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Review

Agricultural Machinery Telemetry: A Bibliometric Analysis

Leomar Santos Marques [1], Gabriel Araújo e Silva Ferraz [1,*], João Moreira Neto [2], Ricardo Rodrigues Magalhães [1], Danilo Alves de Lima [3], Jefferson Esquina Tsuchida [4] and Diego Cardoso Fuzatto [4]

[1] Agricultural Engineering Engineering Department, Federal University of Lavras, Lavras 37200-900, MG, Brazil
[2] Department of Engineering, Federal University of Lavras, Lavras 37200-900, MG, Brazil
[3] Automatic Department, Federal University of Lavras, Lavras 37200-900, MG, Brazil
[4] Department of Physics, Federal University of Lavras, Lavras 37200-900, MG, Brazil
* Correspondence: gabriel.ferraz@ufla.br

Abstract: Agricultural machinery telemetry collects and shares data, which are sent remotely and become precious information. Thus, accurate and instantaneous monitoring can provide an important base of information for adjusting the parameters of the most diverse mechanized agricultural operations, reducing input costs and maintenance expenses. In recent years, this theme has gained more strength and importance for managing rural properties. Therefore, the present study developed a bipartite bibliometric analysis in two lines of research and described the state of the art of this data collection methodology (via telemetry), presenting its technological evolution. The study presents the evolution and connection of telemetry and the processes of robotization of agricultural operations and automation provided by data collection via telemetry in real time. The main countries, keywords, researchers, institutions, and the Dickson quality index indicate a high growth in the last decade. Thus, the present study contributes to decision making regarding research topics, guidance on the state of the art, and contextualization of telemetry's importance in current research.

Keywords: data collection via sensors; data transmission; systematic analysis; state of the art

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1. Introduction

In recent years, there has been a great deal of interest in studying knowledge networks as manifested in recorded knowledge (e.g., published papers and books). Researchers rely on surveys to be comprehensive to identify the most relevant academic records to their work and analyze the interrelationships among various facets of knowledge [1,2].

More than ever, researchers need to know how and where to search, predominantly due to the exponential increase in the production of academic records, which requires academics to think about where they can best access these records [3].

Thus, bibliometric analysis is the quantitative study of bibliographic material, which aims to provide an overview of a particular research field that can be classified by articles, authors, and journals that can help researchers [4].

Telemetry in agricultural machines consists of the conjuncture of machine management information, which may involve speed, displacement, geographic location, production, machine hours, material flow to and from the machine, and maintenance information [5,6]; it is linked to physical conditions of the land and crop, such as field size and shape, topography, line length, turning space at the end of the line, production, and surface condition in the turning area [5].

This technology, which was first used in the late 60s and early 70s, being forgotten for a while, saw an increase in its use again in 2013, the concepts of its initial uses being applied to new, recently improved methodologies, which aim to improve management that correlates with some data (location, maintenance of machines, agricultural inputs, production, and environmental aspects).

Thus, this paper presents a bibliometric overview and a brief mapping of the state of the art of research published on the telemetry of agricultural machinery in recent decades.

2. Theoretical Framework

2.1. Theoretical Premises of Bibliometrics and Publication Mapping

The research should investigate the main documents representing the research fronts referring to a certain topic, in order to identify both international and national collaborations on this topic [7].

According to Campos et al. (2018) [8], a literature review seeks to extract characteristics of published studies to form a perspective of the studies presented. In contrast, bibliometrics should be added to the research to develop search and selection parameters that allow the researcher to reach a volume of articles for analysis and to develop new perspectives of study trends from the gaps in the literature.

Thus, a good conceptual delimitation of the approach and topic to be researched should be carried out to find the essence of characterization of the search for a significant understanding of state of the art presented [9].

2.2. Text Mining

Text mining is a field that attempts to extract meaningful information from text. It can be widely characterized as the process of analyzing text to obtain useful information for specific purposes [10].

The concept should not be confused under any circumstances with the simple web search concept. The latter is about searching for information through a search engine. The information offered when this operation is implemented is very large in quantity, and the operator has to choose the information he needs one by one. With the first, you put all the useless information in the corner and keep only the research-related information you are looking for. The methods involve indexing, neural networks, clustering, and categorization algorithms [11,12].

