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MACHINE VISION AND ARTIFICIAL NEURAL NETWORKS FOR SEAM TRACKING AND WELD INSPECTION

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Abstract. *The robotic welding sometimes is difficult when the geometry to be welded is very complex, making it hard to program. Also, sometimes the weld bead is irregular, due to poor quality parameters control. This can be solved with seam tracking tools, like arc sensing, touch probe or structured light. The use of a structured light, as a LASER line, for example, can also bring others advantages beyond identifying the right position, since it can also capture the shape of the resulting weld bead. With the geometry of the groove, the shape of the bead and with information about the weld, as velocity, current, voltage and feeding rate, the system can be trained, by means of a neural network algorithm, to recognize and analyze if the weld bead is within the specified range.*

Keywords*:* Machine Vision, Artificial Neural Network, Structured Light, Seam Tracking , Welding, Inspection.

1 . INTRODUCTION

The pipeline construction is made trough the welding of tube segments, a complex 5G process were all weld positions are required. The pipelines, mainly the small diameter ones, are welded manually with GTAW for root pass and then with SMAW, as can be seen on left of Fig. 1. In Brazil, the automation on pipeline construction is used but productivity gain can grow up to 100% compared to SMAW process (Felizardo et al., 2007) besides the expressive increase in quality and homogeneity. Fully automatic systems for pipeline welding, like the one on right side of Fig. 1, were nationally developed (Lima II et al., 2005) and the improvement trough video feedback techniques can bring even more expressive gains.

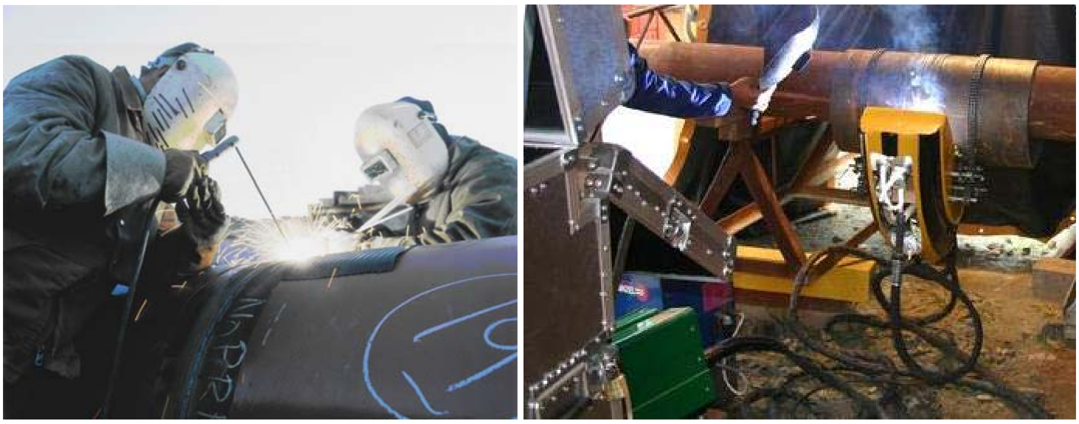


Figure 1: Manual welding of pipes and orbital weld robotic system.

The automation, however, suffers with the normal field welding problems, most of times the low quality of raw materials and tubes alignment. It is necessary to say the tubes are very often 12 meters long pieces with tons in weight and to align it and set the right spacing with milimetric precision is very a hard work. So, small deviations on the weld joint form are very common and enough to deny more sensitive automatic process like the root pass welding. However, the welder can easily deal with these imperfections and do a good weld, hence there is a consensus that the robot need to be adapted to work conditions, and not the opposite.

The objective of the present work was create a sensing system able to detect an inform to the robot the various geometric that the system can find on tube during welding. The system also need to be able to detect the geometric form of

ABCM Symposium Series in Mechatronics - Vol. 4 - pp.768-775

weld bead and communicate to operator the presence of critical problems, which may require manual repair before the groove fulfilling or even automatic repair by the robot.

