

A 20-Year Analysis of the Evolution of Automatic Milking Systems: Processes, Technologies and Livestock Environment [†]

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[†] Presented at the 1st International Electronic Conference on Animals—Global Sustainability and Animals: Science, Ethics and Policy, 5–20 December 2020; Available online: <https://ieca2020.sciforum.net/>.

Abstract: Over the last 20 years, the dairy industry has implemented new technologies related to automatic milking systems (AMS). AMSs have the potential to maximize milk production and animals' welfare thanks to voluntary milking access, as well as to increase the resource efficiency and environmental sustainability of dairy farms. In this study we assessed the state of the art of research on AMS through a systematic review of patent trends in the last two decades. Patents from the last 20 years were extracted from the EspaceNet database. Terms appearing in titles and abstracts of a total of 154 patents were processed using a text mining approach, ignoring low-frequency and meaningless words, and including stemming analysis to aggregate variant forms of the same word. Four clusters were identified: Components, Sensors, Process and Animal. The results showed that the highest number of patents was yielded in the early 2000s, thus indicating great interest in AMS in the initial period. The cluster trend pointed out that the focus on the animal and sensing technologies has been constant over time. In recent years, the priority of research has shifted towards process efficiency and components. Detailed analysis of clusters allowed us to appreciate an increasing interest in the animals' health and body conditions over time (+249% and +391% from 2000 to 2019, respectively). The processes which showed increasing relevance were the ones related to the cleaning of facilities (+291%). The study of new sensing technologies has focused primarily on imaging, allowing researchers to develop new decision models (+348%). The results suggest that AMS patents are moving their attention towards more efficient and sustainable systems. This trend represents an important opportunity for a significant increase in the sustainability of the dairy sector, not only for animals but also for the farmers through the efficient use of the resources, thus enhancing the consumer's perception of sustainability.

Citation: Cogato, A.; Brščić, M.; Marinello, F.; Pezzuolo, A. A 20-Year Analysis of the Evolution of Automatic Milking Systems: Processes, Technologies and Livestock Environment. *Proceedings* **2021**, *73*, 3. <https://doi.org/10.3390/IECA2020-08825>

Published: 2 December 2020

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Keywords: animal systems; automatic milking systems; animal health; sustainability

1. Introduction

The use of automatic technologies is a growing trend in the livestock industry [1,2], and plays a key role in future prospects [3]. Automatic milking systems (AMS) are one of the most significant technological changes in the dairy industry [4], and the number of commercial farms milking with AMSs has increased rapidly in the last few years [5]. In fact, from 2011 to 2014, around 25,000 farms have installed an AMS [6], and nowadays the process can be considered a well-established technology [7]. AMSs have the potential to maximize milk production and animals' welfare thanks to voluntary milking access, as well as to increase the resource efficiency and environmental sustainability of dairy farms [8,9].

This study assesses the state of the art of research on AMS through a systematic review of patent trends in the last two decades (2000–2019) in order to identify research tendencies and critical gaps. In total, 154 patents were extracted from the EspaceNet database and processed using a text mining approach.

2. Methods

The systematic review was carried out by extracting the patents of the last 20 years from the patent server EspaceNet (www.epo.org). Patents were searched using different synonyms to define the AMS and filtered by publication date (2000–2019). Once extracted, the patents were organised into five groups of four years.

The content of “Title” and “Abstract” were processed with the text mining process. Analyses were carried out using Microsoft Excel and GraphPad Prism 8.0.0 (GraphPad Software, Inc., La Jolla, CA, USA). Titles and Abstracts were pre-processed to improve the quality of information retrieval [10,11]. Meaningless features, such as punctuation marks, numbers and symbols, were removed by applying a tokenization process. The list of single words resulting from tokenization was further perfected by deleting the low-frequency words and connectors. Finally, word-sense disambiguation and the stemming processes were applied. These processes allowed for clarification of the ambiguity of acronyms and included in a single lemma all variant forms of the same word.

After the pre-processing, the words included in the dataset were grouped into four clusters: “Animal”, “Process”, “Sensors” and “Components”. First, the trend of the four clusters over the years was analyzed. Then, a word frequency analysis was carried out within each cluster to identify the patent trend tendencies. Frequency analysis was also applied to the applicants to determine the top contributing countries.

3. Results and Discussion

The trend of the patents awarded over time is reported in Figure 1. The chart reports the number of patents starting from 1996, as the employment of AMS in farms dates to the 1990s. The number of patents reached the maximum number in 1998–1999, when the first voluntary milking systems were commercialised [12]. After a sharp decrease, the patent registration has stabilized, despite natural oscillations.

The highest number of patents was granted by the Netherlands (33.6%), followed by Sweden (14.3%) and China (9.7%).