2.3. VOSviewer

VOSviewer is a software tool created by Nees Jan van Eck and Ludo Waltman at Leiden University (department of science and technology) in 2011 to construct and visualize bibliometric networks. Specific networks may, for example, include journals, researchers, or individual publications and may be constructed based on citations, bibliographic coupling, co-citation, or co-authorship relationships. The software also offers text-mining functions that can be used to construct and visualize co-occurrence networks of significant terms extracted from a body of scientific literature (VOSviewer official Website) [13].

2.4. Coefficient of Determination R^2

In statistics, the coefficient of determination, indicated by R^2 and pronounced "R-squared", is the proportion of variation in the independent variable that is predictable from the independent variables. These are statistics used in conjunction with statistical models whose primary purpose is to predict future outcomes or test hypotheses based on other relevant information. It provides a measure of how well the model reproduces the observed results based on the proportion of total variation in the results explained by the model [14–16].

Then the variability of the data set can be measured with two sums of squares formulas:

If $\overline{y}$ is the mean of the observed data:

$$\overline{y} = \frac{1}{n}\sum_{k=1}^{n} y_i \quad (1)$$

where y_i is values between $[y_1 \ldots y_n]$.

The sum of squares of residuals, also called the residual sum of squares (SS_{res}), is:

$$SS_{res} = \sum_i (y_i - f_i)^2 = \sum_i e_i^2 \tag{2}$$

The total sum of squares (SS_{tot}) (proportional to the variance of the data), is:

$$SS_{tot} = \sum_i (y_i - \overline{y})^2 \tag{3}$$

The most general definition of the coefficient of determination R^2 is:

$$R^2 = 1 - \frac{S_{Res}}{S_{Tot}} \tag{4}$$

3. Materials and Methods

The flowchart bibliometric review development and brief mapping of the state of the art of research published on agricultural machinery telemetry in recent decades can be seen in Figure 1, as well as the separation into two pieces of research (S1 and S2) for the development of the state of the art and the evolution of technology.

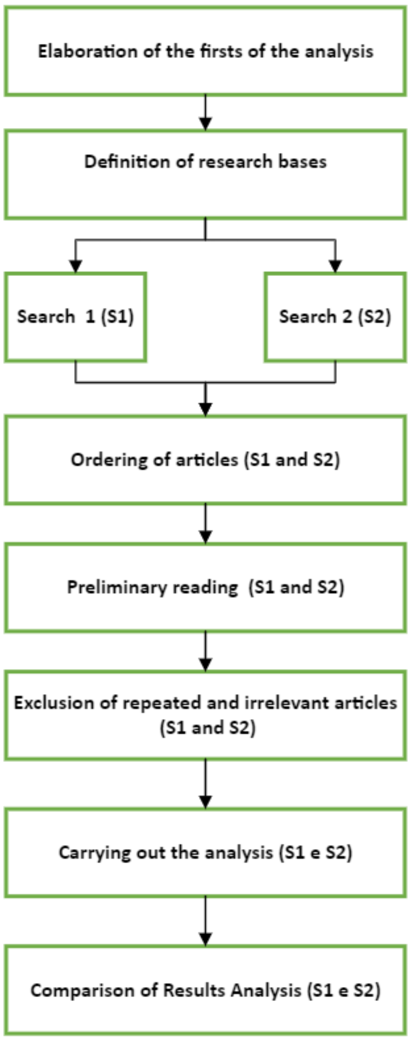

Figure 1. Flowchart of bibliometric review development and brief state-of-the-art mapping.

Initially, the premises of the research were defined as follows:

- Search language: English;
- First article search should contain: agricultural* AND machinery* AND telemetry*;
- Second search was limited to articles containing agricultural* AND telemetry* with a refinement of research areas (Engineering, Agriculture, and Computer Science).

Thus, the research delimited English as the search language in both phases. In the first phase, all articles should necessarily contain the three words in their context: agriculture, machinery, and telemetry, including their inflections by means of the asterisk (*). In the second, the articles should contain only two limiting words: agricultural* AND telemetry*, with the refinement of research areas (Engineering, Agriculture, and Computer Science). These two formulations were used to list all articles, since when searching for isolated terms, the search could present several other articles not related to the research topic.

