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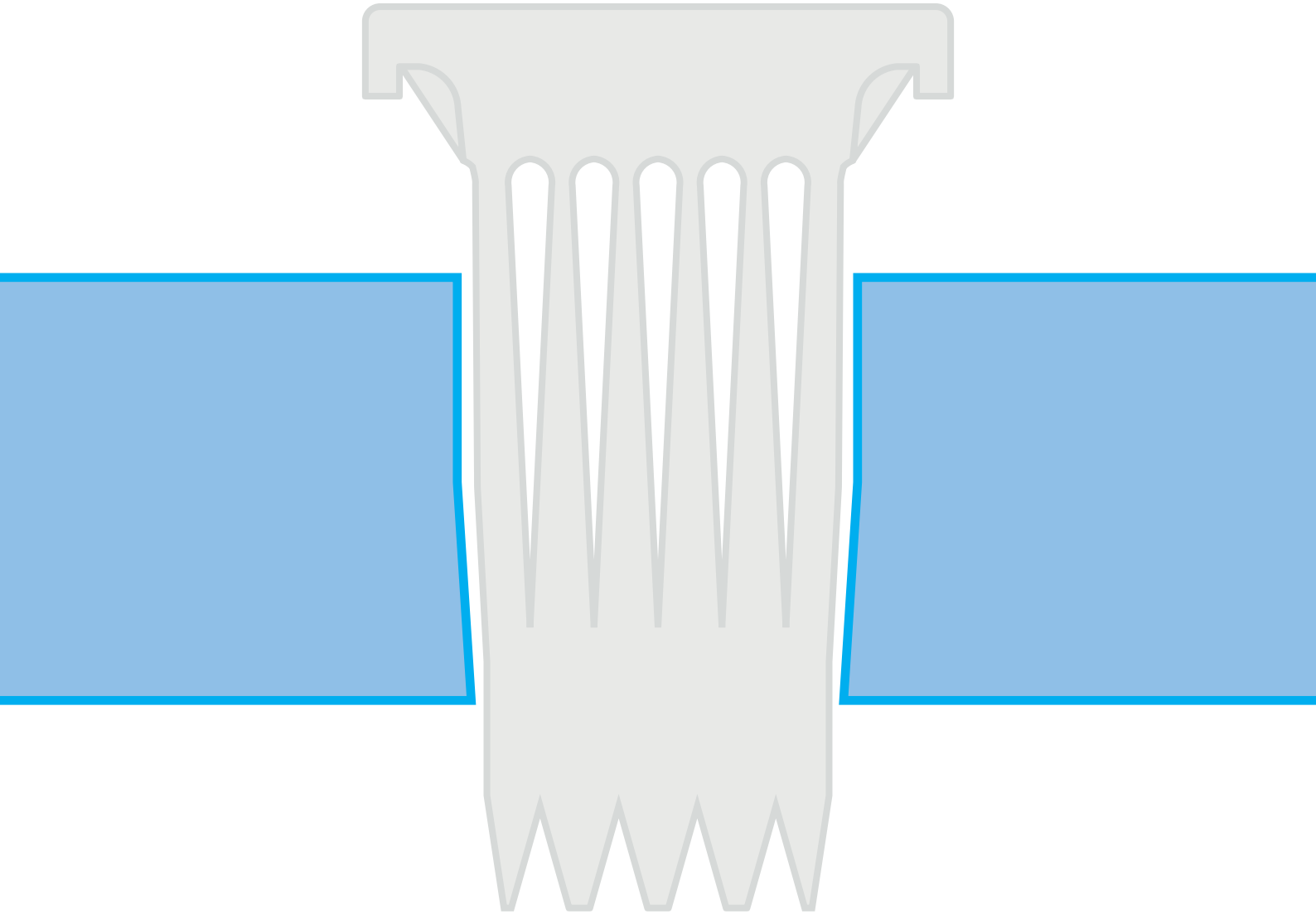

Real-time quality control of joining processes with AI and Big Data

White Paper

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Real-time quality control of joining processes with AI and Big Data

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ASSEMBLY TECHNOLOGY EXPERT

REAL-TIME QUALITY CONTROL OF JOINING PROCESSES WITH AI AND BIG DATA

Introduction

The transport industry is in the midst of a massive transformation and the vehicles of the future are fundamentally different from those of the past. Evolutionary developments in the field of lightweight construction, but also disruptive trends such as electromobility or autonomous driving, confront automotive developers with a whole new set of challenges.

