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Rapid deployment of remote laser welding processes in automotive assembly systems

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ABSTRACT

Remote laser welding (RLW) has received increased attention in the recent years due to its benefits in terms of processing speed, lower investment, cost per stitch, and process flexibility. However, its potential in automotive assembly remains under exploited, mainly due to challenges involving system, process and fixture design, and part variation challenges. In this paper, an integrated rapid deployment framework for RLW process is proposed to improve '*right-first-time*' implementation of RLW in assembly systems. It enables closed-loop optimization of system layout, task assignment, fixture layout, process parameters, robot path planning and programming as an interlinked iterative approach. The results are demonstrated in an automotive door assembly pilot study.

1. Introduction, motivation and objectives

The development of sustainable manufacturing requires *key enabling technologies* (KETs) that can help industries to better understand and respond to economic, societal and environmental challenges [1]. This is especially important in the context of globalization. Indeed, globalization coupled with product customization and steadily decreasing time-to-market have spearheaded unprecedented levels of competition among manufacturers making high performance sustainable production an essential feature by which to address ever growing consumer demand for greater variety of goods and services [2]. At its core this means producing zero-defects products faster, better, and cheaper and accomplishing these by ensuring high rate of *right-first-time* [3].

Remote laser welding (RLW) is emerging as a powerful and promising joining technology (one of the KETs) in vehicle manufacturing. By having laser optics embedded into the robot (Fig. 1), and a scanning mirror head as the end-effector, RLW can easily create joints in different locations of the product through simple robot repositioning and/or laser beam redirection from a remote distance. In essence, RLW takes advantage of three main characteristics of laser welding: non-contact, single-sided joining technology, and high power beam capable of creating a joint in a fraction of a second. However, at present, there is lack of systematic methodologies for efficient application of RLW in automotive manufacturing processes thus preventing manufacturers from taking full advantage of the spectrum of benefits provided by RLW. For example, RLW process design and control are based on very time-intensive and sub-par trial-and-error approach making its application extremely limited in automotive assembly processes. At the same time, simply replacing RSW with RLW is infeasible, thereby necessitating the design of a new assembly line with selected RLW cells and then, validation of its effectiveness such that RLW can be methodically integrated into the existing production system. In order to address the above challenge, this paper presents a '*Push–Pull*' KETs framework for rapid deployment of the '*Push*' KET (RLW technology) in a new assembly system by developing necessary '*Pull*'

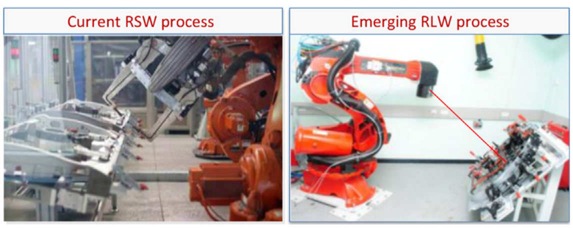

Fig. 1. Resistant spot welding (RSW) vs. remote laser welding (RLW).

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KETs (portfolio of simulation and optimization tools) (Fig. 2). '*Push*' KETs are seen as new technology, i.e., RLW process, with potential benefits, if successfully applied, in manufacturing systems. On the other hand '*Pull*' KETs can be defined as methods necessary to '*Pull*' the '*Push*' KET into a new assembly system to realize its full benefits (Fig. 2). The proposed '*Push*'–'*Pull*' framework is necessary for the rapid deployment of new technology into a manufacturing system. This paper presents a portfolio of '*Pull*' KETs that have been developed and integrated into the RLW Navigator system to help industries take full advantage of deploying the RLW process [4].

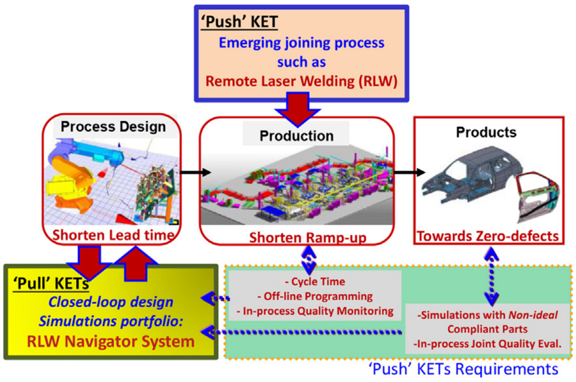

Fig. 2. Framework for rapid deployment of RLW process.

2. RLW Navigator framework

As a portfolio of '*Pull*' KETs, the RLW Navigator provides necessary analytics for rapid deployment of RLW during new assembly process development. The RLW Navigator is based on a *hierarchical decomposition* of manufacturing system which includes the following modules together with their KETs and the flow of information as also shown in Fig. 3: (1) *System design* embeds RLW technology in the fabric of complete production systems. (2) *Workstation planning* determines the detailed configuration of an RLW workstation and its operation, up to off-line programming (OLP). (3) *Process design* sees that all technological constraints are satisfied by appropriate fixture layout and process parameters. (4) *Process control* performs in-process quality monitoring and adjustment of the main process parameters so as to produce joints of required quality.

