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A Methodological Approach to Multisensor Classification for Innovative Laser Material Processing Units

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Abstract *– Online quality detection and online laser beam control are important research topics to improve the overall quality of nowadays laser beam material processing units. In both cases innovative units are at study where the state is monitored by a set of heterogeneous in-process sensors conveying a large amount of information. However, low experiment reproducibility, lack of dominion knowledge and high costs greatly limit our ability of finding an optimal solution.*

In this paper we propose a methodology to guide the engineer's design choices towards an optimal implementation of the inductive classifier.

Keywords *–*

I. INTRODUCTION

Nowadays an increasing attention towards material laser material processing is registered in those industrial sectors where narrow process windows and high quality levels are mandatory. Welding metals with laser is especially attractive for many aspects: Laser devices can concentrate enormous amounts of power on very narrow spots, without needing a complex setup. A correctly executed laser weld will have small area, high penetration depth, optimal mechanical properties, often even better than those of the base metal, and will be stable with time. What is more surprising, industrial laser welding processes have also a degree of flexibility incomparable to that of any other welding process: The only requirement for a piece to be welded is its optical visibility, since no contact between the welding head and the piece is required. All these features will come only at the premium of high capital costs due to the necessity of producing a stable beam, controllable in intensity and duration, with a very high output power and a correct wavelength. In facts, metals are very good light reflectors, even better at the typical emission wavelengths of the most common laser devices. As the metal melts, its light reflectivity suddenly lowers and the laser power is more promptly transferred to the workpiece.

At the present time all these issues greatly limit the industrial fields where a laser based process can be applied. Fine-tuning the process parameters over factors like reflectivity and actual geometry of the workpiece is a demanding issue, which is still unsolved. Nowadays it is common industrial practice to set the process parameters in an open-loop fashion, usually trusting on the experience of a human operator to fine tune the parameters when process drifts excessively increase the percentage of rejects. Improving the overall economicity of laser material processing units by detecting process drifts as soon as possible (i.e., moving from post-process statistic inspection towards online quality monitoring and automatic process tuning) is the key which would enable moving laser material processing to industrial environments with too high yield requisites for current processes.

This paper will be structured as follows; In Section 2 we will expose the issues which motivate a methodological approach; In Section 3 we will describe our approach, explaining each step with meaningful examples; In section 4 we will show how applying a methodological approach yields meaningful advantages over an unstructured approach, for what concerns both understanding the problem dominion and defining a solution close to the optimal one.

II. PROBLEM DEFINITION

We can resume all these issues by stating that laser beam processes are characterized by scarce a priori information, and that limited experimental data can be obtained from them in a reproducible way. Differently from what happens, for example, with numerical transmission, where large amount of real or simulated data can be obtained with a relatively low cost, setting up for laser welding and cutting has high capital costs, both for the laser welding device and for the sensors, and perhaps high operative costs. Moreover, thoroughly exploring the space of configurations often means the need to operate beyond the ordinary welding conditions. Physical changes in the sensible parts due to operation stress alter the experimental condition, thus severely compromising experimental reproducibility.

To limit this issue we can avoid exploring the zones of the parameter space that may cause more stress to the sensitive parts of the setup, trading off polarization against reproducibility, but the issue generally remains serious. The situation is worsened by the fact that we do not know whether the observed variables are related to any or all the meaningful process parameters, neither how these parameters affect the final weld quality, not even if “weld quality” can unambiguously be defined. Finally, the lack of a mathematical model for the process makes impossible to obtain more data by simulation. All these aspects imply that we must use the available data efficiently, looking for the best trade-off between complexity and performance. Moreover, understanding what we can (and what we cannot)

obtain is of primary importance to rethink the requisites in the (likely) eventuality they would reveal unattainable.

A. First alternative

The Bayesian theory of classification tells us that there exists a lower bound on classification accuracy, which does not depend on the particular classification algorithm adopted, or on the number of available samples, but only on the distribution of samples in the feature space. If we estimate those distributions, we can have an idea on what will be the maximum performance attainable with the available dataset.

It is necessary to extract from the signals produced by the sensors those features that are relevant to the classification problem, thus making simpler the classifier design and improving classification accuracy. Here the problem is understanding which features describe the process in a way almost accurate as the full signals, and which constitute a minimal set, avoiding both the "curse of dimensionality" and incomplete process description.

B. Second alternative

Our methodology organizes the work so that "what can be saved will be saved". This objective is met by structuring the methodology so that the assumptions which are more likely to be removed, or whose removal will more affect the work done, are made later in the methodology, when most of the work has already been done.

$$5\ Y + 4z * \sin(r) \tag{22}$$

We may assess a lower bound for confidence over performance by applying the results exposed in [8], which establish how the optimal confidence value the one obtainable with the optimal Bayesian classifier. In our work this step proved very useful to understand how "trustable" are the performance figures obtained for our classifiers. In an industrial environment this step would be done "a priori" by choosing the number of samples during the experiment design methodological step.

Table II. Floating-point operations necessary to classify a sample.

Model	Feature extraction	Preprocessing	Classifica-tion
A. KN N	>200,000 flops	~10 flops	~200 flops
ff NN			~10,000 flops

Two classifier structures, two-layer feedforward neural network with sigmoid hidden neurons and the KNN classifier, were compared against a performance metric and a cost metric. We trained a high number of networks and assumed that the network which best performed over a validation set of samples not used to train the network is also the best network. At this purpose the sample set has been randomly partitioned in a design and a validation subset, and all the networks have been trained/validated over them. We used the available a priori information about the data set structure in order to reduce the polarization introduced when partitioning.

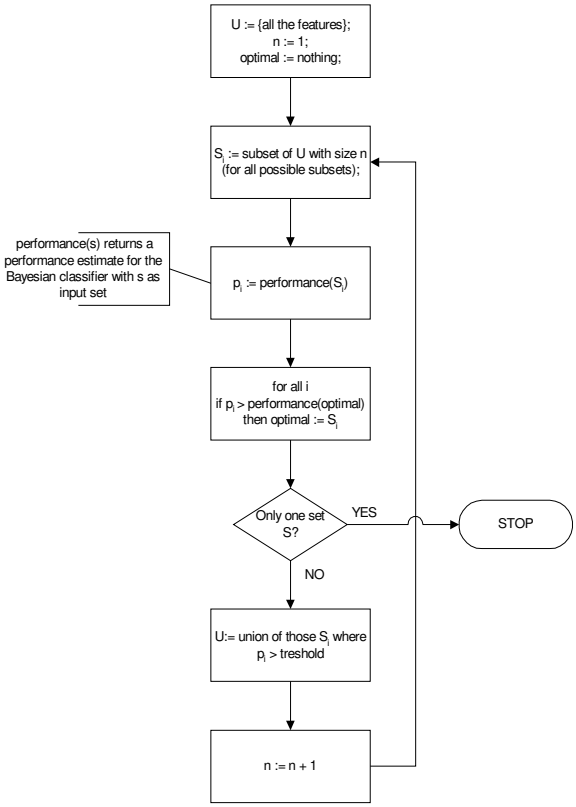

Fig. 1. A flow chart of the feature selection heuristic.

A set of candidates is selected among the highest-rank ones, then the procedure is iterated with all (or some of) the two, three, … input classifiers that can be built from all the possible unions of the sets produced at the previous iteration.

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