E-mobility and lightweight design transform the transport industry

With regard to e-mobility, the integration of batteries also places new demands on manufacturers. Due to their heavy weight, the batteries require changes in the construction, design, and materials used. The same applies to lightweight construction, which makes both electric and conventional cars safer and more sustainable. An increasing number of components are replaced with different kinds of light and composite materials. As a result, new constraints are being placed on developers and designers, and components and parts must be even lighter and yet more resilient. In addition, the costs must be kept in focus. The only way to keep up with the pace of developments and offer the most efficient and safe solutions is by consistently making use of the tools offered by digitalization. This inextricably includes the use of digital applications in the form of Industry 4.0 solutions.

The digitalization of fastening processes

An often underestimated but essential link between the different materials used in these new applications is the fastening technology. The safety of the construction literally depends on it. Furthermore, the joining process must be fast, efficient, and cost-effective. The multi-material mix used in the automotive and transport industries presents manufacturers with numerous challenges when it comes to choosing the perfect fastening technology: The solutions must be optimally designed to suit the properties of the materials and the needs of the respective application. This requires that the fastening technology keeps pace with the innovation level of the materials. An efficient approach to ensure that the fastening technology meets the highest possible standards is the use of Artificial Intelligence (AI). The Swiss company MM-Welding, a joint venture between Bossard Group and SKion GmbH, has developed a fastening technology platform for lightweight und multi-material designs that combines the insights of AI with its unique fastening technology.

The MM-Welding technology is an innovative fastening technology platform that uses ultrasonic energy to create a form-fit anchoring in various lightweight materials. With the help of its SmartSolutions software, the company can ensure complete quality control of the fastening process.

Manufacturing and Artificial Intelligence (AI)

The digitalization of manufacturing processes and the implementation of efficiency programs belong to the current top issues driving companies in the transport industries. As a tool essential to digitalization, AI is also making its way into assembly operations.

AI has a big impact on the manufacturing industry with the clear objective to make production more efficient, more flexible, and more sustainable. Mastering AI in the industrial field is thus becoming a decisive factor to separate the wheat from the chaff. Companies that do not embrace it will be doomed to play in little league. So better be prepared!

Avoiding expensive recalls by 100% control and traceability

Recalls are among the most expensive incidents for automotive companies. Not only due to the horrendous cost caused by the replacement of defective parts, but also the damage to the company's reputation can also have long-term negative consequences. The only way to avoid this is by ensuring optimal quality control. Unlike conventional spot checks, AI can be used to extend quality control to 100 % of the produced components. This is also how MM-Welding can ensure complete quality control of the fastening process. By means of Machine Learning algorithms, only connections that meet specific quality criteria are accepted and delivered.

Machine Learning: Know-how in material properties and software delivers the best results

MM-Welding uses Machine Learning which represents a subgroup of Artificial Intelligence. Algorithms are the crucial basis for Machine Learning: In MM-Welding´s case, Deep Neural Networks (DNNs) have proven to be the most precise predictors.

Machine Learning (ML) itself is an exceptionally large and diverse field, but for simplification, it can be divided into 3 main categories: Supervised Learning, Unsupervised Learning, and Reinforcement Learning. In Supervised Learning, the algorithms are trained with labelled data, while Unsupervised Learning techniques work without labels. In Reinforcement Learning, virtual agents are trained to optimize a defined reward function.