The modules have their own internal decision mechanisms which make use of the appropriate KETs typically in an iterative manner (see intra-loops in Fig. 3). The modules are briefly presented below, but note should also be made of their interplay denoted as *inter-loops*. In the *system configurator* inter-loop set of welding tasks, cycle time and selected resources (primarily, the RLW robot) are consolidated: While the *system design* module can make decisions about these key variables based on estimates only, the *workstation planning* module can verify whether and how these high-level decisions can be aligned with each other in light of the detailed configuration and operation plan of a workstation. Similarly, in the *station configurator* inter-loop the key technological decisions are refined, specifically for fixture and welding parameters selection and optimization. While these tasks form part of the *process design* module, fixture layout has to be assessed in terms of accessibility which is a core competence of the *workstation planning* module.

3. '*Pull*' key enabling technologies (KETs)

3.1. System design module

The goal of the *system design* module is to support the rapid early-stage design of the assembly system and to properly integrate RLW stations in the system, thus allowing to fully exploit the potentials of RLW. This module is also the first interface with the system designer. As shown in Fig. 3, the input data for this module are as follows: (i) production models and product related information, including stitch layout; (ii) target production volumes and throughput; (iii) database of resources, with their nominal reliability parameters, process capabilities, space and cost requirements; and, (iv) basic operational cost factors (e.g. workforce, maintenance, floor space costs).

Grounding on these input data, the *system design* module analyzes system configurations to achieve a minimum requirement on throughput while minimizing multiple objectives including the number of resources (buffers and robots), costs, energy, and floor space. The main outputs of this module consist of the: (i) layout concept; (ii) basic concept and contents of the RLW workstation, number of robots, robot model, and workload (set of stitches); (iii) maximum value of CT_{RLW}, i.e., total time the RLW station requires to process one part that can ensure process feasibility in terms of productivity requirements, also considering machines' reliability; (iv) optimal buffer sizes and the key performance indicators (KPIs) of the evaluated configurations. This then feeds into the *workstation planning* module.

The above is achieved within the *system design* module intra-loop by two interacting sub-modules, namely *process estimator* and *system analyzer*. With the first sub-module, the designer interacts with the software platform through a customized graphical user interface (GUI) to populate the system with manufacturing resources, selected from a pre-defined component database, thus generating an initial assembly line configuration and layout. In the same sub-module, the user can define and visualize an initial task sequencing. It is possible to cluster all resources performing homogeneous sets of operations into stations. The *process estimator* sub-module calculates some basic system KPIs. Once the initial configuration has been generated, all the related reliability data are automatically retrieved from a reliability database. The station models, as well as the system topology to be optimized, are provided as input to the *system analyzer* sub-module by means of so-called *transfer functions*. Next, the *system analyzer* sub-module tests several alternative system configurations before implementation, by exploiting the features of a fast performance evaluation module [6], based on approximate analytical methods. Upon convergence of the selected optimization algorithm, the set of candidate Pareto-optimal configurations are visualized to the designer. In addition, it is possible to further perform post-processing on the candidate solutions, via robustness analysis and discrete event simulation. The control of the flow of information between these sub-modules and the optimization is performed by a workflow implemented within the commercial software platform modeFRONTIER 4.5 (ESTECO).

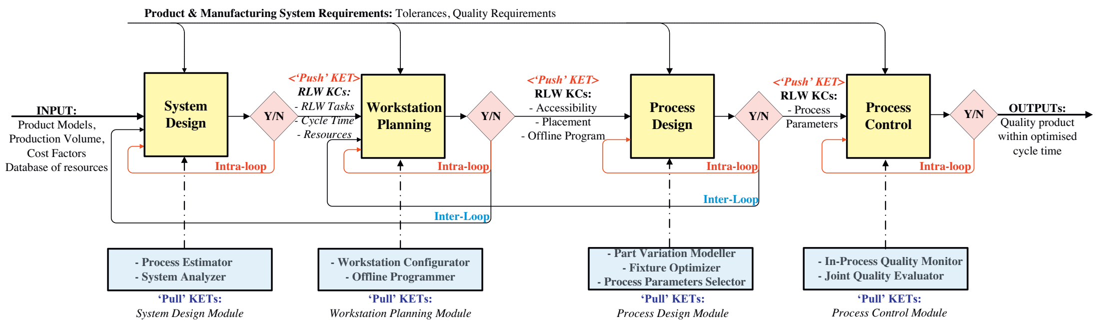

Fig. 3. Framework of the '*Pull*' KETs for rapid deployment of RLW process ('*Push*' KET).