

Optical 3-D Metrology for Aiding the Autonomous Welding of Steel Constructions

Dirk Berndt¹, Axel Fix¹, Tino Müller¹, Erik Trostmann¹, Christian Teutsch¹

¹Fraunhofer Institute for Factory Operation and Automation (IFF), Department of Intelligent Sensor Systems, Sandtorstrasse 22, 39106 Magdeburg, Germany
email: dirk.berndt@iff.fraunhofer.de

Summary

We present a vision system integrated in a flexible manufacturing cell (FMC) for the automated welding of large components. The system mainly consists of an image processing unit for the interaction between a robot and its environment and the tracking of the robot transport vehicle (RTV) for the transportation of the equipment.

1. Introduction

In order to remain competitive, the European metal working industry aims for customer-oriented production more and more. That means, the automation of the welding activity in an environment producing customised products has potentially wide-ranging benefits for many other industries such as construction, shipbuilding, off highway vehicle, structural fabrication, military vehicles, and heavy handling equipment. Actually, smaller parts of large steel constructions are welded manually. Because of the fixation, manipulation and the necessary large production cells an automated manufacturing was impossible.

Therefore, the NOMAD¹ project was initiated within the 5th Framework Program "Growth" of the European Commission. This project aimed to develop and demonstrate an autonomous, flexible, robotic welding system capable of fabricating individually customised products as easily and quickly as large multiples.

In this work, we especially consider the vision system for the detection and localization of the components to be welded and the robot itself. After giving a short overview on the system in section two we present our new approaches in section 3. Finally, we summarize the work with a look at further developments in section 4.

2. System Overview

The developed prototype consists of the following components: a global image processing unit, a mobile robot platform (RTV), a 6-axis robot with welding actuator and local sensors, logistics for process planning, robot programming and system monitoring.

Within the framework of the NOMAD project, the use of area cameras and according image processing algorithms seemed to be the best choice to have a reliable system for global measuring tasks. Information about the entire scene is extracted with high accuracy and allows further procedures, such as route planning and the RTV path-following as well as logistical processes to work reliable and fast.

¹ AutoNOMous MAnufacture of Large Steel Fabrications (NOMAD); Consortium: Caterpillar Belgium S.A., Delfoi Oy Finland, ESAB AB Sweden, Fraunhofer IFF Germany, Nusteel Structures Ltd. UK, Reis Robotics Germany, Robosoft S.A. France, TWI Ltd. UK; Contract: G1RD-CT-2000-00461

The image processing unit for the identification and recognition has to detect and measure the spatial position of the components to be welded on the one hand and the actual location of the mobile robot platform on the other.

A passive, 4-camera system is employed as a measuring tool, which uses photogrammetric methods for calibration and localization of the steel construction within the work area. Furthermore, a simulation-assisted comparison of the measured and identified scene objects against the actual 3D-CAD-model is used to calculate the spatial location (position and orientation) of the parts to be welded in the working-cell. The mobile robot platform (RTV) was outfitted with coded markers to allow the detection of its location. After localizing and decoding these markers, an exact determination of position and orientation is possible.

3. The Vision System

The Vision System and the image processing unit have two main tasks:

1. Determination of position and orientation of the components to be welded after their positioning in the work area,
2. Tracking the mobile robot platform when it moves within the work space.