As an example of Supervised Learning, one can think about image recognition. Huge datasets, millions of images are used for training. The images need to have labels, like "dog", "cat", "car", to make sense of the information (pixels) contained in an image. During the training or learning phase, the algorithm learns relevant connections between the image data (pixels) as input and the labels as output. After training, the algorithm can look at a never-before-seen image without label and predict its label, based on the experience gathered during the learning phase.

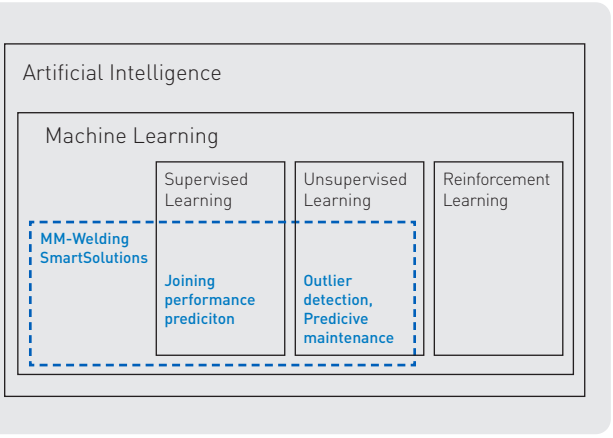

Fig. 1: Application fields of MM-Welding's SmartSolution software

Within Supervised Learning, one can distinguish between regression tasks and classification tasks. For a regression task, the labels are numbers on a continuous scale. For example, predicting tomorrow's temperature based on given input data. For a classification task, the labels are divided into classes, e.g. "dog", "cat", "car" or "positive", "negative".

An example of Unsupervised Learning is one of the biggest online shop recommendation system. It clusters customers in groups of similar preferences to provide tailored recommendations. No specific labels are needed for this task, the data can be directly used. This is relevant because the labelling of data is often a costly and lengthy manual process requiring experienced humans.

An example of Reinforcement Learning is Deep-Mind's AlphaGo, the first computer program to defeat the professional human Go world champion. The objective function that is optimized is to win the game. So, the algorithm can be trained by playing millions of simulated games and optimize its own strategies based on whether they lead to a win or a loss of the agent.

For MM-Welding, other techniques besides DNNs show promising results. More traditional Machine Learning algorithms like Support Vector Machines or Random Forest Ensemble Methods can be used and lead to very high prediction accuracy. Another decisive factor is data. There is a saying that "data is the new oil". An algorithm is only as good as the dataset that is used during the training phase. MM-Welding has identified this early and developed its own database to collect data since the early stages of the company in 2017. This allows us to train our algorithms with sufficient data, leading to a good performance of the software.

How to fasten different materials efficiently

The issue with using conventional fastening techniques is that they are primarily designed to connect into the bulk of the metallic materials. In lightweight construction, on the other hand, combinations of porous materials, such as fibre composites, sandwich panels and lightweight materials, are joined.

The "cavities" in these materials - and thus the lack of solid mass of the material - make the use of common joining systems difficult or even impossible. The innovative MM-Welding technology opens up completely new possibilities for manufacturers to join porous materials, from foamed materials e.g. expanded polypropylene (EPP), to those with honeycomb structures.

By introducing the MM-Welding technology into fastening or connecting solutions, the joining of elements is implemented in a process-safe manner and in many cases without much preparation. Ideally, the fastening element should become part of the carrier material.

Cost savings through complete automation of the fastening process

The MM-Welding process uses ultrasonic energy to partially liquefy thermoplastic materials to create a functional and strong form-fit connection to another material in fractions of a second. To achieve this, thermoplastic elements in e.g. pin-like or sleeve-like form are used to connect components.

MM-Welding is different than the current ultrasonic welding applications, which do not include fastening elements and normally do not lead to mechanical form-fit connections, and thus has a distinct application range. It can be used for various applications, especially in the transportation area, such as:

- various foam materials (polyurethane, expanded polypropylene, etc.)
- sandwich materials
- honeycomb structures
- non-woven materials
- plastic-metal connections
- incompatible plastic-plastic connections

The MM-Welding fastening method can be manually or automatically carried out, achieving a total process time often below one second. The reduced process time, together with the process simplicity and reliability, offer an ideal replacement for many currently employed fastening methods. The use of MM-Welding technology ensures cost savings across the entire production cycle. Thanks to the flexibility of the fastening solutions, designers can choose from a wide variety of materials.