Thus, division S1 aimed to find all articles that contain the three terms together; however, it does not guarantee that all articles were found. Thus, it was decided to carry out a new search, which contained the terms agriculture and telemetry; however, when the number of keywords was reduced, many of the results referred to unrelated areas of research, being thus limited. If in S2 the areas of knowledge correlate to the terms (Engineering, Agriculture, and Computer Science), the search algorithm reverts to results in which, when the number of words is reduced, the greater the number of articles found, but the greater the possibility of finding unrelated articles.

The research bases were defined in the aforementioned Scopus previewer and Web of Science databases, so it was possible to obtain a greater number of relevant research articles for the selected terminology.

Thus, the search obtained in the two databases was saved in the phase of obtaining searches related to the delimited terms. It was saved, and each of the found articles was divided by the two search templates.

In the preliminary reading phase, we sought to organize the articles before reading, reducing the time used in the initial reading process. The preliminary reading phase aims to contextualize the terminology and prepare the criteria for the exclusion and relevance analysis phase.

In the exclusion and relevance investigation phase, the criteria established for the evaluation funnel were:

- Does the article really address the topic of research on telemetry applied to agricultural machinery? (If not, exclude it from the results);
- Can the article be considered innovative, either in methodology or as an application of new technologies? (If yes, include in the brief state of the art);
- Is the article present in both databases? (If yes, delete one).

The data from the two databases were downloaded and divided into two forms of research to carry out the analysis. The data from the previous phase were excluded, and the VosViewer software was used to analyze the keywords and the links among them. The data provided by the database were used to analyze the documents.

The comparison was based mainly on the quality of the results obtained and the articles in which they were inserted in the research to present the general chronological state of the art, advances in technology, and the bibliometric analysis of the two research models.

4. State of the Art

Telemetry, initially, was a little different to how it is known today. However, it followed the same concept of data collection. Thus, in its first appearance, the term telemetry was discussed in the engineering memorandum of Bennett and Oliver (1970) [6], where it describes a communication system that used telemetry for data collection through magnetic tapes and some analog computers for data reduction. The article discusses three areas that the International Harvester Company was putting to work in electronics (magnetic tape, data reduction, and data dissemination). In this study, the operator was exempt from the inhibition often generated by taking care of cables, wires, and instruments within the agricultural equipment. Thus, according to the researcher, he soon forgot about telemetry and, thus, returned to his normal activities. The transmitter had a range of hundreds of meters from the station where it was located to the receiving station, which in some cases did not need to move.

In 1976, in the research developed by Orme (1976) [17], a computer with dual hard disks, a revolution for that time, was installed in a trailer to function as an acquisition and reduction data system. The proposed system had a radiotelemetry system with a range of 8 km and a capacity of 31 analog data channels, where it was possible to install the sensors and collect data from the equipment field tests. However, the research did not show the data of the equipment from which the data collection was carried out; it only presented the receiving and collecting data equipment.

The study by Freeland et al. (1988) [18] presented a low-cost F.M. radio telemetry system that allowed real-time remote monitoring of field data describing the operational parameters, energy consumed by the tractor, and inputs used to operate the machines and implements. This research used a microcomputer mounted on a tractor for data collection. The telemetry system was built with telephone modems and portable two-way F.M. radios, which allowed the remote control of the tractor's onboard computer to receive, decode, and verify the data processed by it. The real-time data acquisition system was mounted on a tractor to monitor the tractor's and agricultural implements' operational parameters.

Few publications were made until Kim et al. (2013) [19], who resumed telemetry study with the development of a load measurement system installed on a tractor. The system consisted of strain gauge sensors to measure torque on transmission and power take-off input shafts, using a radio-telemetry E/S interface to acquire the sensor signals and embedding software to acquire the data in hard-ground terrain.

Castillo-Ruiz et al. (2015) [5] tracked three models of commercial olive harvesters using a GNSS (Global Navigation Satellite System) and GSM (Global System for Mobile Communications) devices during two harvest seasons in Spain and Chile, using equipment that was developed to determine its time efficiency and effectiveness based on canopy agitation for fruit detachment. Their study linked the location data to data from the plantation topology. Thus, it was possible to evaluate, through the machine telemetry, the optimal value of the orchard design parameters and which of the three models of machines presented the best performance.

