Using Internet of Things to Improve Eco-efficiency in Manufacturing: A Review on Available Knowledge and a Framework for IoT Adoption

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Abstract. Green manufacturing and eco-efficiency are among the highest priorities of decision makers in today's manufacturing scenario. Reducing the energy consumption of production processes can significantly improve the environmental performance of the human activity. This paper aims at investigating, according to currently available technologies and to their short-term feasible evolution paths, how the Internet of Things (IoT) paradigm could actually be implemented to increase efficiency in energy consumption, and reducing energy consumption cost.

Keywords: Internet of Things, eco-efficiency, framework.

1 Introduction

The manufacturing sector is one of the largest energy consumer, estimated at more than 31% of global energy consumption [1]. Relevant energy savings are expected to be achievable both from increasing the energy efficiency of production and logistic processes as well as in innovative energy monitoring and management approaches [2]. In this scenario, emerging technologies such as IoT paradigm are believed to play a lead role in increasing energy efficiency, working at different levels. More specifically, IoT could play such a role first by increasing the awareness of energy consumption patterns (real time data acquisition level), and then by improving local (single machine) or global efficiency (multiple machines) by decentralizing data elaboration or even actuation decisions. In this regard, the paper is arranged in two sections. The first section is dedicated to a literature review covering energy efficient management, and IoT paradigm. Relying on this knowledge, the second section is devoted to present a framework for IoT adoption when pursuing energy efficiency targets in manufacturing. Some concluding remarks are drawn to address future research.

adfa, p. 1, 2011.

2 Literature review

2.1 Energy Management and Monitoring

Many methods and tools have been used for reducing energy consumption, such as energy monitoring tools, process modeling, simulation and optimization tools, process integration, energy analysis, and decision support tools, etc. [3]. Often energy reduction approaches in industry are related to lean manufacturing concepts, and rely on empirical observation as in [4]. The adoption of eco-efficiency needs to be included at all levels of production process, including the machinery [5]. Energy consumption of a machine is not strongly related to the production rate; conversely, the amount of consumed energy is mostly related to the time spent in specific operative states [6]; according to [7] the potential energy savings from reduction of waiting time or in the start-up mode are estimated around 10-25%.

Real time data from energy monitoring systems is necessary for improving energy efficiency on manufacturing [8]. For optimizing energy consumption of manufacturing processes, energy consumption awareness should be achieved first [9]. Monitoring and analysis of the energy consumption of machines are major steps towards increasing energy efficiency [10]. Some conventional production systems are not able to collect data on the amount of energy consumed in production processes [11]. In this regard, IoT based solutions can be very useful to drive energy efficient applications: smart metering is an example to show the importance of the IoT in the energy area; in addition to providing real-time data, it could make decisions depending on their capabilities and collaboration with other services, as mentioned in [12].

2.2 Internet of Things

Actually IoT technologies consist of an integration of several technologies, as identification, sensing and communication technologies, which consist of RFID, sensor, actuators, and wireless information network [13]. The IoT paradigm has opened new possibilities in terms of data acquisition, decentralized data elaboration/ decision making and actuation. The real time monitoring system enables continually monitoring production processes and machine status [14], and covering the disturbances through production line, such as machine failures, production errors, etc. as in [15]. Adoption of IoT technologies in manufacturing processes have been investigated in some researches, as shown in table 1. Few researches have investigated how and when IoT is useful for improving energy efficiency at the shop floor.

Author	Year	Manage and control inventory and material (trace and track)	Monitoring shop floor	planning and control shop floor	Monitor and control the production process /machine status
Meyer [15]	2011	x	x	x	x
Poon [16]	2011	x			x
Meyer [17]	2009	x			x
Zhang [18]	2011	x	x	x	
Zhou [19]	2007	x			x
Huang [20]	2008	x		x	
Chen [21]	2009	x			x
Hameed[22]	2010				X
Wang [23]	2011			x	X

Table 1. Research on RFId and IoT application domains in manufacturing

3 A framework for IoT Adoption, and managerial impact.

Stemming from the literature review, and focusing on discrete manufacturing systems, a framework for IoT adoption has been conceived, which considers the following factors:

- Type of energy fee structure. Two types of energy fee structure have been considered, fixed price, and variable energy price [24].
- Eco-efficiency targets (awareness, improvement, optimization).
- Existing IT infrastructure; Rely on the American national standard framework as in [25]¸ which specifies 4 levels as listed below. For each of these levels, depending on the current state of IT adopted by the factory, different IoT applications may be conceived.
  - Level 1 defines the activities involved in sensing.
  - Level 2 defines the activities of monitoring and controlling processes.
  - Level 3 defines the activities of the work flow to produce the end products
  - Level 4 defines activities include plant schedule, inventory levels materials movements. Information from level 3 is critical for level 4 activities.

By combining the aspects above, the framework in Figure 1 points out a set of feasible application domains, covering some of the existing possibilities. For each feasible domain (i.e. energy fee structure, existing IT infrastructure and eco-efficiency targets) the paper qualitatively discusses the current applicability of the IoT paradigm and points out which specific functionalities could be entrusted to such solutions (measurement, sensing and actuation).