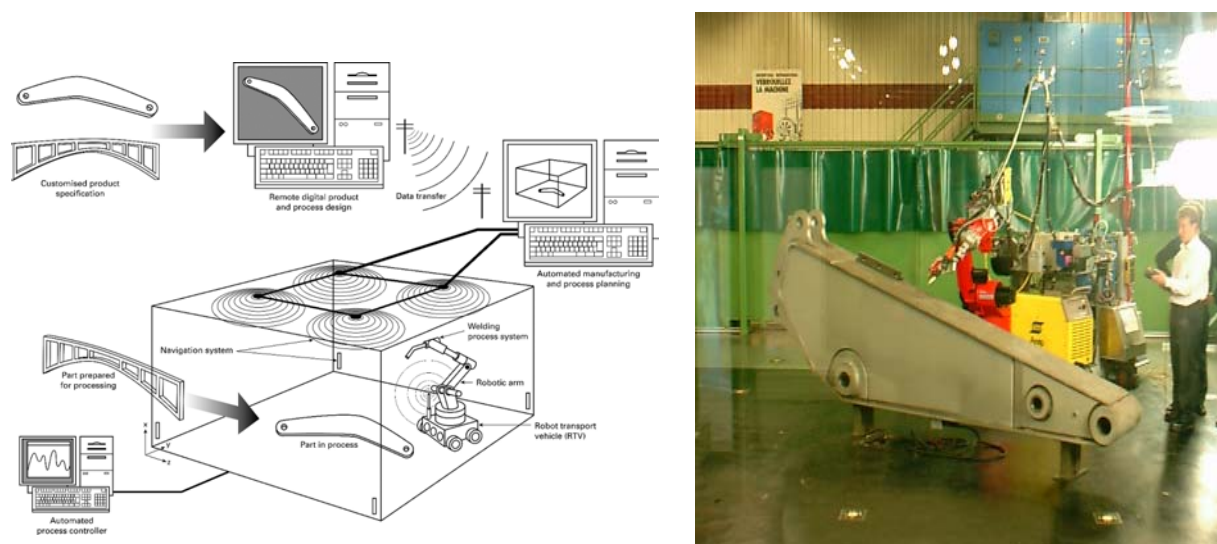


Figure 1. Schematic system overview (a) and the work space (b).

We use four graylevel camera devices combined as one vision system and mounted at the height of 6 meters above the ground plane to observe the objects inside the entire work area. Additionally, several coded markers are fixated on the ground plane. The code allows a unique mapping and assignment of single markers independent on their position in the image space of the actual considered camera. Their relative position was calibrated using a theodolite. Using this preliminary information, the intrinsic and extrinsic parameters of the camera system are calculated and its spatial position and orientation is determined after setting it up to the ceiling of the hall. Thus, we defined a global coordinate system for all devices inside the work area. The camera calibration procedure is based on a standard algorithm, which was first introduced by Tsai.

3.1. Determination of position and orientation of the construction

The recognition of the spatial position and orientation of the steel construction is mainly based on a simulative image comparison between artificial rendered and real images taken by the cameras at the ceiling. Therefore, the artificial images are generated based on a 3D-CAD-model of the actual scene with cameras and steel construction. For each of the virtual cameras the projection of the considered component to the virtual image space is calculated. The camera with the optically best perspective is used as reference. With the help of image segmentation algorithms the object (including centre of gravity and direction) in the virtual image as well as in the real image is detected.

The object recognition is realized as an iterative procedure. Step-by-step the 3D-CAD-model is two-dimensionally moved and rotated. Within each step, the centre of gravity and the object direction is evaluated in the virtual as well as in the real image. The iterations finish, if the objects in both images overlap sufficiently (see Fig. 2(b)). This algorithm converges after only a few iterations. Finally, the precise orientation and alignment of the steel construction with respect to the cameras is calculated.

In the following paragraph we describe an iterative processing and object recognition with the virtual and real images.

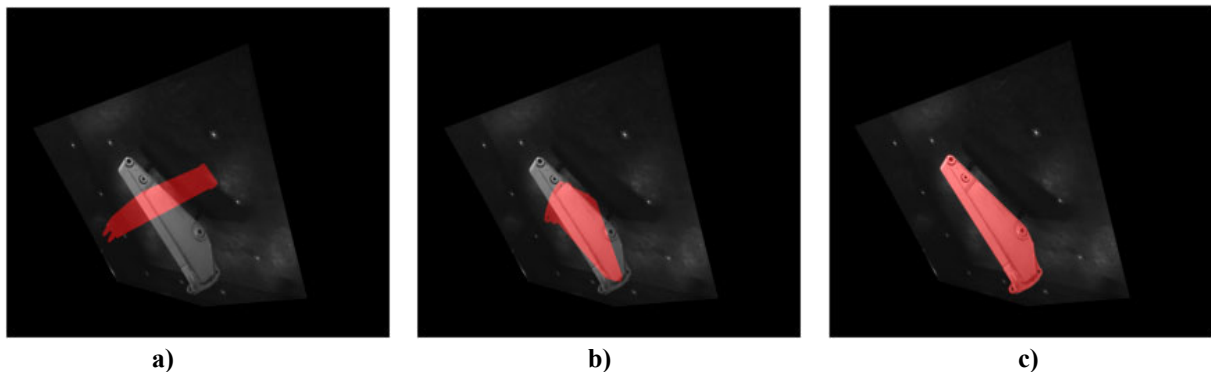


Figure 2. Functionality of the iterative procedure. Initial situation (a), 65% overlap after 4 iterations (b), final result with 98% overlap after 6+4 iterations.

