DARWIN – Data Animation and Refinement for Revealing Welding Instructions

1 Main goal and vision

The subject addressed is welding, with the aim of suppressing welding defects. Spatter (drop) ejection during laser beam welding is chosen as the demonstrator defect and technique. The vision is to accomplish a software tool that supports the discovery of essential knowledge hidden within experimental welding data. Suitable animation and refinement of the complex data available will enable advanced studies by experts to reveal instructions (guidelines for suppressing welding defects.

DARWIN addresses cognitive interpretation of large amounts of multidimensional, complex data.

2 State-of-the-art of the demonstrator subject and needs

Welding is a key manufacturing technology. A welding defect as the cause for fracture, see Fig. 1(a),(b), of a product in service can have catastrophic consequences (e.g. the sinking of the 275 m long MSC Napoli in 2007 (www.maib.gov.uk). Industry is conservative and sceptical about introducing modern welding techniques, despite their high potential, such as new opportunities for product development. Laser welding is characterised as a high potential/high risk technology. Despite obvious advantages (compared to traditional methods) like the high precision possible (through the laser beam), the quality produced can suffer from narrow process windows, i.e. sensitivity to changes in parameters and conditions.[1],[2] Although the number of industrial applications is growing significantly, laser welding is still a niche technology. For example at Volvo CC (despite being a laser pioneer) only 1% of the about 1400 welding robots are equipped with lasers. Exceptions can be found in Germany, the distinct world leader in laser technology (thanks to huge research activities - “The Century of the Photon”), where the ultramodern VW Golf-factory welds 70% (of 100 meters per car body-in-white) with lasers (thus shrinking the factory size to 25%) and the Meyer shipyard just replaced 75% (of 9 km per passenger ship) of (arc) welding by laser hybrid welding (thus widely eliminating the expensive correction of thermal distortion after welding, i.e. 30% of the production costs). Beside the advantages in productivity and quality, lasers enable manufacturers to weld advanced materials like high strength steel without the usual metallurgical softening around the weld.

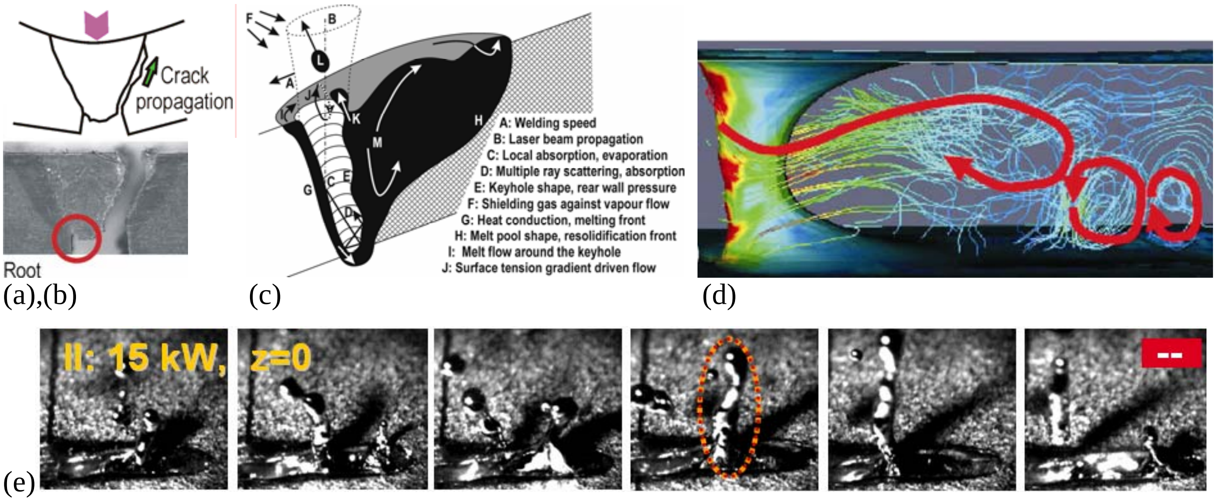

Fig. 1: Visualisation of laser welding today: (a) Weld under load with crack propagation from a root notch defect, (b) causing fracture; Physical mechanisms (here: melt flow) in the weld pool (c) theory illustration, (d) numerical simulation (FEA/CFD), (e) high speed imaging (sequence: spatter ejection)