In 2021, an attempt was made to provide a simple alternative for performing wireless telemetry measurements. The proposed system performed measurements of the power take-off torque requirement during machine operation in farming. Furthermore, it measured several other parameters, such as cutting depth, number of rotating blades, transmission ratio, engine speed without load, and tire size. Thus, he correlated these parameters with the torque at the tractor's power take-off. According to the author, the presented system did not cause telescopic disturbance, including in the vertical inclination of the cardan axis [20].

5. Technological Advances

New advances in methodology began to emerge following current and global trends in engineering and industry. Concepts involving digitization and the internet of things (IoT) were implemented in agricultural equipment to connect them to each other and the environment. It was not enough to collect specific data; the devices had to collect several high-frequency parameters. Thus, telemetry in agricultural machinery began to be applied and made available in several products on the market (AGCO AgCommand, John Deere JDLink, Claas Telemática, Raven Slingshot, and Trimble Connected Farm) [21,22].

Research has also undergone this evolution. A study published to monitor the performance of a coffee harvester presented communication adequacy until then used only in the "Open Platform Communications" (O.P.C.) industry in a unified architecture, to reduce end-to-end communication latencies, results that improved not only monitoring, but also the applications for mobile robotics, given the communication speed [22].

Telemetry, through research, began to encompass equipment from which data was not yet collected, such as spraying machines, thus showing its benefits for the management of various operations from planting to harvesting. Thus, Sarri et al. (2017) [23] developed a prototype of a telemetry system suitable for harvesting machines applied in winemaking. This system monitored the performance of spraying operations in real time and was composed of a tracking module for data acquisition. The data collected included: latitude, longitude, sprayer speed, elevator status, power take-off, sprayer operating side (left and right), operator presence, pressure values in the centrifugal pump and spray head, and the flow rate. This allowed complete monitoring of the spraying activity, which was able to find process errors and propose corrections.

The evolution of the mobile data network provided by 4G applied to telemetry in agricultural robots led to the emergence of crucial adaptations for implementing agriculture 4.0, since it can transmit data in real time, with high bandwidth requirements. Thus, real-time video monitoring of equipment began to be applied to agricultural robots, adding another tool to crop monitoring and management [24].

Accurate and instantaneous monitoring can provide an important basis for adjusting both seeding and harvesting parameters. In this sense, mobile applications had a high contribution to instantaneity in decision making. For real-time monitoring of multiple sensors, using cabling on the machine or even multiple screens to monitor each system is no longer necessary. Mobile applications have come to facilitate this communication, reducing telemetry implementation costs, and can even be compared with more accurate systems [25].

Thus, instrumentation and telemetry techniques are reliable and can be useful for database generation, telemetry-based equipment, aggregate signal clustering, and pattern recognition, such as neural networks, which have raised the level of generated information. These methods have improved data-processing technologies, and the collected data has become crucial information, not only for the present but for all future harvests [13,26].

6. Considerations and Discussions of the State of the Art and Technological Advances

The telemetry studies of agricultural machines started by answering a simple question: "Will it be possible to install sensors and transmit data collected from the machine to another central system?". Thus arose the first and biggest problem faced by the telemetry of agricultural machines, which consists in the transmission of data; several systems and ways were proposed, such as sending data via cables, short distance radio, F.M., and 4G, so it began to consolidate.

The second problem arose from the same question, concerning which sensors should be used and whether they are extremely important. Thus, some studies, such as the one by Freeland et al. (1988), captured the signal from several sensors installed in the machine.

However, these were not the only problem thrown up by the questions; in parallel to this, during the evolution of data transmission, the storage of received data became increasingly large, and the insertion of several sensors became increasingly complex, so early disks were developed for this storage, and extremely large equipment was developed for this purpose, which in some cases required a trailer, as in Orme's 1976 study, to be transported. As the evolution of data storage has improved and reduced, new challenges have arisen, and today transmission and storage in done in the cloud.

Linked to the evolution of data storage, telemetry today faces new challenges linked to robotic harvesting equipment using GSM and GNSS. Among the main difficulties faced by researchers today are data processing and accuracy of data collection, mainly from GNSS and GSM, which support both equipment and precision agriculture.

7. Results and Discussions

In the first search, a total of 34 documents were found with the English terms agricultural* AND machinery* AND telemetry* in their titles, abstracts, or keywords. Notably, one appeared in 1970. Of the 34 documents found in the two databases (Scopus previewer and Web of Science), five were present in both databases, and four were not directly related to the researched topic, as shown in Figure 2.