Further advantages:

Quick: MultiMaterial-Welding is much faster than alternative fastening technologies, allowing more efficient in-line processing and eliminating the need for curing time (total process time < 2 seconds)

Strong: Significantly stronger bonds than some other fastening methods

Flexible: Can be used without pre-positioning for tolerance compensation

Clean: Clean processing, since no additional materials or pretreatment of the surfaces are required, and no waste is produced

Reproducible/measurable: Statistical control over the process guarantees the quality of the individual connections

Proven technology: The technology is used in several industrial processes and in other industries (e.g. medical, furniture and automotive industry)

But MM-Welding is not a conventional fastener company, it is combining the strengths of its proprietary fastening technologies with the power of AI to offer their customers real-time production quality control, performance predictions and more. MM-Welding operates in the hardware and software world and combines the best of both. The combination of MM-Welding and Artificial Intelligence allows for the automation of the complete fastening process.

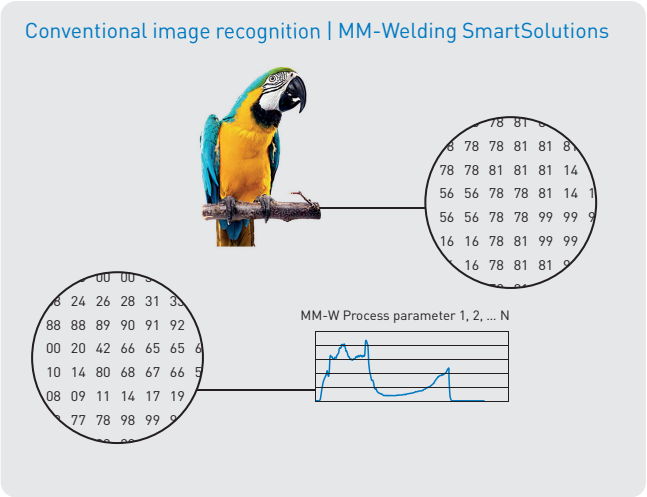

Fig. 2: Image analysis using pixel data compared to process analysis using process data

SmartSolutions Software: Simple and safe processing

MM-Welding´s SmartSolutions Software transforms production data into meaningful and actionable insights for customers in real-time. It allows quality control of 100 % of produced parts and eliminates the need for destructive testing. It ideally addresses the need for full traceability and control in an Industry 4.0 set-up.

MM-W SmartSolutions applications are built on Supervised and Unsupervised Learning methods. For most performance prediction applications, Supervised Learning methods are applied. As input data, sensor readings of the MM-Welding process collected by the welding machines are used, e.g. force, energy, velocity over time. As the output of the models, the joining performance is used, e.g. tensile strength of a connection. An algorithm is trained by feeding enough example input and output data to it. After the algorithm is properly trained, it can be used in serial production to predict joining performance in fractions of a second only based on input data created and measured during the process. Therefore, it allows for real-time predictive quality control of each connection point created during production without the need for any destructive testing.