Despite still being a niche technology, the ongoing experimental (and theoretical) activity in industry and research is huge. Large amounts of experimental data have already been produced and the experts have greatly increased their knowledge base. (Note the difference between the rational documentation of raw data and the intuitive complex skills of human minds) The output (new laser applications) is comparably little. The many experiments carried out do generally not build upon former findings, as hardly any situation is identical to a previous one due to the many parameters (15-30) governing the process. The laser welding process is a very complex combination of phenomena like beam absorption, heat conduction, phase changes, liquid flow (incl. spatter), see leading edge research in

Fig. 1(c)-(e), gas flow, plasma, metallurgy, process geometry, etc. and is only partially understood. Generally applicable rules are rare. In addition most studies are case studies and very few researchers try to generalise the findings. Classical design of experiment methods from a few data are excluded as the process behaves not monotonously. Nevertheless, the process contains generally applicable solutions, but they are not obvious. Beside some recent efforts of Fraunhofer ILT Aachen (the distinct world leader in laser processing), creating a data-tolerant database visualisation platform, Luleå TU is the only research organisation worldwide addressing the problem. As a first result [1] the Bifurcation Flow Chart (BFC) method was developed, see Fig. 2(d), as a standardised tool for documenting essential rules (for suppressing defects) discovered during experiments [2]. Due to the standardised format it was possible to combine findings about the same type of defect from very different applications, see Fig. 2(d). From this standardised combination the vision arises to stepwise discover the whole parameter map, see Fig. 2(c). Other disciplines like chemistry, pharmacy and biology act more systematic than the welding community. These sectors apply the software of partner Umetrics AB by the Design of Experiments method and the Multivariate Data Analysis method for refining their data through data analysis, categorisation and visualisation interfaces, see Fig.2(a),(b).