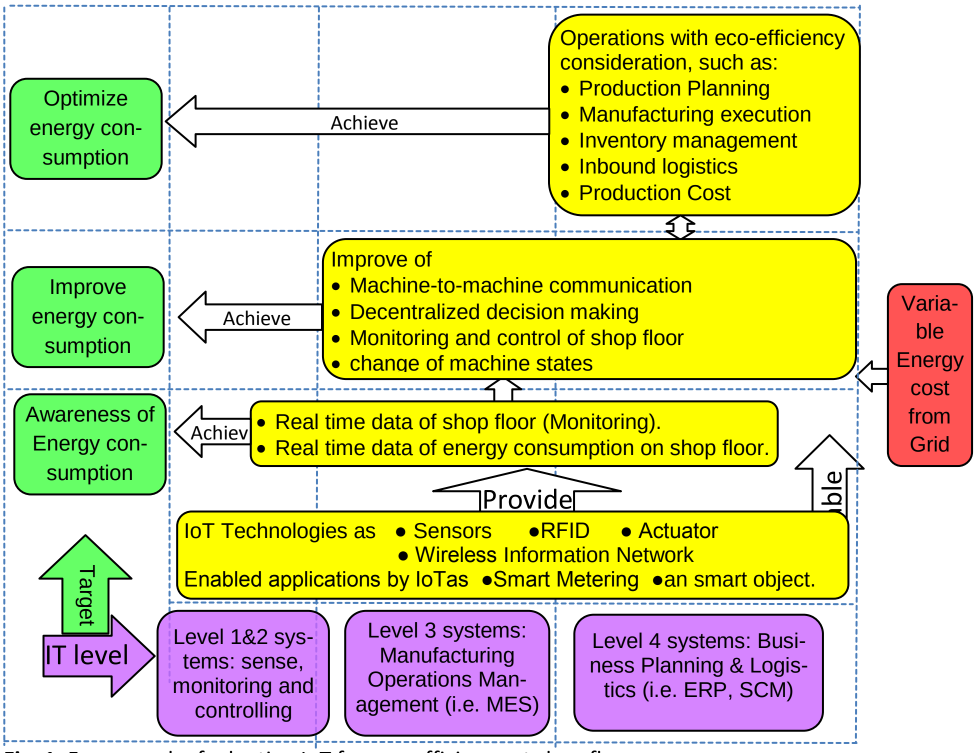

Fig. 1. Framework of adapting IoT for eco-efficiency at shop floor

Real time data from IoT including data from smart metering will be used to increase the awareness of energy consumption of each processes and machines, and providing new measures. Taking energy consumption in consideration during planning processes will lead to improve and optimize energy consumption, which requires more flexibility in planning and control, enable machine to machine communication, and adopting of decentralized decision making at shop floor. With adopting variable energy cost, the way of improving and optimizing energy consumption will be different, compared with fixed energy cost. IoT applications and real time data will play an important role in configuring, schedule, changing machine states, defining of current energy consumption during each process, monitoring, planning and control of the production processes at shop floor. IoT can feed MES with real time data from shop floor, and inventory movements, etc.; then, an efficient decision can be made. In this regards, adopting of decentralized decision making is important, whether decision will be made by shop floor supervisor, an employee, or by the machines. Examples of these decisions are: change the priority of production processes, change machine status, reschedule the production process, and inventory movement at shop floor.

Actually many scenarios can be applied in real world depending on the framework. In Table 2, three scenarios are discussed to explain the framework, encompassing both fixed and variable energy cost structure. The first scenario assumes the available IT in a factory is level 1 and 2; the target is increasing the awareness of energy consumption. The second scenario assumes the available IT in a factory is level 3; and the target is improving energy consumption. The third scenario supposes the available IT in a factory is level 4; and the target is optimizing energy consumption.

Scenarios	Fixed Energy cost structure	Variable Energy cost structure
1	Adoption of IoT Technologies with its applications, such as Smart Metering (smart object) increase awareness of energy consumption, by providing detailed energy consumption data for specific machine, process, product and shift.	Integration of variable energy cost with real time data increases the awareness by providing real energy cost for specific process, machine, product, and shift. Accordingly, decision maker, etc. can take the proper decision depending on the new available data on short and long term.
2	Integrating of real time data from shop floor with manufacturing systems (e.g. MES) leads to improve energy consumptions by increasing monitoring and control of shop floor, enabling machine-to-machine communication, and by adopting decentralized decision making to make the proper decision depending on current	Considering variable energy cost during production process will help to minimize energy consumption cost, for example, by changing machine states to reduce cost and wastage of energy consumption; this means the decision making will be depending on changeable energy price, and energy consumption data

	production process.	from IoT technologies for current production process.
3	The integration of real time data from smart metering on energy consumption (per machine and per process), real time data on inventory, production status, and other real time data from the field on production process, will be useful for optimizing energy consumptions. This data can be also useful for production schedule etc., Acquired data on energy should be feed to ERP systems to be considered during next production planning and during configuring of production systems, etc.	The integrations of variable energy cost information, with other information from MES, and ERP Systems, will be useful for optimize energy consumptions. Some alternatives will be offered for decision making, such as, changing machine statues, and reschedule production process (when it is possible, and depend on the energy cost). This means production planning is required to be more flexible to fit with energy price. Acquired data form IoT on energy consumption will effect on future production processes.

4 Conclusions

Adopting of IoT technology (as smart metering) is able to provide high level of awareness of energy consumption at all factories level. The awareness leads to find available energy saving opportunities in production process, this lead to reduce energy consumption. Also, IoT technologies may provide new opportunities for improved monitoring of the inventory, and traceability and visibility of manufacturing process, which lead to improve the processes at shop floor, accordingly reduce of energy consumption. Integration of the collected real time data with manufacturing systems, such as ERP and MES help the decision makers to make decisions with considerations of energy consumption. Variable energy cost structure effect on the way of achieving awareness, improving, and optimizing of energy consumption at manufacturing plant. More investigated is needed; in how effectively connect IoT technologies (i.e. sensor) to machines, connected to interconnect sensors and collect data in a business sustainable as (costs, flexibility, etc.). And how to insert the energy perspective in current manufacturing's planning and control, and decision making.

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