2. DEVELOPMENT

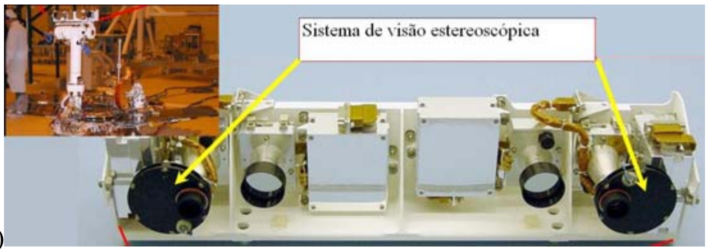
The image inspection systems, or computer vision, exist from decades ago, but on last years there is a huge expansion on that technology by digital cameras and more accessible computer processing power. The field of computer vision is wide and presents multiple ways to inspect each problem.

2.1. Types of Image Sensing

There are many ways to analyze video images, and the most common is the image analysis, which works extracting information from an ordinary 2D image. It is very useful on application like bar code reading and face recognition, but do not provide any information about deep.

Adding a second camera, in a fixed angle from the first one, there is the stereoscopic vision (Fig. 2(a)), where the deep of subjects of interest can be calculated trough the triangulation of the two acquired images. Both methods have the benefit of provide a complete image on all analyzed frames.

For more accurate analysis of the involved dimensions we use a structured light method. The structured light is an intense light bean, usually LASER, with predefined geometric form, usually one (Fig. 2 (b)) or more lines, or a square.

(a) 

(b) 

Figure 2: Stereoscopic vision system of Mars exploration rovers (NASA/JPL) (a), and structured vision system (David-Laserscan) (b).

2.2. Image acquisition systems

The camera is the main equipment, and a right choice has great influence over the final result. Cameras can be analogical or digital but the high cost of video capture cards for analogical cameras make the digital cameras much more attractive, mostly because they immunes to noise, have better resolution a higher capture speed, on some cases.

The set of lenses and filters will directly affect the image quality. Some lenses can distort the image edges inducing to errors. Also, reflexes and shadows which affect the final result. To avoid those problems a set of filters is used to filtrate the light on specific wavelengths an polarization that matters, producing more accurate images.

The radiation emitted by the arc is very strong and have a too wide specter and hence hard to filter. A useful option, described by Franco (2007), is the synchronization between image capture and pulsating arc, because in the welding by pulsating arc or short circuit transfer the arc is extinct for a short moment, enabling an clear image.

2.3. Image treatment

The synchronization system is not perfect because monitoring the arc voltage may produce false positives of arc extinction. As the obtained results with the lit arc are too bad, a simple algorithm, based on image histogram as seen on left of Fig. 3 can avoid a bad quality frame provide wrong data to control system.

The selected frames pass trough tresholding process, where the image is converted to grayscale and binarized where all pixels over a specified gray value are set to white and under that value is set to black. This process is useful to isolate the laser line from the background to later analysis. The LASER line usually have many pixels of thickness, like the line on center image of Fig. 3. So, a filter it is needed to make it only one pixel thickness, which can be made by taking only de lowest, highest or average edge or by erosion. On Fig. 3 at right we can note the best result is obtained taken the lowest border.

ABCM Symposium Series in Mechatronics - Vol. 4 - pp.768-775

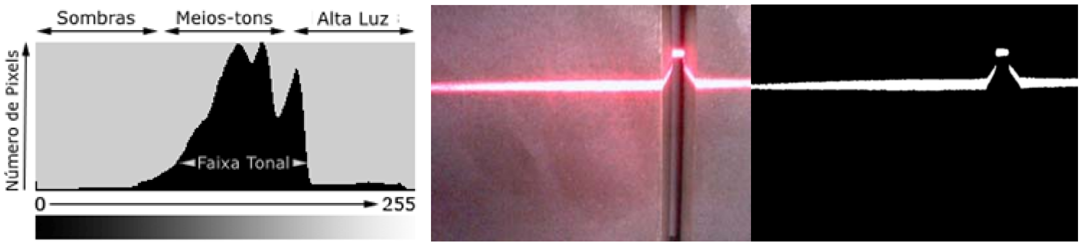


Figure 3: Histogram analysis (DAVID-LASERSCAN) and LASER line before and after the tresholding.