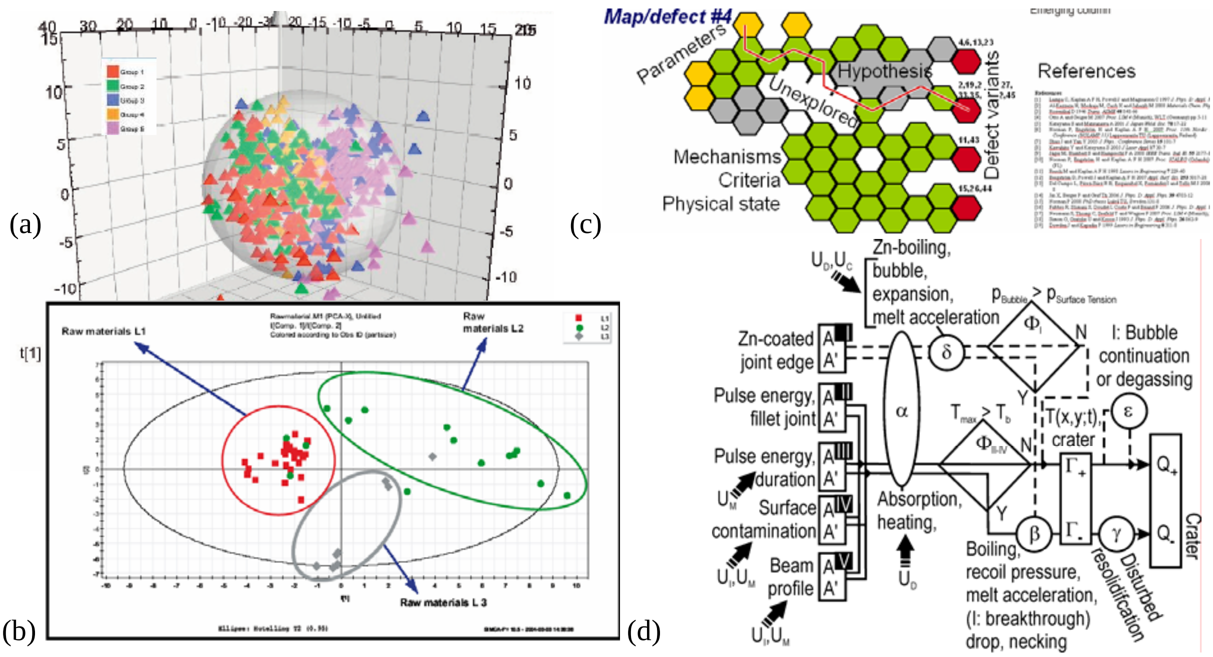

Fig. 2: Chemistry and biology data refinement by Umetrics AB: (a) 3D-categories, (b) 2D-domains; Welding data approach by LTU LAS: (c) vision of stepwise map exploration, (d) combining 5 BFCs

Welding in general, laser welding in particular, has a strong need for systematically exploring the large picture of parameters and defects – in order to categorise common rules and to define their limits.

3 Objectives and deliverable demonstrator

The main objective of DARWIN is to develop a demonstrator expert system for welding through

... developing a database with an algorithm for dynamic data refinement and categorisation
... identifying the human capabilities and limitations in interpreting data through visualisation
... developing suitable animations of the parameter space, the physical 3D-space, abstract spaces
... developing a software for knowledge-progress by experimenting with data-visualisation

to be demonstrated for spatter defects to be suppressed during laser welding.

The demonstrator product at the end of the project will be the expert system for welding data in the form of software, including the data for spatter during laser welding, studied as the demonstrator case.

4 Expected impact (see also Section 2)

The target sector directly addressed by DARWIN is manufacturing of metal products (e.g. vehicles, machinery, electronics, civil engineering, etc.) along with the scientific welding community and knowledge support (e.g. via system or material suppliers or by consultants and teaching). The potential users of the DARWIN-software are highly skilled (laser) welding experts (product development or production engineers, consultants in the wider sense, researchers) as well as welding operators.

The above target sector is huge – with welding as a key technology. Failure in the choice and operation of a welding technique can cause product failure (e.g. spatter) and major problems for production. Advanced techniques like laser welding have, beside high productivity and other advantages, high potential for introducing new design and new materials to a product. For example; lightweight design of cars for reducing fuel consumption can often only be enabled by laser welding (generating a weld with high strength). However, laser welding often cannot be adequately controlled due to lack of knowledge, despite many data and skills. The impact from refining these data and skills to generalise the knowledge and make it more applicable would be a quantum leap towards control of the welding process and in turn of product quality and strength. It would thus accelerate innovations.

Basically the methodology has the potential to be transferred to many different disciplines with similar data/process structures and needs for control. DARWIN is also a suitable tool for teaching/training. For the subject visualisation research on human perception of data-visualisation is of high relevance.

5 Partnership

Academic partners (see also CVs):
Luleå TU, Prof. Alexander Kaplan, research area: **Laser materials processing**, welding (LTU LAS)
LTU, Dr. Johannes Hirche, research area: **Computer games and computer graphics** (LTU COM)
LTU, Prof. Håkan Alm: **Engineering psychology**, perceptual and cognitive processes (LTU PSY)

External partners (also: www.umetrics.com, www.esab.com, www.outokumpu.com, www.svets.se)
Umetrics AB, Patrik Dahlin: SME, **software** developer for multivariate experimental **data analysis**
ESAB, Doc. Leif Karlsson: electric arc (and hybrid laser-arc) **welding equipment** (and knowledge)
Outokumpu AB, Lic.Elin Westin: Manufacturer, also **laser welding, of stainless steel tubes** (OSTP)
LaserCentrum i Gnosjö AB, Bengt Johansson: **SME job shop on laser welding** and cutting (LCG)
Swedish Welding Commission (400 members): disseminating welding **knowledge**; standards (SWC)
Also the computer game developer ***Data Ductus AB*** just expressed its interest and is under discussion.

A new consortium is formed by the project. While LTU LAS cooperated with most of the external partners earlier, none of the three academic partners ever before cooperated with each other and Umetrics has never been involved. This highly interdisciplinary consortium is very unusual for welding (the thematic discipline addressed). Their approach has high potential to reveal new solutions.

