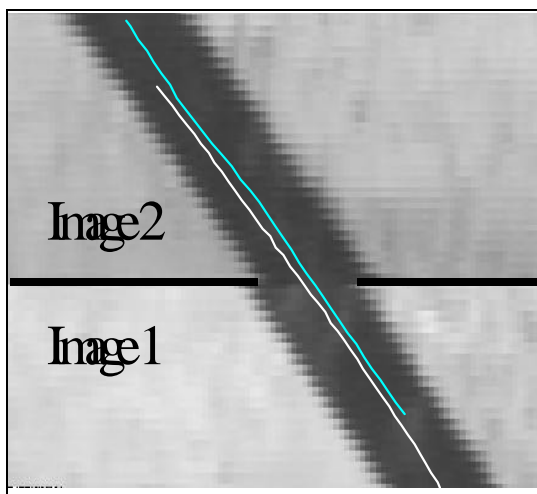


Figure 10 Intersection of 2 adjacent splines

The expression of a spline is: $y = Ay_j + By_{j+1} + Cy_j'' + Dy_{j+1}''$, where:

$$A = \frac{x_{j+1} - x}{x_{j+1} - x_j}; \quad B = 1 - A = \frac{x - x_j}{x_{j+1} - x_j};$$

$$C = \frac{1}{6}(A^3 - A)(x_{j+1} - x_j)^2 \text{ and}$$

$$D = \frac{1}{6}(B^3 - B)(x_{j+1} - x_j)^2$$

Interpolation using splines is possible when the values have a monotonous behaviour. To solve this problem we transform the junction coordinates into its parametric representation by the displacement s where $s = \sqrt{(\Delta x^2) + (\Delta y^2)}$.

5. Results

Below it will be presented a comparative chart between Gomide & Guillén vision system, and the system developed in the present work, with and without the process of writing images and junction coordinates to the disk during the execution. Writing to disk was important during the development of the system because the images could be opened and the results analysed. In addition, some images of the path generated will be shown superposed to pictures of the metallic pieces used.

	Gomide & Guillén system	System with disk storage	Without disk storage
Time between images (ms)	200	3000~3200	500~530
Robot speed (mm/s)	10	15	15
Image acquisition time (ms)	N/D	45~52	45~52
Junction processing (ms)	N/D	N/D	6~8

N/D: not determined

With the junction coordinates and the images stored in disk, it was possible to open the images and to obtain the splines for each one of them using MATLAB®.

(1), the previously acquired one is processed in order to extract junction's coordinates (2) and these coordinates are stored (3) what can be represented by the following diagram.

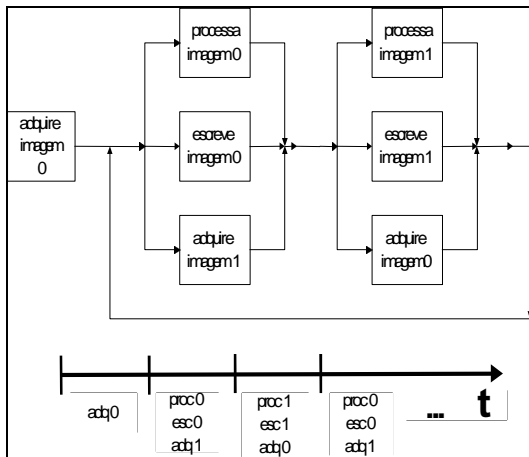


Figure 4 Process Sequence

The reason why it is possible to work with 2 images is that the camera is always ahead of the torch in a configuration named *Look-Ahead Image Processing*. The system has to be fast enough to process the image and to leave the instructions to the robot controller available for execution before the torch reaches the area related to that image.

In the sequential PC-based vision system developed by Gomide & Guillén [2] welding happens in two stages: junction recognition where the camera goes along the metallic pieces to be welded obtaining the junction coordinates; and the welding actually when there is no image acquisition .

