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OFFLINE CONCEPT FOR OPTIMIZATION OF ROBOT PATHS FOR REMOTE LASER WELDING WITHOUT SCANNERS

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ABSTRACT
As a promising technology, remote Laser welding has been established to save time and money by reducing auxiliary process time to a minimum. While fast beam guidance by scanner devices is state of the art, robot based remote Laser welding systems without scanners seem to be the next level. To compete with scanner systems, fast path planning for robots is crucial. The authors present a new concept for offline optimization for this problem, regarding requirements and boundary conditions by the process and machinery.
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Keywords: Robotics, Remote Laser Welding, Path Planning, Fibre Lasers

1. INTRODUCTION
Remote Laser welding (RLW) is a relatively new technique based on an old principle. Similar to Laser marking systems, beam deflection with RLW systems from a distance of approximately 0,5 m to 1 m for solid-state RLW systems and about 1,5 m for CO_2 RLW systems [1] is achieved by a set of rotary mirrors and relocatable lenses mounted in a unit called scanner (Fig.1).

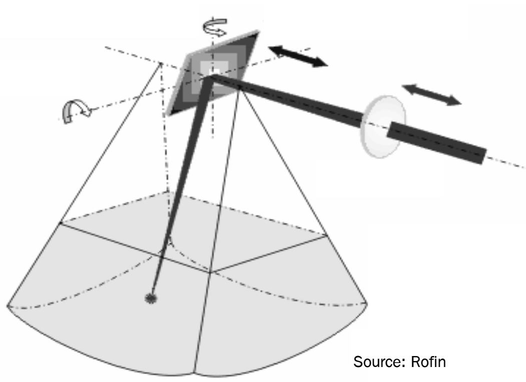

Figure 1. Principle of RLW with scanner

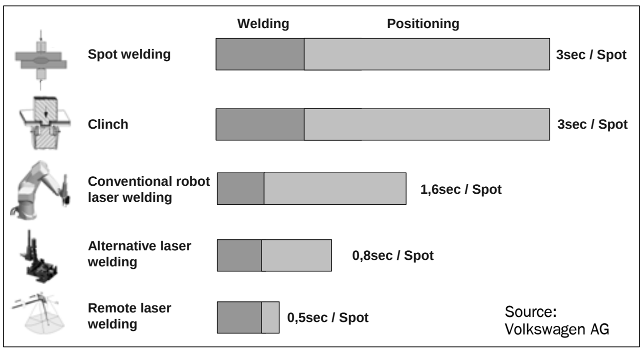

Figure 2. Primary and auxiliary process times of different joining technologies

There are two major advantages of RLW over conventional Laser welding with short focal length. One is the low inertia of the versatile elements in a scanning unit, that allows travelling speeds of the Laser focus spot of up to 1000 m/min [2,3], leading to a significant reduction of cycle time. While welding time still depends on the used Laser source, auxiliary process time can be drastically reduced by RLW compared to other joining technologies (Fig.2). The second major advantage is the long distance between optics and workpiece that enables the use of simpler clamping fixtures and qualifies Laser welding for a wider spectrum of products. Following an automotive case study, RLW in comparison to conventional spot welding systems has potential for a reduction of cycle time of 60% and overall investment of 30% due to fewer stations and fixtures [4].

2. RLW WITHOUT SCANNERS

A new approach for beam guidance for RLW was introduced by the German robot manufacturer Kuka [5] and envisions the use of the robot itself for positioning the spot on a workpiece without scanner (Fig.3). Scannerless RLW (SRLW) has certain advantages compared to scanner based welding-on-the-fly concepts (Fig.4). Using standardized robots and Laser optics, that need no complex control communication between the two connected, partly redundant kinematics, SRLW is relatively cheap in terms of invest and maintenance. Compared to scanner devices in welding-on-the-fly concepts, the main disadvantage is founded in the higher cycle time. The problem is manual programming of an optimal path with regard to cycle times. It is almost impossible to find the shortest way, because of an infinite number of valid robot paths, enabled by varying possible lateral or longitudinal beam inclination on a workpiece.

Figure 3. Robot RLW without scanner

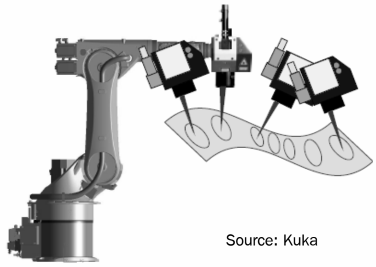

Figure 4. Concept of welding-on-the-fly

To improve cycle times of robot movements for SRLW, an optimization strategy is needed. The required effort for calculation is too high to be done by a robot control in real time, therefore the optimization must be realized in an offline system.