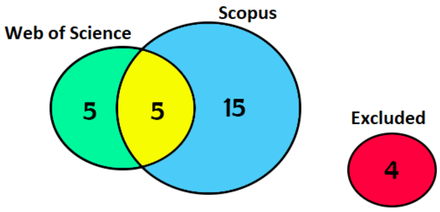

Figure 2. Representation sets of articles found in Scopus previewer and Web of Science databases.

The number of publications for these specific terms shows a moderate positive trend (R^2 = 0.55) in the the growth rate, indicating an increase of more than 100% in the total number of articles published between 2016 and 2021 compared to previous years to 2016 in the databases surveyed (Figure 3). However, it is observed that, even with the growth, the number of publications specified is still limited to three publications per year, demonstrating that there is still a possibility of growth in the research area. It is also possible to highlight that publications on the topic began in the 1970s. Throughout the 70s and 80s, scattered contributions on the subject were observed. It is also noteworthy that, between the years 1990 and 2006, publications were found with the requirements of this research.

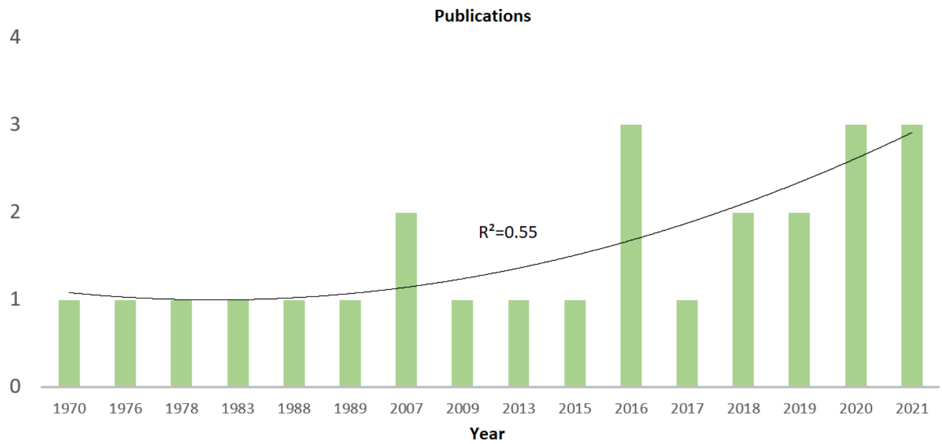

Figure 3. Total annual publications on Agricultural Machinery Telemetry from 1970 to 2021 in Scopus previewer and Web of Science databases.

This study indicates that the United States and Germany contribute the highest output, with 24% of publications, followed by Canada (12%), India and China (8%), and, with smaller percentages, Brazil, South Korea, Spain, Finland, Lithuania, and Russia (4%), as seen in Figure 4.

The network visualization map shows the 20 main descriptors used as keywords in the set of publications analyzed in this study (Figure 5). The various items were grouped into four groups, represented by different colors on the map. Each cluster shows a set of closely related words from the same search field, where cluster size and number can indicate variations in search lines. Thus, the keywords that stand out the most in the network visualization map due to their high occurrences and total link strength are agriculture, agricultural mechanization, equipment, and machinery telemetry. There is a strong relationship trend between agriculture and robotics, equipment telemetry, agriculture, remote control, and agricultural machinery. This combination was expected for the terms of the keywords, since when developing state of the art, it was possible to observe this evolution and connection of telemetry and the processes of harvesting robotization and automation provided by collecting data via telemetry in real time.