We need then to vectorize this one pixel thickness line in order to extract the features of interest, like lines, curves, corners, blobs, discontinuities, maximums and minimums. Each feature demand a proper algorithm. The line and corner detection is important to define the groove and curves are important to define the weld bead.

It is important to notice that the processing speed is also very important. So, to keep 60 frames per second rate the algorithms need to be optimized to the target image.

With feature extraction completed we have the groove, weld bead and neighborhoods vectorial models, allowing to detect and calculate robot tool position errors, weld bead surface imperfections as well as errors in relative positions between the plates.

3. MATERIALS AND METHODS

This experiment was performed with industrial cameras provided by The Image Source, model 21BF04, with firewire interface that allow to use cables longer than USB technology and have a input to synchronize the image and the electric arc. The system was attached to an objective lenses system from COMPUTAR VARIO, providing adjustable focus and iris. For a better image quality was used an infrared filter, polarizer filter and an interferometric filter which blocks all visible wavelengths except 532±2nm, all filters acquired from Edmund Optics. The camera and filters can be seen on Fig. 4. The reference LASER line was made using line generators from AixiZ LASER, in versions of 532 and 635nm and 5mW of power.

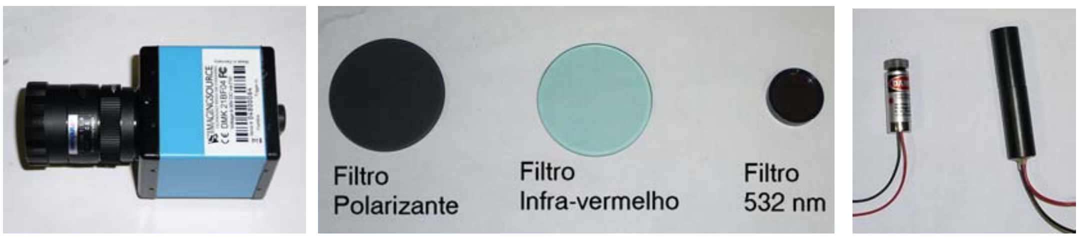


Figure 4: Equipment used for sensing.

The algorithms were tested and enhanced using MATLAB and later rewrote in C++ using the open source library OpenCV, from Intel.

For image capture, the LASER was mounted perpendicular to target object and the camera was fixed at 150mm from the target object in a 45º angle from the LASER. On this configuration, all vertical displacement of the LASER line which is detected by the camera means the object is on an equal distance. It means the Y axis displacement on image regards in a 1:1 relation to Z axis displacement on real world. Fig. 5 shows a schematic drawing of triangulation system described.