3. OFFLINE OPTIMIZATION

3.1. Concept

Analysing a remote welding task, there is some basic data that has to be specified. As shown in Fig.5 the input data for optimization can be classified into workpiece, component and process parameters. These parameters are needed for calculating robot paths as well as for an easy and intuitive graphical description of the welding task by representing valid inclination angles and focal z-offset by 3D geometry. The implemented system provides specific interfaces for importing as well as input masks for manual editing.

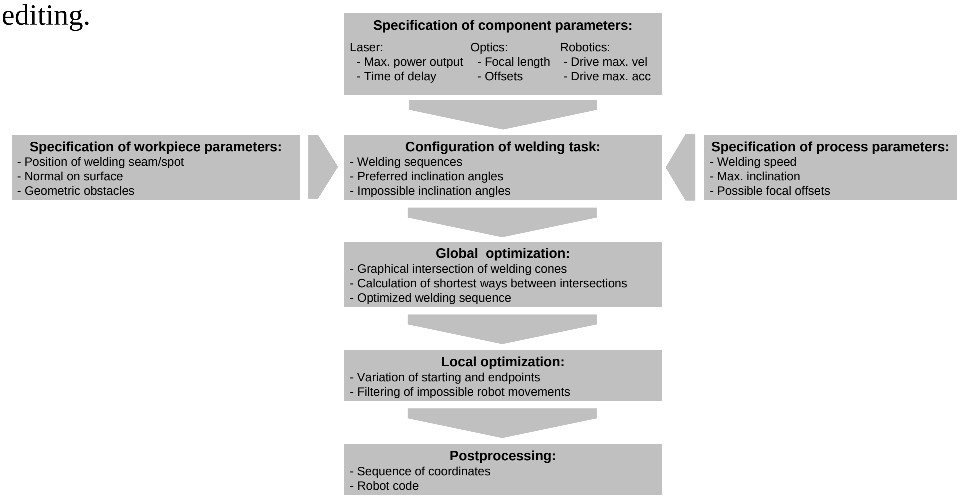

Figure 5. Concept of the offline optimization

A user of the offline system can predefine welding sequences to reduce thermal distortions, add preferred inclination angles or reduce maximum inclination either by technological restrictions based on experience or case-specific if the way between optics and workpiece is blocked. The edited configuration describes the welding task with all relevant boundary conditions and serves as source for the optimization. Optimization itself is done in two steps, a first global calculation for determining improved welding sequences and a local calculation, in which inclination in start and endpoint of a single seam is varied. A final postprocessing delivers either sequences of coordinates or executable robot code.

3.2. Parameters

As mentioned in 3.1, needed data can be classified into component, workpiece and process parameters. While most machinery parameters like maximum velocity of robot drive or focal length can easily extracted from technical data sheets, process parameters like optimal welding speed or maximum lateral and longitudinal inclination have to be elaborated by fundamental experiments. Welding experiments with a 2kW fibre Laser on steel with focal lengths of 1,053 m showed, that a maximum lateral inclination of ±20° and a maximum longitudinal inclination of 30° is possible. Also a focal z-offset within 40mm can be tolerated with regard to penetration depth for this specific case.
Geometric workpiece information is commonly represented by 3D volumetric bodies in a robot offline simulation. Little adjustments of positions after the optimization procedure can result in massive degradation of path quality, therefore the geometric information must be very precise. Using robot code, created by 3D based offline simulations, typically leads to positioning inaccuracies of ±2mm. Inaccuracies occur by translative and rotatory offsets and geometrical mismatches between model and real workpiece that may e.g. occur by deformations inducted through clamping units. Therefore geometrical information should be gathered from the real workpiece, for instance by non-contact sensors.

3.3. Configuration of a welding task

Before calculation of improved robot movements can take place, the welding task must be configured in terms of boundary conditions. Along the normal of each frame, a conical volume is created, representing maximum inclination and offset values (Fig.6). The frustum with a height equal to the possible focal offsets represents valid volume for robot movements (Fig.7).