We can distinguish between (i) partners dealing with data (in welding as the subject), namely LTU LAS in public research, OSTP for their own production, ESAB and LCG for their customers, SWC public and for their member companies, (ii) partners animating and refining data for research (LTU COM) or for their customers/users (Umetrics), and (iii) LTU PSY studying the human data perception.

6 Methodological approach

The ***subject*** addressed is the suppression of defects during welding. The demonstrator sub-domain to be studied is the suppression of spatter during laser welding. The approach has high potential to be transferred to different disciplines with an input-process-output/quality pattern, e.g. biology, economy.

Hypothesis: It is assumed that the raw experimental data contain hidden non-trivial information on the welding process as well as the expert has complex intuitive skills with hidden information. We state the hypothesis that essential hidden information (welding instructions for suppressing defects) can be revealed by connecting the above two information resources in a manner suitable for humans, i.e. by suitable data refinement and animation. Such discovery would be a big scientific breakthrough.

Methodology: Initially, creative solutions for visualising data by computer animation will be explored, in particular by post-processing and categorising the data, by accessing different views simultaneously and by suitable I/O-interfaces (e.g. mouse-tuning of a welding parameter) [3]. In parallel, the human capabilities and limitations for the perception (rather than cognition here) [4] and interpretation of data will be studied, in particular with respect to computer-animated data. From the findings a suitable software tool (taking into account the potential of data animation and of corresponding human perception) will be developed (using the free *QT*-user interface from *Trolltech*), as follows, see Fig. 3:

- The database layer Ω: to enter previously published and new experimental data into a database
- The data refinement layer Ψ:
  - The data processing level Ψ1: post-evaluation and modelling of these data can be tried
  - The categorisation level Ψ2: categories can be defined and allocated to the data
- The data animation layer Σ:
  - The parameter space animation level Σ1: many parameter combinations can be tried
  - The abstract animation level Σ2: visualisations of properties derived by Ψ are tried
  - The physical animation level Σ3 : variants of visualising the physical properties in 3D

Eventually, the software will be improved by pilot welding experts applying it to pilot welding cases.

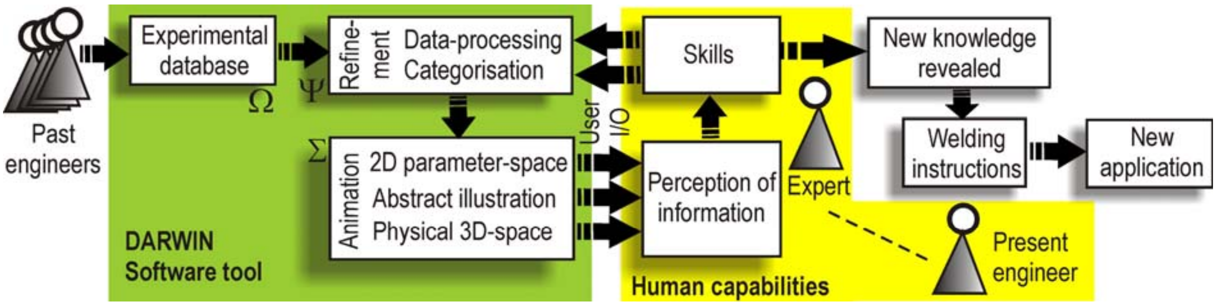

Fig. 3: Interaction process-data-computer-people-process in the proposed DARWIN expert system

The DARWIN software will try to make the best use of human skills and of the information content of data – in order to reveal new essential knowledge (welding guidelines to suppress defects). We regard it as essential to offer many stimulating and inspiring variants of data-animation to the expert in a focused manner. This requires a user interface that offers quick, smooth and easy manipulation of data and views without distraction by non-essential graphical elements and messages or by delayed computer responses. Such a playful experimental environment can lead to unexpected but valuable discoveries. By iterative data refinement and perception the expert can gradually explore hidden information. The generalised knowledge (from specific entries) can then be applied by other (passive) users for new applications, see Fig. 3, who in turn can provide a new database entry.