ABCM Symposium Series in Mechatronics - Vol. 4 - pp.768-775

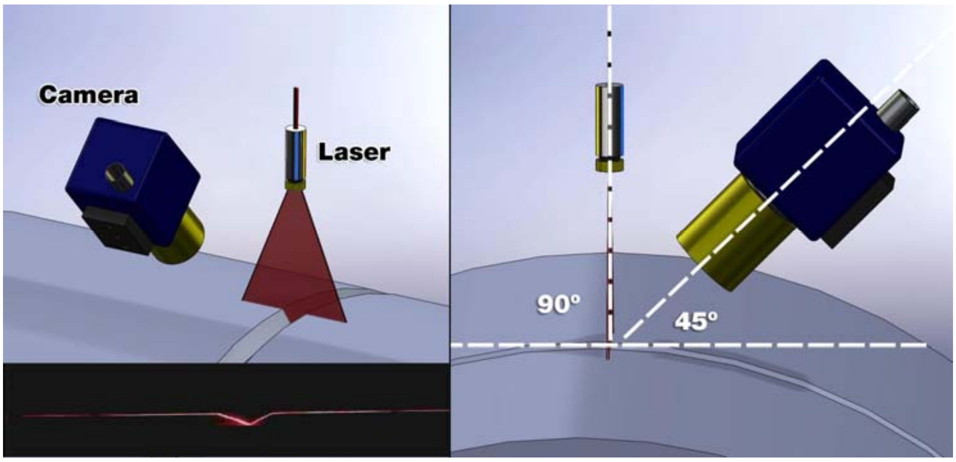


Figure 5: Image triangulation scheme

4. RESULTS

Trough the groove monitoring technique with structured light was possible to detect a variety of flaws usually found on union of two large sized tubes. Besides the assembling defects, the system is naturally able to detect small defects from groove manufacturing. Due that the first step is detect and describe the exact groove format on the place to be weld. Given just the tube thickness the system can detect the angle and nose size of the groove, the spacing between the tubes as well the corners which will be reference for the future added cords (Fig. 6).

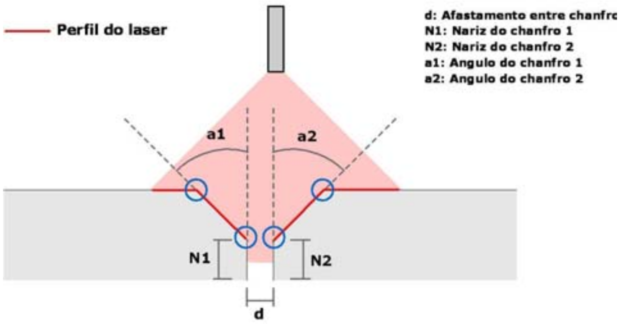


Fig. 6: Features extracted from the groove.

Once detected the groove form, the robot can proceed with the programmed welding routine or abort the weld, if the opening is too large. Alternatively can initiate a restorative action, like weaving movement, to ensure the good execution of the weld. Another very common defect is the nonalignment between the welding torch and the groove, due the groove are not made on a perfect perpendicular plane, or because the robot can occasionally be misaligned. When it happens, the triangle formed for the groove in the image moves from center, as show on Fig. 7, and the program informs to robot that a corrective action need to be done to keep the torch on proper place. That correction is also known as seam tracking.

ABCM Symposium Series in Mechatronics - Vol. 4 - pp.768-775

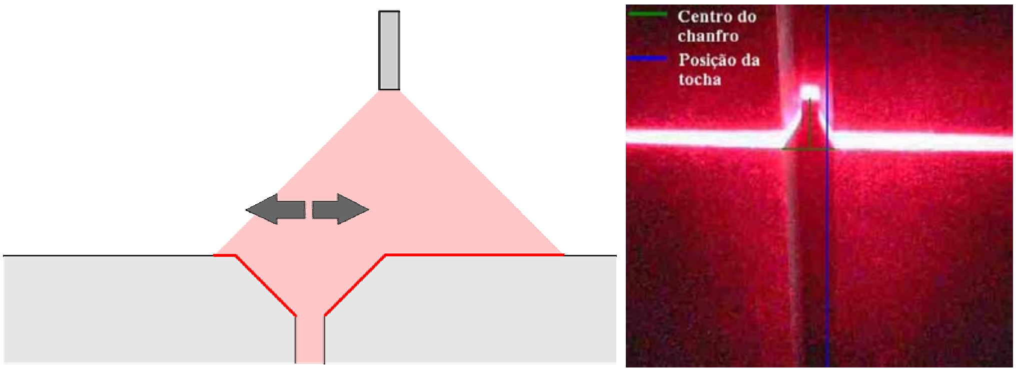


Figure 7: Trajectory deviations detection.

Eventually, angular deviation can happen on tubes junction, inducing both an angle and distance changes. This is a serious error which can be easily detected, as show on Fig. 8, but if ignored can disable the junction, because an spacing too small prevent an appropriate penetration and is impossible to weld with a too large spacing.