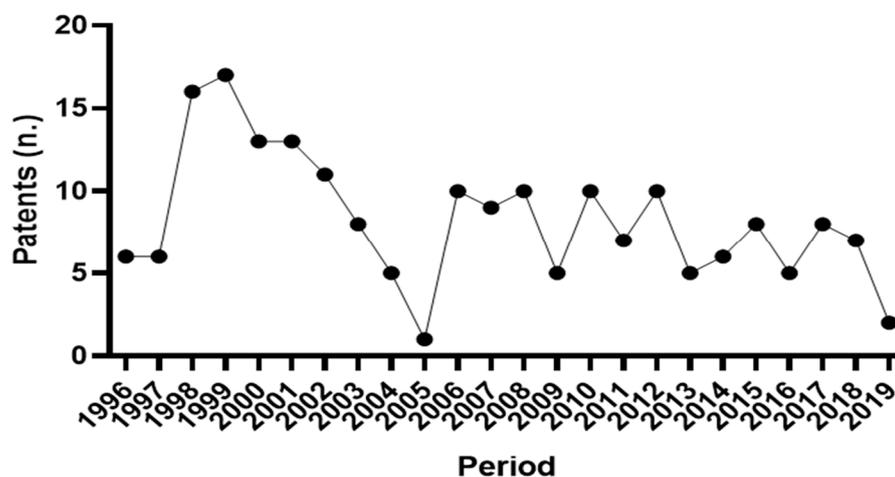


Figure 1. The trend of patents per year.

The text mining process allowed us to identify the following main clusters: Components, Sensors, Process and Animal, weighting 30%, 29%, 25% and 16%, respectively. As reported in Figure 2, the trend of the clusters was not constant over the 20 years. Initially,

the research focused on sensors to support high-technology milking systems [13]. In the last 10 years, the development of sensors has been incorporated into the improvement of the efficiency of the process. Meanwhile, the target of the patents has moved towards components.

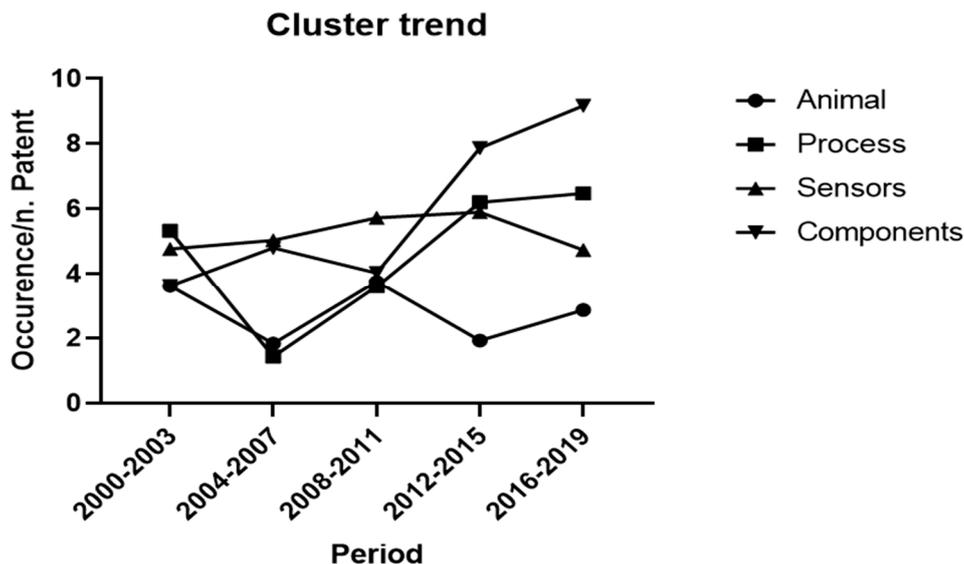


Figure 2. Trends of the four clusters during the observed period.

As concerns the single clusters, the frequency analysis of the cluster “Animals” showed that after the initial implementation of the feeding, interest has recently focused on the dairy barn. Moreover, more consideration has been given recently to the animals’ body condition/weight and health (+249% and +391% from 2000 to 2019, respectively). To maintain high-efficiency production and ensure animal welfare, health-monitoring equipment is strongly required [14], and the evolution of the AMS has also involved the use of automated weighing scales [15] and more recently optical-based techniques [2].

Confirming these findings, the topic with the highest increase in the last decade within the cluster “Sensors” was related to imaging techniques. Models are strictly connected with sensing technologies, which support farmers’ decision-making. In fact, the models showed a 348% increase from 2000 to 2019.

As regards the cluster “Process”, the analysis highlighted the increasing relevance of the management of the cleaning operations for facilities. For example, the use of the word “water” increased rapidly from 2000 to 2019 (+291%). Moreover, the implementation of pulsation technologies (“pulsation” +65% from 2000 to 2019) reflects the evolution toward more efficient milking units, ensuring udder health [16].

Within the cluster “Components”, the word frequency analysis showed that the industry spent the first decade perfecting the teat cups (−44% from 2000 to 2019), whereas in the second decade it focused on storage systems, e.g., improving tanks and pumps. Moreover, in the second decade, several patents were registered about the milking arm.

4. Conclusions

In this study, we analyzed the AMS patent trends over the last two decades. The systematic review approach allowed us to identify research tendencies and gaps. Cluster analysis showed that the AMS industry is focused on the implementation of more efficient and sustainable systems. The evolution of components, sensors and technologies ensures both compliance with high-quality products and animal welfare. Topics related to the animal aspect are still underdeveloped, but their increasing trend allows us to expect a progressive evolution in relation to the issue of animal welfare.

Author Contributions: Conceptualization, A.C. and A.P.; methodology, A.C., A.P. and F.M.; software, A.C.; validation, M.B., F.M., A.P.; formal analysis, A.C. and A.P.; investigation, A.C., M.B., and A.P.; writing—original draft preparation, A.C. and A.P.; writing—review and editing, A.C., M.B., F.M., and A.P.; supervision, A.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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