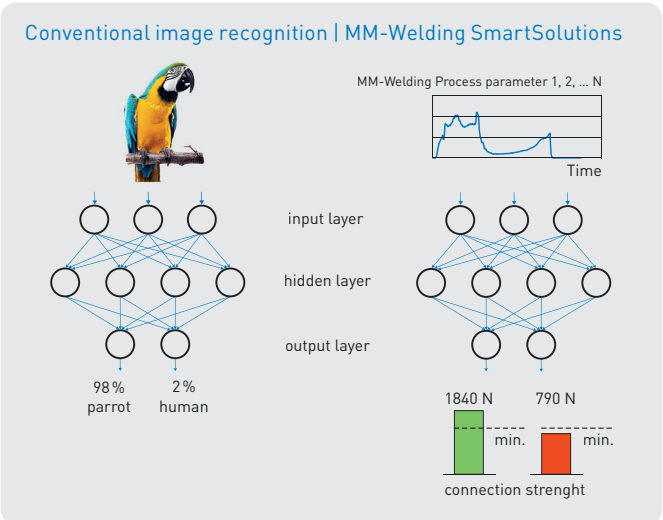

Fig. 3: Image labeling compared to process outcome prediction

Real-time production quality control

The focus of SmartSolutions is on fastening solutions for multi-material mixes and the innovative use of MultiMaterial-Welding technology. SmartSolutions software is unlocking the potential of big data and AI for the fastening solutions to provide real-time production quality control, strength predictions and more. MM-Welding´s SmartSolutions reach very high prediction accuracy, meaning that the connection performance can be predicted very accurately.

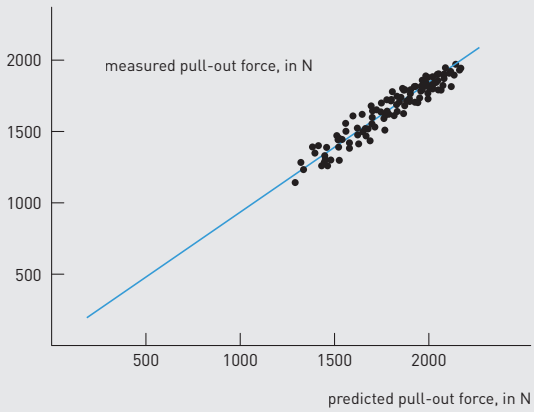

Fig. 4: Predicted and measured pull-out force in N.

For example, for a fastener with a required performance of 1500N pull-out force, the algorithm would be able to predict the value within a specific window of uncertainty. Figure 4 shows this relation for a specific application. On the horizontal axis, the values predicted by the SmartSolutions algorithm are displayed, while the vertical axis shows the real values measured empirically for validation. Note that these validation labels were not used during the training phase and are only used to assess the accuracy of the model. Once the algorithm is validated and has proven its accuracy, the experimental measurements can be avoided entirely.

Continuous further development

MM-Welding has many innovative products in its portfolio to address today's challenges in joining technologies. Due to development towards lightweight construction, electromobility and Industry 4.0, conventional solutions no longer meet the requirements for example asked by the automotive industry. MM-Welding closes exactly this gap. The company offers a complete technology platform, from fasteners and automation solutions to quality process control software. As a result, the customer is provided with a complete solution package that has proven itself in numerous serial projects.

Another very promising field that MM-Welding is exploring is the use of autoencoders for outlier detection. In this case, the company is leveraging the power of Unsupervised Learning to use data which does not have labels. Autoencoders use a mirrored DNN architecture. The input data is condensed through a neural network to a smaller representation of itself (encoder) and then expanded again by another neural network to its original form and size (decoder). This architecture works very nicely for outlier detection when the data used for training only includes regular samples.

When an outlier is processed by the model, the reconstruction by the decoder will likely fail and yield a high error. By setting a threshold on the reconstruction error, one can identify outliers – samples that look different from the norm. In production environments, the identification of bad parts that can arise for a wide variety of potentially unknown or previously unseen reasons is critical. This algorithm has a high potential for quality improvements and cost reduction simultaneously. MM-Welding was also discussing with various partners the possibility of extending SmartSolutions quality control software to other areas than MM-Welding´s proprietary technology. An obvious candidate is conventional ultrasonic welding applications between two polymer parts, known and used for decades. Since similar machines are used, SmartSolutions can directly be applied to those applications without minor adaptations. In general, every production process that creates time-series data can be tackled by the SmartSolutions software. The applications seem endless and MM-Welding is committed to unlocking the potential of data in various areas.

Please do not hesitate to contact us if you have any further questions. We are pleased about your request. Our contact details: **www.bossard.com**.

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