Hard- and Software fusion for process monitoring during machining of fiber reinforced materials

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Abstract.
Machining of fiber reinforced composites remains a challenging process at the end of the value chain. Malfunctions of machinery and bad surface quality cause a tremendous loss of value and need to be reduced to increase competitiveness in lightweight applications. Monitoring of machining steps can be carried out by many different techniques and strategies all with their unique benefits and drawbacks. These provide information about machining hours, wear status of the tool, potential malfunctions of the system and can estimate the quality of the machining process. This contribution presents an approach to fuse different sensing systems on the hard- and software side to combine the information of different systems that provide a consolidated basis for the analysis of the machine status, tool status and machining quality. To this end we present results from a sensor fusion approach to measure acoustic information during the machining and a software framework that was developed to provide a blueprint for real-time capable solution for feedback control.

Keywords: CNC machining, carbon fiber reinforced polymers (CFRP), condition monitoring, data fusion.

1 Introduction

The current production landscape is characterized by various trends. On the one hand, companies are faced with the need to flexibly produce smaller batch sizes in order to meet the increasing demand for individualized products without loss of productivity. On the other hand, technical developments offer new, previously unknown and thus unused possibilities for process support and improvement [1].

Machining of fiber reinforced materials - essentially milling, turning, finishing and drilling - is a process step that is essential for the fabrication of the final product as none of the production technologies of fiber reinforced materials immediately results in the final shape or surface quality required. However, the requirements posed to machining of these materials are constantly increasing. Tool life should be increased, contours should be milled more precisely and faster, the load capacity of the tool should be increased and downtimes of machines should be minimized. This is especially the case in series production, where repetitive processes need to be continuously improved and economically optimized.

Hence there is a strong trend towards exploitation of process data acquired by sensing technologies during machining of fiber reinforced materials to address these needs. However, integration of new sensing systems is sometimes costly and existing data sources inside conventional CNC machines may sometimes prove already as efficient means to solve some problems. Nevertheless, there is a serious gain in results when combining different data sources from different sensing systems. We present some recent work out of the project “WiR Augsburg” to provide a sophisticated framework for fusion of sensing systems as well as data fusion steps to move from rudimentary data acquisition systems to decision making “smart” machinery exploiting state-of-the-art artificial intelligence algorithms.

2 Hardware fusion

As seen in figure 1, the typical data acquisition systems found for monitoring of machining operations can be categorized into roughly three main types. There is classical machine data from CNC machines or turn tables comprising the continuous recording of tool position, tool or work piece velocity, overall operation conditions and many more. Into the same category fall systems which are already used on a broad basis for the controlling of the machinery, such as force/torque control systems to measure cutting forces as well as to collect 3D or 6D information about the loads acting on the tool [2–5]. Typical for the hardware in this category is that these systems are readily integrated into the machine controller and results may be extracted directly via industrial bus systems such as Profinet or OPC/UA.

As second category one can identify the acoustical monitoring systems. In this context, this can methodologically be split into three different sub-categories of measurement systems that are already established. Namely, these are vibration analysis systems and monitoring systems for acoustic emission, whereas the latter may be subdivided further into burst and continuous acoustic emission. There are existent standalone solutions for each of those types which typically are a serious financial investment. They have shown much potential to provide additional insight in the machining process, yet may not easily be integrated in existing shop floor solutions when it comes to use of industrial bus systems. We recently proposed a hardware fusion solution [6, 7] to integrate the required sensing capabilities into one sensor system. This is attached to one data acquisition unit, whereas differentiation between signal interpretation for vibration analysis or acoustic emission monitoring is done on the software side as will be explained next.

As third category we can identify camera monitoring systems that move along with the tooling to inspect the machining operation. For most applications of machining of fiber reinforced materials, it was identified that these systems do not provide much use cases, as the mixture of abrasive dust particles and fibers as well as lubricants or water inhibit a good view during the process and may degrade the optics over time. Nevertheless, scenarios with post-processing inspection via optical systems may prove useful, given the optics are properly protected during machining and enough time is provided for fog clearance after machining [8, 9]. These systems are currently all considered custom-made equipment.