The complementary interdisciplinary expertise of the partners, see Section 5, is essential for success, as their roles address several key issues; Initially, a menu of creative visualisation methods will be generated by the computer experts: LTU COM will contribute with visualisation expertise from computer games and scientific visualisation in general. A particular challenge is memory-efficient adaptive data-rendering. Umetrics AB will provide cross-disciplinary visual data analysis solutions for pharmacy, biology and chemistry. In a field study the reaction of test persons on these visualisation methods will be explored by the psychology researchers LTU PSY with respect to potential and limits of human perception and interpretation of information behind the different visualisation types. As a next step variants of the user interface (and its speed) and corresponding psychological perception elements like distraction, imagination, association and memory will be taken into account.

It is important to explore typical patterns of data usually achieved from experiments (laser welding causing spatter). For studying data and expert behaviour it was important to choose three companies applying laser welding knowledge in different ways. These companies will contribute with welding data documented from former experiments and with (limited) new experiments (on their expensive laser welding systems) as well as with experts as test persons. ESAB as the world leading welding equipment supplier with a test lab needs to provide broad knowledge (and ideally even a software tool) for its manifold customers. The job shop LCG requires a broad knowledge base for its laser welding applications for many different customer applications. In contrast, OSTP as an end user with a limited product range (stainless steel tubes) but high production volumes requires deeper knowledge focused on its application. Even the large companies ESAB and OSTP do not apply centralised knowledge databases, although often demanded. LTU LAS will collect data (parameters, process information, e.g. high speed imaging, results) from the companies as well as from literature and will run selected experiments (with excellent facilities, e.g. high speed imaging, Fig. 1(e), and worlds second most powerful cw-laser of modern type, a 15 kW fibre laser, used in Fig. 1(e)) as database input. The typical structures and patterns of the data will be studied and analysed, including possibilities for data refinement, post-processing or categorisation (all in discussion with the industrial partner experts).

Eventually, from the findings from the basic visualisation and perception study and from the data study, different software concepts will be developed and discussed. The most promising concept will be realised (by LTU COM in cooperation with Umetrics AB) as the demonstrator, with an interface suitable for the data pattern and the user, with a graphical interface (for the three animation levels) ideal for human perception and with a database enabling data refinement and categorisation in a flexible manner. This demonstrator will then be applied, tested and further developed by the whole partnership within their respective roles, particularly by the three companies providing experimental data. Beside developing the software, this testing and development phase will inherently reveal essential knowledge on spatter formation during laser welding, the demonstrator subject.

From this development process the demonstrator will result as an innovative mature expert system that demonstrates for spatter during laser welding how data can be refined and visualised in a new manner by a flexible interface to reveal welding instructions on how to suppress spatter defects.

7 Dissemination and commercialisation

At the end of the project a demonstrator will be accomplished – software with data, refined. Part of the demonstrator-data cases will be commercially sensitive and confidential, part will be public. While the public demo cases will be fully accessible, the company demonstrators will hide part of the raw data (if commercially sensitive), but all basic methods and all essential results will be demonstrated. A Web-based reduced demonstrator will be installed as the most effective way of dissemination. A complete demonstrator will be provided on DVD, with the software and user-interface and the demonstrated data-cases. In addition, dissemination will take place through publications, conferences, seminars, etc., particularly by the Swedish Welding Commission with its many dissemination channels

As identifying the human needs for data visualisation is integral part of the project all the above dissemination activities will profit from this strength for attracting experts to the demonstrator. Particularly in the conservative subject *welding* there is a big discovery vision behind, to be illustrated.

The property rights for commercialisation of the software product will be negotiated in detail at an early stage. Basically the intention is to commercialise the software via Umetrics AB and perhaps Data Ductus (software developers) and ESAB for their welding equipment customers. In the final project phase the generalisation (to other welding techniques, defects), maturity, transferability (to different disciplines) and commercialisation of the demonstrator will be discussed, resulting in a concept.

Different kinds of users (in Sweden and worldwide) can be:

- One central public database expert system worldwide (e.g. administered by the Swedish Welding Commission on behalf of the International Institute of Welding, IIW; or by LTU) open for new entries either from members (fees) or from any registered user (fee or free).
- Private databases within companies, with important confident information protected from external access, but capable to upload public data and knowledge.
- Public databases by owners/administrators interested in (limited to members, or unlimited) public access to knowledge, e.g. universities

The standard format enables selective data-transfer between the users on demand.

8 References

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