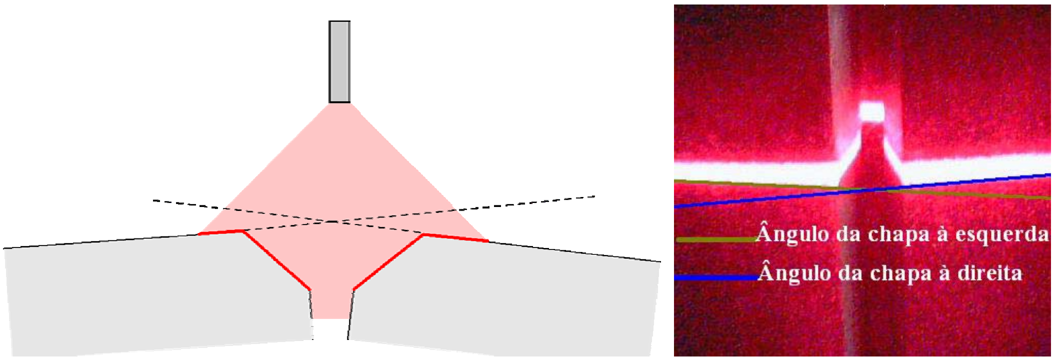


Figure 8: Angular alignment between tubes.

The tubes also can show circularity imperfections, which means they are usually flattened a bit, or elliptic, due manufacturing reason and self weight. So, when one of the tubes are imperfect or even both are perfect but the assembly was not quite concentric, we have the movement of one of the sides of the LASER line, as can be seen on Fig. 9.

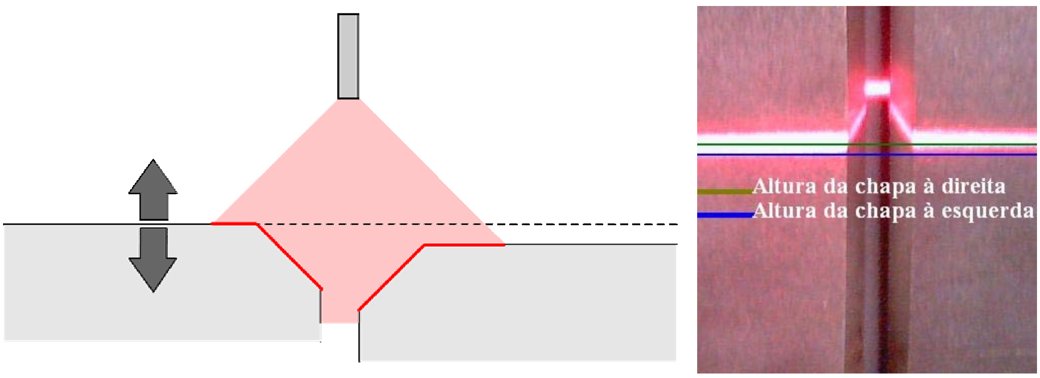


Figure 9: Circularity or concentricity defects.

After completing a pass, which means half tube from down to up in orbital welding, the software construct the complete 3D image of the groove to be welded and calculate the best trajectory for the existent geometry. Fig. 10 shows a flattered tridimensional model of a tube segment.

ABCM Symposium Series in Mechatronics - Vol. 4 - pp.768-775

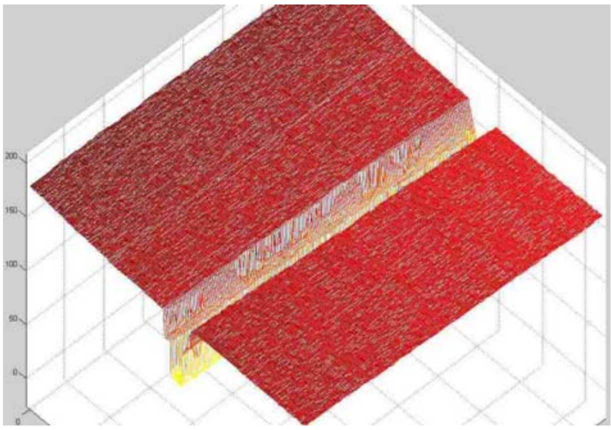


Figure 10: 3D vision of a groove segment.