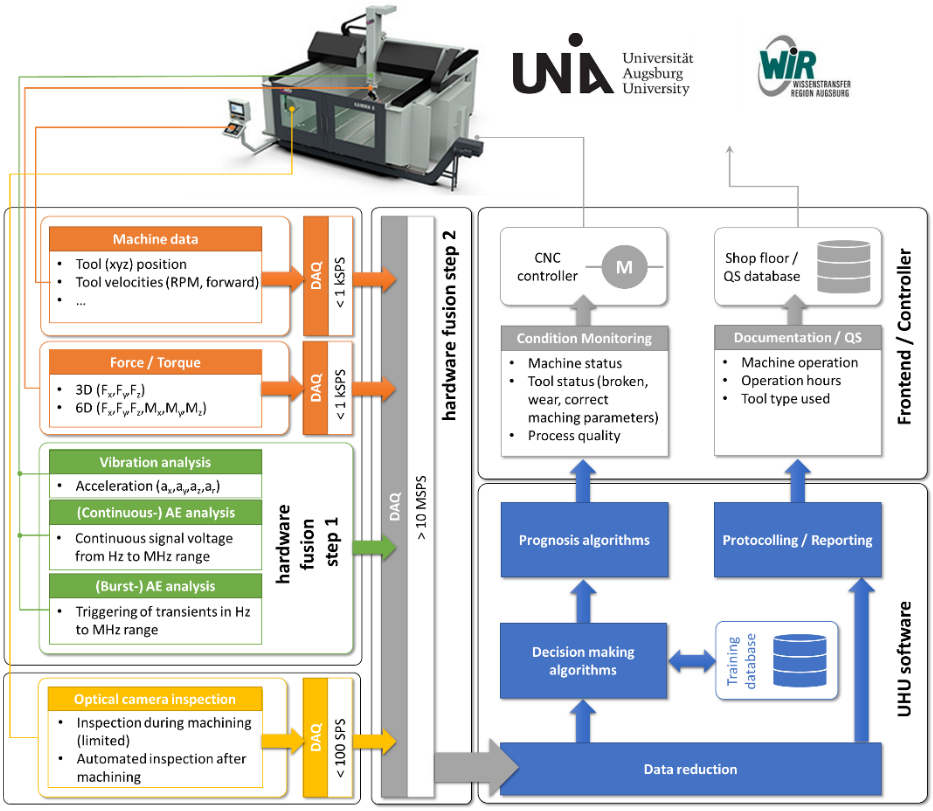

Fig. 1. Flow chart of hardware fusion steps for machining of fiber reinforced materials.

3 Software fusion

As an input from the different data acquisition systems one expects time series data packages, which are either one-dimensional (scalar values as function of time) or two-dimensional (vector or array values as function of time). In the present use case these are data streams of machine data, sensor voltage readings of acoustic sensors or image arrays of camera systems. Typically, these data streams are sampled at vastly different frequencies, so one key item is to provide a common time stamp for the whole data basis. Depending on the planned use of the data this determines the next processing steps. If the sole purpose of data acquisition is merely documentation, time lags do not cause much harm and real-time capability is not important as long as the system can dump the data during down-times of the machinery. However, as contrasting requirement, if online controlling of the CNC machine is intended (e.g. to change the tool when it is wearing out or to protect the work piece after tool breaks) real-time efficiency is crucial.

For the latter we developed the software framework Ultra-Highlevel-Ultrasonics (UHU) which is based on the aspect that the acoustic sensors provide the highest sampling rates considered (>10MSPS) and hence the software framework needs to be capable to process this data stream in real-time. Moreover, the UHU environment is intended to incorporate other data streams such as force/torque data streams or to integrate camera systems to operate on a common platform. The UHU approach sequentially processes packages of fixed time intervals of the data stream in a multi-core parallelized environment in a combination of edge and cloud computing as described in [10]. The core capabilities are based around a two-step feature extraction. For the first step, basic features in the time and frequency domain are extracted. A combination of those features for each package over a varying time span is then forwarded to decision-making algorithms (e.g. adaptive machine learning algorithms) which turn the low level features into high level predictions like tool wear status, location of defects, etc. Therefore, a backbone in form of a training database is linked via an interface. At the same time, other protocol and documentation steps may be delivered from the software or fed into a digital twin, so to complete the view of the current machining operation. For machining of fiber reinforced composites, the analysis of the acoustic signals also provides insight on the machining quality as well as on the tool wear status [2–5, 11–13], which can be delivered to a graphical user interface or can be directly reported into a shop floor QS system or database via an OPC/UA interface.

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