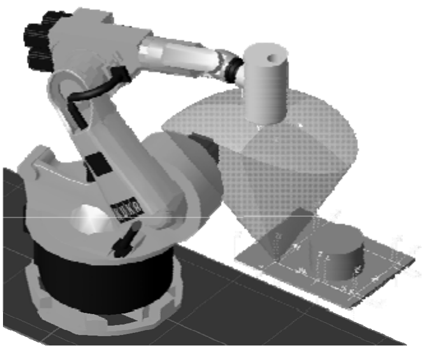

Figure 6. Visualization of welding spots and valid volume for robot movement

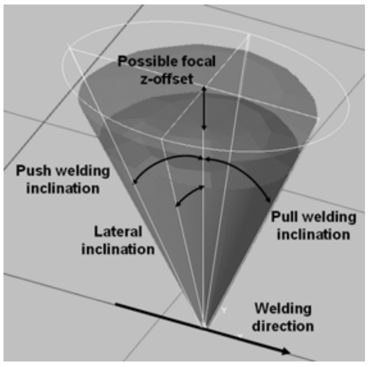

Figure 7. Design of conical welding volumes

If a cone is intersecting with a structure, which means that some area of inclination angles is invalid, the cone can be manually reduced. In future work this may be done automatically by collision detection. The user must assign welding velocities to all welds. If required, presetting of welding sequences can also be added. The developed welding configuration is used as source for calculation of robot movements in the next step.

3.4. Optimization

The optimization procedure is divided in two steps. In the first step, an optimal sequence of welds is identified by a global calculation over all welds with the aim to minimize movement of the slower main axis of the manipulator. Therefore, valid frustums, e.g. shown in Fig.8, are intersected with others to locate shared volume. Within these intersections it is possible to reposition the focal spot on the workpiece from on endpoint to the next starting point mainly by reorienting the robot wrist axis.

For smaller workpieces with convex shape, there may be only one or two intersections from which it is possible to weld all seams. For larger and convex shapes with a number of e.g. 50 welds, there can be many intersections and also a lot of single frustums that do not intersect with others.
Within the remaining volumes, two spots with any valid position are created. For every spot, the inverse kinematics is calculated. By comparing and weighting the differences, an optimized sequence of welds can be found, e.g. P2 > P3 > P5 > P8 > P9 (Fig.9). In the second step of the optimization, the identified single positions are incremental varied within one of the three directions in space. If the calculated solution of the variation is superior, the variation in the direction continues until the quality of the solution is lowered. The calculated solution approximates most likely to a local optimum. By varying the random selected positions in step one, it is possible to find a better solution. Depending on the lot size of the product to be welded, there has to be found a trade off between the number of iterations, which can embrace several hours for calculating, and the aspired cycle time.

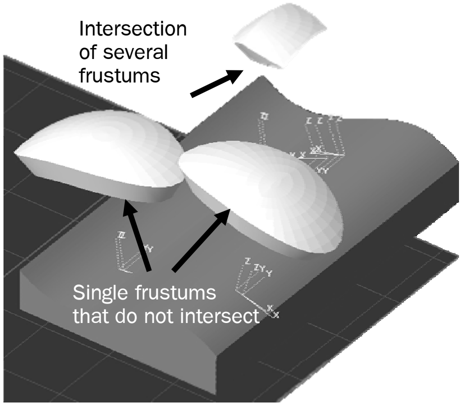

Figure 8. Frustums and intersections

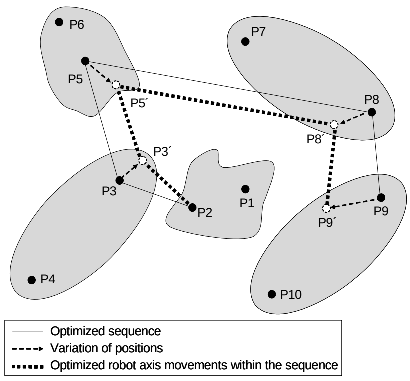

Figure 9. Optimization of weld sequence and local variation

4. CONCLUSION AND FURTHER WORK

The technology of remote Laser welding without scanner is a new and promising approach to reduce efforts for machinery and maintenance. This paper shows an approach to approximate an optimum of cycle time, depending on system, workpiece and process parameters as well as user defined presettings. The quality of path optimization strongly depends on the selected optimization algorithm and also on the desired calculation time. Experiments with the introduced method and also other approaches that are currently developed have to be elaborated on future works to find a trade off between calculation time and cycle time improvement.

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