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System architecture for mastering machine parameter optimisation

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In mobile machines, as well as in manufacturing, the overall productivity is essential for business competitiveness. As the operation of a modern mobile machine is affected by various parameters, they need to be tuned to reach an optimal performance – however, due to machine complexity, parameter optimisation is difficult for a typical operator. To enable parameter optimisation locally in machines, this article presents a system architecture to generate information and knowledge from machine fleet data and to utilise them in machine operations in the field. Measurement data is collected and analysed to discover the associations between machine performance and parameter values. While some results are plain statistical distributions, any resulting more sophisticated domain knowledge is stored as rules. Rule-based reasoning enables a zone of interoperation between the information system and domain experts. Once information and knowledge have been generated, they are made available to machines that run the actual parameter assessment application. Results made with forestry data indicate that the system has a considerable potential to improve machine productivity.

1. Introduction

Even a minor productivity improvement may result in a substantial advantage as well as reduced fuel consumption and overall environmental impact. In material handling and processing, mobile machines are essential in the production chain. While modern equipment has a high automation degree, there is still room for significant improvement in its operation.

Mobile work machines are complex technical systems that consist of a number of *parametrisable* components. Typically, components are customisable rather than having a fixed operating context. For example, while the typical excavator task is to dig, different soil types may require different parameters for the optimal performance. Further, even work types may vary (such as pile driving instead of digging).

Mastering parameter knowledge to optimise performance is not a trivial task in a large scale. The number of parameters may reach hundreds in a modern machine. While a domain expert might have a solid basic understanding of typically good parameter values, an average operator certainly has not. Besides, even domain experts do not know all parameter – performance dependencies so advanced analysis methods are required to discover new knowledge from measurement data. The ultimate goal is to raise the automation degree of parameter optimisation: how to take control over a large data set collected from a machine fleet, how to manage parameter and performance value knowledge and how to apply it in individual machines during operation. Presumably, such optimisation is extensively performed autonomously by machines in the future. In this paper, a distributed system architecture is introduced for the task.

The research methodology followed by the work is to resolve requirements, to create a concept based on them and to evaluate the concept by implementing a prototype. The methodology can be seen to follow both design science and constructive research approach as presented by Piirainen and Gonzalez [1]. Section 2 summarises related work. The various aspects and requirements of the system are covered in Section 3. The design of the system is introduced in Section 4 and a prototype is presented in Section 5. Finally, Section 6 contains results and discussion followed by conclusions in Section 7.

2. Related work

This section covers previous studies related to industrial service architectures. Also, vehicle data collection and refinement as well as rule based systems are considered.

Bringing service-oriented design to the industrial context has been discussed in various studies. Jardim-Goncalves et al. propose a platform to improve enterprise collaboration and system interoperability in industry [2]. Colombo and Karnouskos argue

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that service design eases both device integration and reconfiguration after constantly changing business requirements [3]. Cândido et al. propose an infrastructure where services facilitate device deployment during production system lifecycle [4]. The E-maintenance concept in manufacturing includes not only equipment data collection and utilisation but also knowledge management for decision support. Bangemann et al. write about a maintenance systems integration platform that enables geographical distribution and utilises web services [5]. Karim proposes a framework for service-oriented E-maintenance applications as well as a methodology for the identification of supportive services [6]. A practical industrial service architecture for condition monitoring has been introduced by Hästbacka et al. [7].

Vehicle and machinery data utilisation have been studied in several articles. Lu et al. have researched fuzzy rules generation for fault diagnostics [8]. Dingus et al. have documented the collection of a large car data set in everyday conditions [9]. Wu et al. have utilised mathematical methods to recognise engine faults from audio data [10]. Palmroth has researched the analysis of mobile machine data to assist operator learning [11]. Golparvar-Fard et al. have developed an algorithm to recognise earthmoving equipment actions from video [12]. He et al. demonstrate how a cloud application may assist either in finding a parking place or in vehicle data mining [13].

Particularly in agriculture, machinery data acquisition is a growing concern. Steinberger et al. as well as Peets et al. have studied data collection from heterogeneous data sources [14,15]. Iftikhar and Petersen have researched bidirectional data transfer from and to machinery [16]. Fountas et al. have designed a farm machinery information system to facilitate data utilisation [17].