The initial situation is shown in Fig. 2(a). The real and the virtual object have an arbitrary orientation and alignment to each other. After 4 iteration steps a correlation of 65% is reached (Fig. 2(b)). Finally, the virtual and the real object match after 10 iteration steps and the spatial position of the component is determined (Fig. 2(c)). Even if the quality of the virtual image is relatively low, a correlation of at least 90% is reached. In most cases, the translatory error is below 10mm and the rotatory error is less than 0.1° .

3.2. Determination of position and orientation of the mobile platform

The robot transport vehicle is moving within the entire work area and its recognition has to be dynamically. Therefore, two coded markers are placed at the top of the vehicle. Each of the 4 cameras, observing the scene, detects the markers in real-time. Based on the camera calibration, the spatial position of the markers and, thus, of the vehicle is calculated (see Fig. 3). Unfortunately, a photogrammetric approach with at least two cameras is not possible, because, in 90% of all cases the vehicle is seen by only one camera. That's the reason, why we use only one image and assume a constant height of the markers to the ground plane.

The position of the robot vehicle within the entire work space is determined with a precision of 10mm and an angular error of 1°.

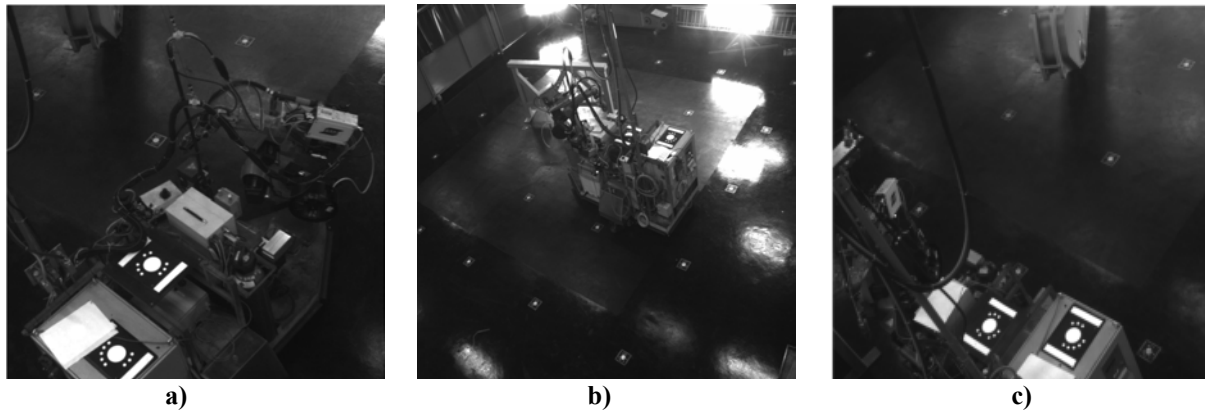


Figure 3. Work space and welding robot with coded markers as seen from three different camera positions. Because of occlusions (b), two coded markers are required.

4. Summary

We presented an approach for the automated tracking of an autonomous welding robot under industrial environmental conditions. Therefore, we used a multicamera system, which observes the mobile robot platform as well as the steel construction to be welded. Because of the large field of view of the cameras (>50m²) and their high distance from the robot vehicle, conventional image processing and 3D-Vision algorithms had to be enhanced.

The spatial location of the construction is based on a virtual image comparison procedure. We use the CAD-model of the constructional component and the calibrated positions of the cameras to reconstruct a virtual image of the entire scene for each camera. A simulative comparison between real and artificial image delivers the position and alignment of the item.

Additionally, we use coded markers to track the moving robot within the work space. Each of the four cameras recognizes the markers and delivers a spatial position. We did not use a photogrammetric approach, because the markers are seen by only one camera in most cases. This problem was solved by assuming a constant height, which is sufficient, because the robot operates on a plane ground.

In the future, additional developments and alternative measuring methods for quality control as well as of production processes will increase the feasibility of the presented system. So, the NOMAD project can be seen as the first project in this seminal area, since methods with global and local error-tolerant sensors were combined to achieve this high degree of flexibility.