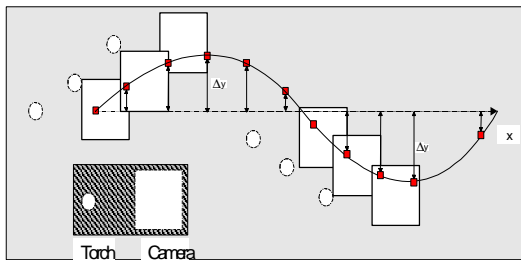


Figure 5 Stage 1

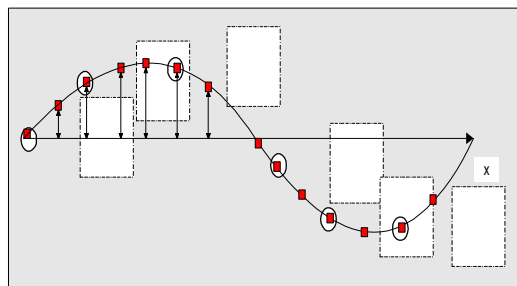


Figure 6 Stage 2

The characteristic of concurrent processing of the present system allows path-generation in real time, as illustrated below. The lines across the path represent previously processed junction coordinates to which the manipulator is being guided, while the squares along the line representing the junction are the points being processed at that moment. The dotted circles stand for the torch and the large square for the camera's field of vision.

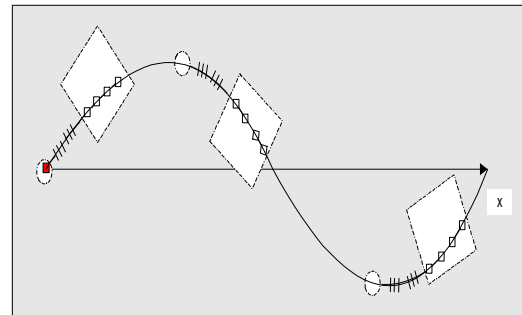


Figure 7 Real time welding

4.1 Junction Detection

The junction is detected by the comparison of the grey level of the pixel being analysed with a threshold level. It was used a process called triangular scanning, proposed by Gomide & Guillén in [2], a variant of comb scanning where instead of returning to the first column of the image on each line being scanned, the search for the junction on the following line starts at a set number of pixels to the left of the pixel where the junction was detected in the line scanned at that moment, assuming that the image is scanned from the left to the right.

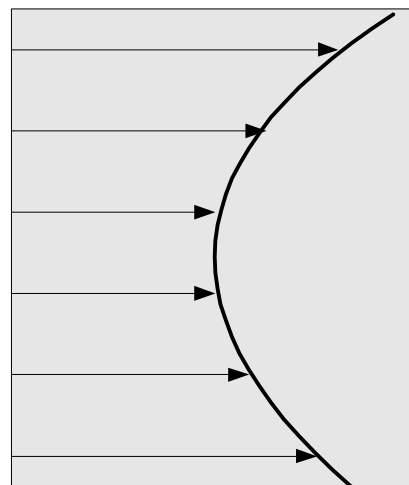


Figure 8 Comb Search

Many studies in this field have been developed by the researchers of GRACO for some years, such as [4] and [5].

2.1 Description of Robot Welding Process

As mentioned above, the manipulator has to know the path above the junction to be followed, what is called path planning. The most common robot programming interface is called teach-in-box. Through the teach-in-box the path can be passed to the robot by some methods such as:

- **Manual programming** which consists in physically driving the manipulator over the desired path;
- **Point teaching programming** where the manipulator is taken to some points over the path. These points are stored and the controller of the manipulator is responsible for the interpolation of these points and consequently for path generation.

There are also ways of programming manipulators without the use of the teach-in-box, for example:

- **Off-line programming:** in this case the path is created, verified and simulated under a computer graphics environment and afterwards downloaded to the manipulator controller through a digital link;
- **Task programming:** The manipulator has a set of predefined tasks stored in its memory. The programmer defines the tasks to be executed and the manipulator gathers them generating the path.
- **On line programming:** Information received from sensors added either to the manipulator or to its working cell are processed by an embedded system which is responsible for path generation among other tasks.

2. Hardware Description

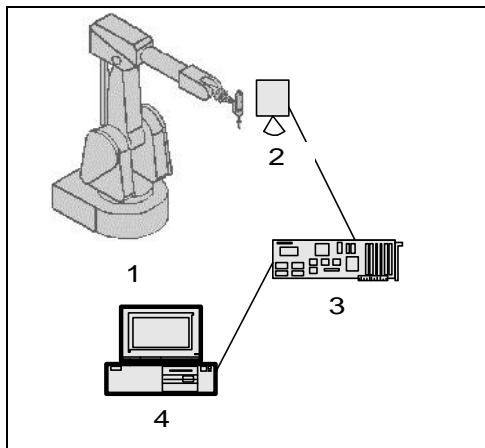


Figure 2 Hardware Illustration

1. Asea Boveri Brown (ABB) IRB2000 with S3 controller;
2. Pulnix TM-6CN 8-bit monochromatic CCD camera;
3. Inmos T805 transputer with Brooktree Bt819 frame-grabber;
4. Pentium PC.