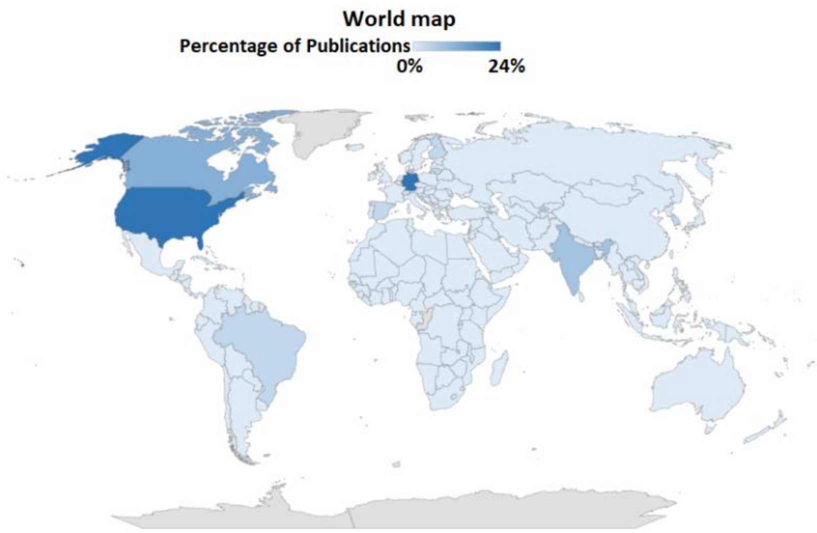

Figure 4. Total publications in the world from 1970 to 2021 in the Scopus previewer and Web of Science databases on agricultural machinery telemetry.

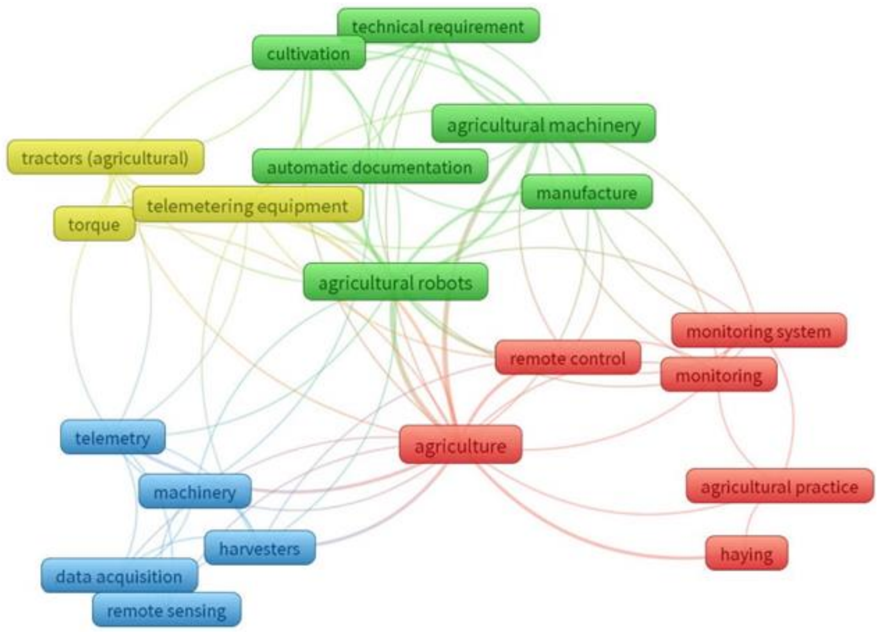

Figure 5. Map generated from the analysis of the most repeated keywords in articles published between 1970 and 2021 in the Scopus previewer and Web of Science databases on agricultural machinery telemetry. Different colors represent the diversity of thematic clusters found with the associated keywords: red (group 1), green (group 2), blue (group 3), and yellow (group 4) and links between keywords.

The researcher who published the most articles referring to agricultural* AND machinery* AND telemetry*, with two articles published, was Virendra Kumar Tewari, who is an agronomist and an elected member of the Indian Society of Agricultural Engineers and the Institution of Engineers. In contrast, the other researchers published only one related article. The institutions that published the most, with 20% of publications each, are the Indian Institute of Technology Kharagpur, located in India, and the University of Osnabrück, in Germany.

The second search returned a total of 208 documents with the English terms agricultural* AND telemetry* in the titles, abstracts, or keywords. Notably, and unlike what was expected, when excluding the articles already found in the first analysis, it was noticed that the first articles only appeared in the year 1986, since the eight articles found in the search in the period from 1965 to 1985 were not related to the research objective. Of the 208 documents found in the two databases (Scopus previewer and Web of Science), 35 were present in both databases, 82 were not directly related to the researched topic, and 24 had already been represented in the previous research, as shown in Figure 6.