Rule based systems are useful tools in the energy management of hybrid vehicles and machines. For example, Lin et al. have utilised dynamic programming to generate rules for power management [18]. Hybrid excavators have been included in power management research by, for instance, Kim et al. [19].

Rules have also other applications in mobile machines. Rules can assist in selecting the best machine or equipment for some specific purpose as studied by, for example, Amirkhanian and Baker [20]. Further, den Hartog et al. have utilised rule based models to predict the performance of mobile machines [21]. Bradley and Seward have utilised rules to raise the intelligence and the automation degree of excavation [22].

Compared to previous research, the work to be presented is unique as it combines the aspects of a service architecture, a distributed machine fleet, machine data refinement and refined data utilisation locally in machines as well as knowledge management with rules. Two previous works have considered system architecture, machine data processing and rules for knowledge management. Kannisto et al. have developed an architecture for operator feedback generation [23]. Kannisto et al. introduce a system for mobile machine parameter optimisation [24]. Compared to this work, it is on a more conceptual level, and no experimental results are presented.

3. Machine information management requirements

Parameter optimisation is likely present wherever mobile machines are utilised. While this section considers the problem from a general viewpoint, forestry domain is also considered particularly. This work is considered novel as equally comprehensive publications about service architectures for managing machine parameter optimisation are not known to exist.

3.1. Domain related challenges as motivator

An information system to aid parameter optimisation would be beneficial in forestry machines. They have several instruments for handling tree stems; for instance, the boom of a machine has typically several actuators that operate boom joints or grab or process stems. While operator skills are important, the overall machine performance is largely affected by the precision and speed the machine responds to operator actions which is effectively determined by machine parameters. (The influence of machine parameters has been suggested by Väyrynen et al. [25].) Unfortunately, parameter optimisation requires knowledge that is unavailable for typical machine operators, and even domain experts do not have all the knowledge potentially available in measured machine data. The global or even regional variety of forests – and its effect on which parameter values perform best – brings additional challenge so operating contexts should also be considered. In the end, not only data analyses are required but their results should also be available for operators to assist parameter optimisation. Further, domain information and knowledge are expected to evolve constantly as new data is collected and new analyses are executed – that is, repeated updates are required. The parameter optimisation process can be illustrated with a loop as in Fig. 1.

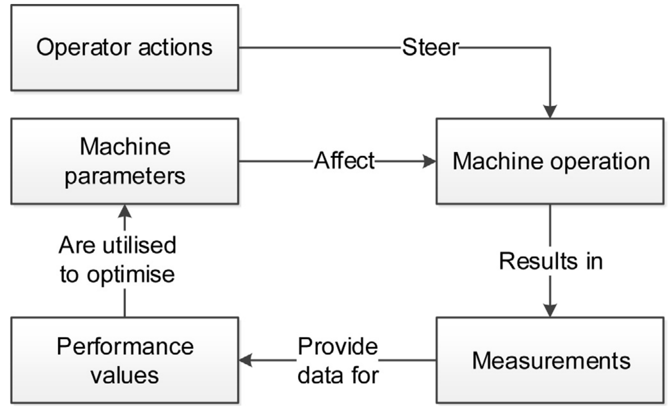

Fig. 1. Parameter optimisation loop for improving the overall machine performance.

The solution should enable the generation, distribution and exploitation of domain information and knowledge discovered in data analyses – even local utilisation in machines is desirable. Depending on the industry, considerable requirements and limitations may arise from machine distribution. In forestry, machines may operate far from each other, the corporate office and public infrastructure. Also, the machines may have no Internet connectivity for days or even weeks. In a business ecosystem, parameter optimisation may be managed by various actors (at least operators, the machine manufacturer or a local dealer). Their scope and access to physical machines varies, but distribution is inevitable.

3.2. Required system features

The research questions are as follows:

> What kind of conceptual information system architecture is required to centrally manage the information and the knowledge related to machine parameter optimisation? How to enable the distribution of information and knowledge to geographically dispersed machines so they can be utilised locally during operation? How to implement such an information system?

To concretise parameter optimisation, let us look at an example about determining the amount of hydraulic flow directed to a machine boom. The flow basically determines the power available for boom operations: more flow results in faster responses. However, at some point, the motion would become even too quick