3.1 Transputers

Transputers are single circuits containing a processor, local memory and 4 high speed serial I/O ports which can be easily connected with other transputers allowing many parallel processing network architectures, by simple cable connection at the backplane of the transputer cabinet.

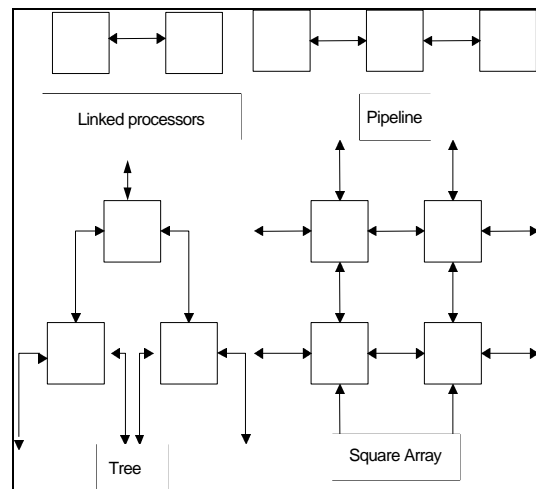


Figure 3 Examples of network architectures

The network is hosted by a computer which is seen by the network as another transputer. The peripherals of the computer can be accessed by the transputer connected to him. The programs for the network, including its logical configuration, are developed and compiled in the computer and afterwards downloaded to the network and executed. There are language packages developed for transputers in FORTRAN, ANSI C and OCCAM for different operational systems (MS/DOS, SunOs, VMS). In this work the ANSI C toolset for MS-DOS version D7314A provided by Inmos, the transputer creator was used. Nowadays Inmos is part of the SGS-Thomson group.

4. Algorithms

Transputers implement on hardware the CSP (Communicating Sequential Process) model. The program is divided in processes which can communicate among themselves by channels. The algorithm developed in the present work consists on three processes dealing with two images: while one image is acquired

Computer Vision Parallel Processing for Welding Robots Guidance

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Abstract

Because of the sharp increase in the use of sensors in automation, several applications are being developed such as self controlled aircrafts, submarine inspection robots, remote operated manipulators and others. This work is a contribution to the researches on automated processes of the *Grupo de Automação e Controle – GRACO* of the *Universidade de Brasília – UnB* aiming the development of an automated welding work cell with parallel computing and concerns computational vision processing, aiming path generation for the manipulator tool.

As the automation of such work cell involves many different tasks, there must be a network of parallel processors in order to handle these tasks and the data involved allowing real time processing. The vision system was developed using transputers, parallel processors to which a brief explanation will be given further, and focuses on image acquisition and junction recognition for path generation. The structure of the system will be presented in addition to an explanation of the algorithms implemented. Then, some results obtained are presented and perspectives for future work commented.

1. Introduction

Robots can be defined as mechanical devices controlled by software capable of accomplishing programmed movements within its work cell [3].

The great effectiveness of robots in assembly lines is verified in situations of flexible automation, i.e., situations of medium to large scale production where there are possibilities of changes in the task to be performed. The advantage is that these changes can be done simply by reprogramming the manipulator's software.

In large scale production, hard automation is more appropriate, although changes in the task performed require hardware modifications, therefore interrupting the assembly line for a longer period of time than what would be required in the case of robots.

By the addition of sensors to robots, together with the reduction of cost and increase of efficiency brought by technologic advances, the cost-effective interval is widening in both directions in the following graphic.

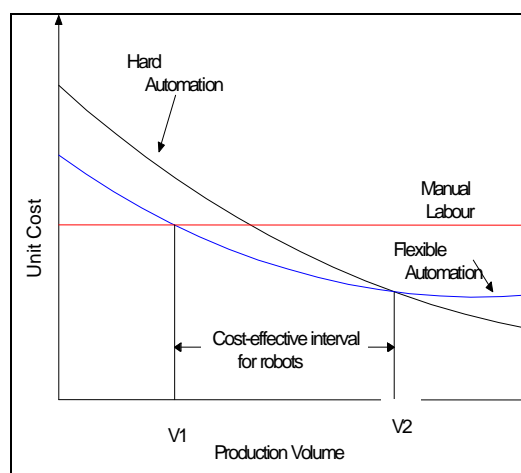


Figure 1 Manufacture process optimal volume intervals [3]

In order to have an automated robotic welding cell, an important feature to be added to the manipulator is a vision system. By the images acquired from the pieces to be welded, the junction between them is detected, and consequently the path the manipulator must follow is determined.