Once every error on junction was detected and corrected in the best way as possible, the LASER does the acquisition of deposited cords, in order to check if it was on right place, if has a lack of material on some point or the presence of a crater of dimensions larger than acceptable. A frame of the cord monitoring is shown on Fig. 11 and the cord tridimensional reconstruction over the plate is shown on figure 12. In that case was used the upper edge as well.

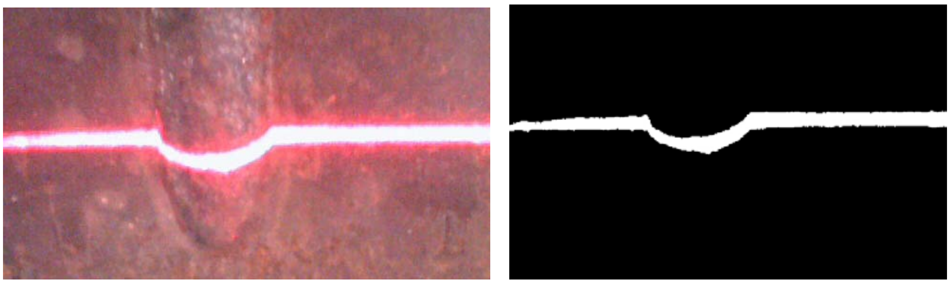


Figure 11: Cord form monitoring.

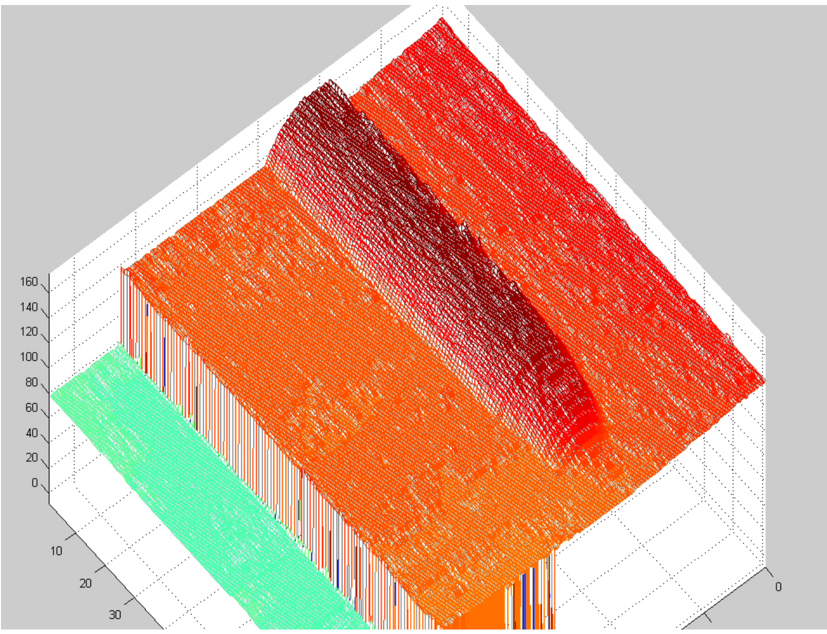


Figure 12: Cord tip 3D reconstruction.

ABCM Symposium Series in Mechatronics - Vol. 4 - pp.768-775

The system to track junctions, or seam tracking, found an even more robust application on high complexity junctions, with derivations and tubes T junctions. Although the computational model, as shown on Fig. 12, is able to prevent the format, it does not take in account manufacturing errors. Because that the trajectory need to be traced on the fly by the vision system, which is capable to trace a much more realistic trajectory since it uses interpolation trough thousands of control points.

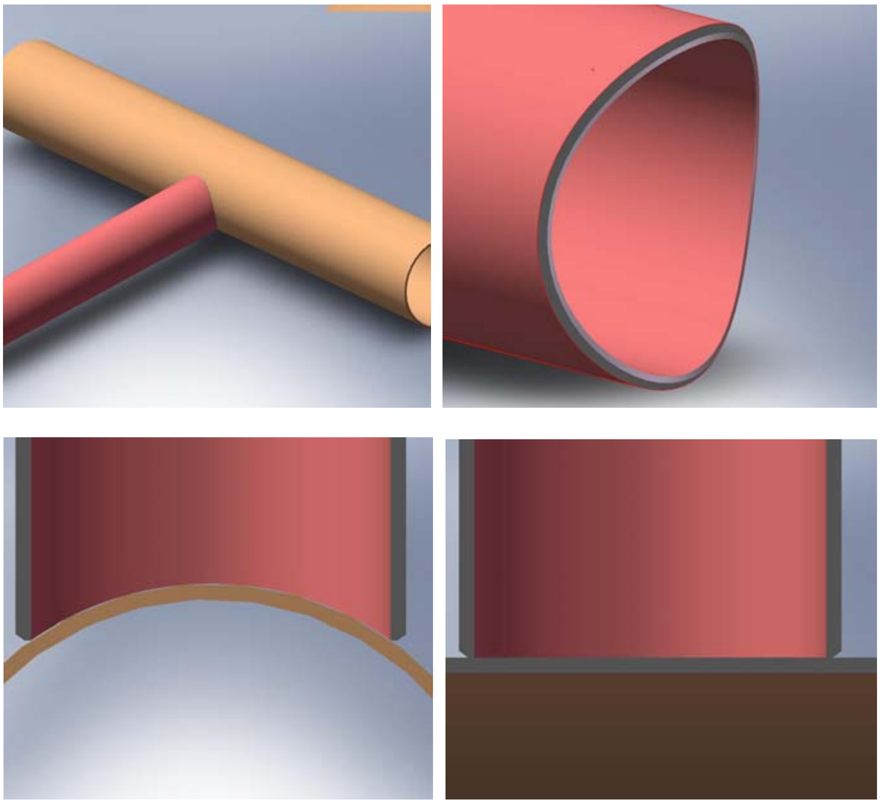


Figure 12: T junction, very common on hot tapping procedures, with complex trajectories, and variable junction to be welded, with almost flat groove at 0º and 180º.

5. USE OF NEURAL NETWORKS

Based on the information obtained by the vision system, a neural network can be used to recognize and analyze if the weld bead is within the specified range. Fonseca (2008) use a neural network to obtain, from welding parameters as welding current, voltage and speed, the geometry of the expected weld bead, for beads over plate and in the plan position. A similar methodology can be used to predict the expected geometry of the weld bead in other positions and for beads over groove. So, the neural network is trained to model the process as shown in Fig. 13.

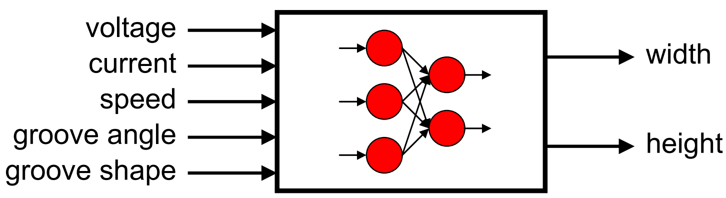


Figure 13. Welding process model using neural networks.

In Fig. 13, the model inputs are the welding voltage, current and speed, as in Fonseca (2008) added to groove angle (0^{o} to plan position, 180^{o} to overhead position and so on) and the groove shape (provided by the vision system before the weld).

ABCM Symposium Series in Mechatronics - Vol. 4 - pp.768-775

After the neural network processing, the expected weld bead width and height are obtained. These values are then compared to the actual values provided by the vision system after the weld. If the values do not match, then it is expected some defect in the weld.

6. CONCLUSION

The image system is capable to provide data for the pipeline robot orbital welding on a wide range of scenarios, proving to be a robust tool for the task. Image filters and synchronization systems will allow image capture closer to weld torch, given a smaller delay between what is actually happening and the result which has been acquired. The vision system also enable the automation for complex junctions and the defects prediction using neural networks.

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7. RESPONSIBILITY NOTICE

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