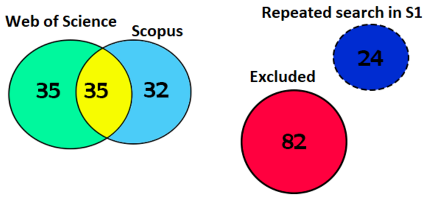

Figure 6. Representation sets of articles found in Scopus previewer and Web of Science databases.

In the second survey, the number of publications for these specific terms showed a strongly positive trend (R^2 = 0.76) in the growth rate, indicating an increase of more than 200% in the total number of articles published between 2016 and 2021 compared to the years prior to 2016 in the databases surveyed (Figure 7).

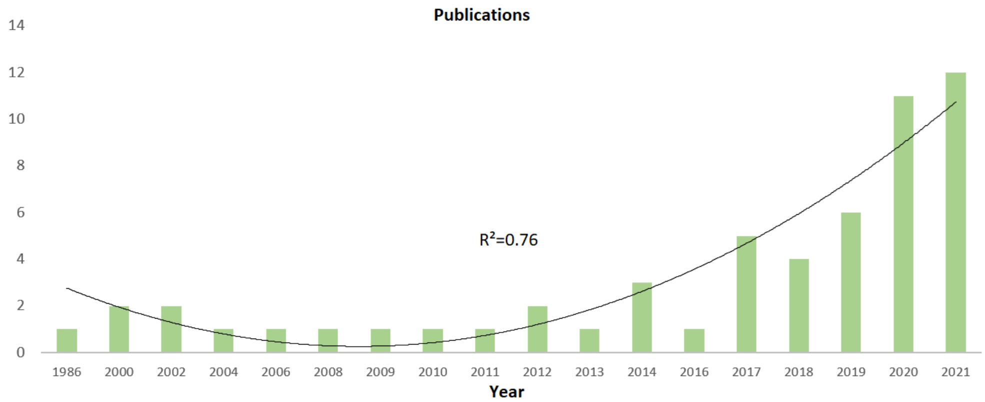

Figure 7. Total annual publications on Agricultural Machinery Telemetry from 1986 to 2021 in Scopus previewer and Web of Science databases.

The study carried out indicates that the United States contributes the highest output, with 23% of publications, followed by India (21%), China (19%), Germany (12%), Brazil and Romania (8%), and, with smaller percentages, Canada, France, Japan, and Indonesia (2%), as seen in Figure 8.

The network visualization map shows the 21 main descriptors used as keywords in the set of publications analyzed in this study (Figure 9). The various items were grouped into four groups, represented by different colors on the map. Each cluster shows a set of closely related words from the same search field where cluster size and number can indicate variations in search lines. Differentiation was observed in three distinct clusters that were, however, interconnected. The green cluster shows that the words are related to robots, agricultural automation, and the internet of things. In the blue cluster, words related to data transmission and storage are observed. In the red cluster, words such as precision agriculture, remote sensing, and sensors can be observed, referring to data collection forms.

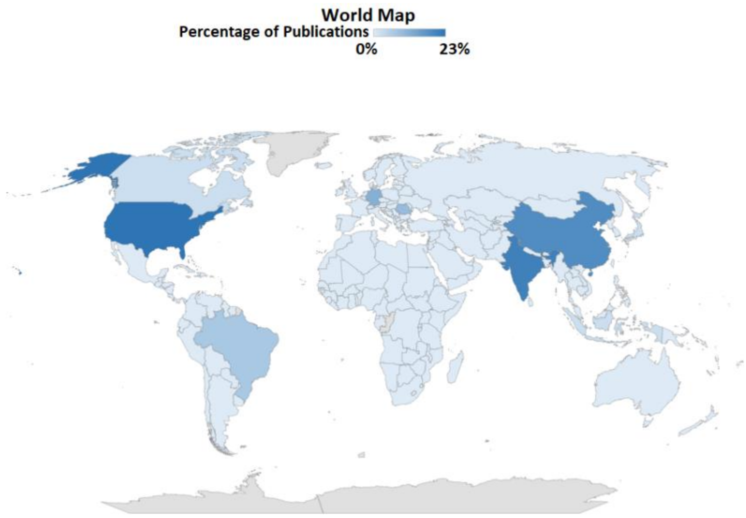

Figure 8. Total publications in the world from 1970 to 2021 in the Scopus previewer and Web of Science databases on agricultural machinery telemetry for the second analysis.

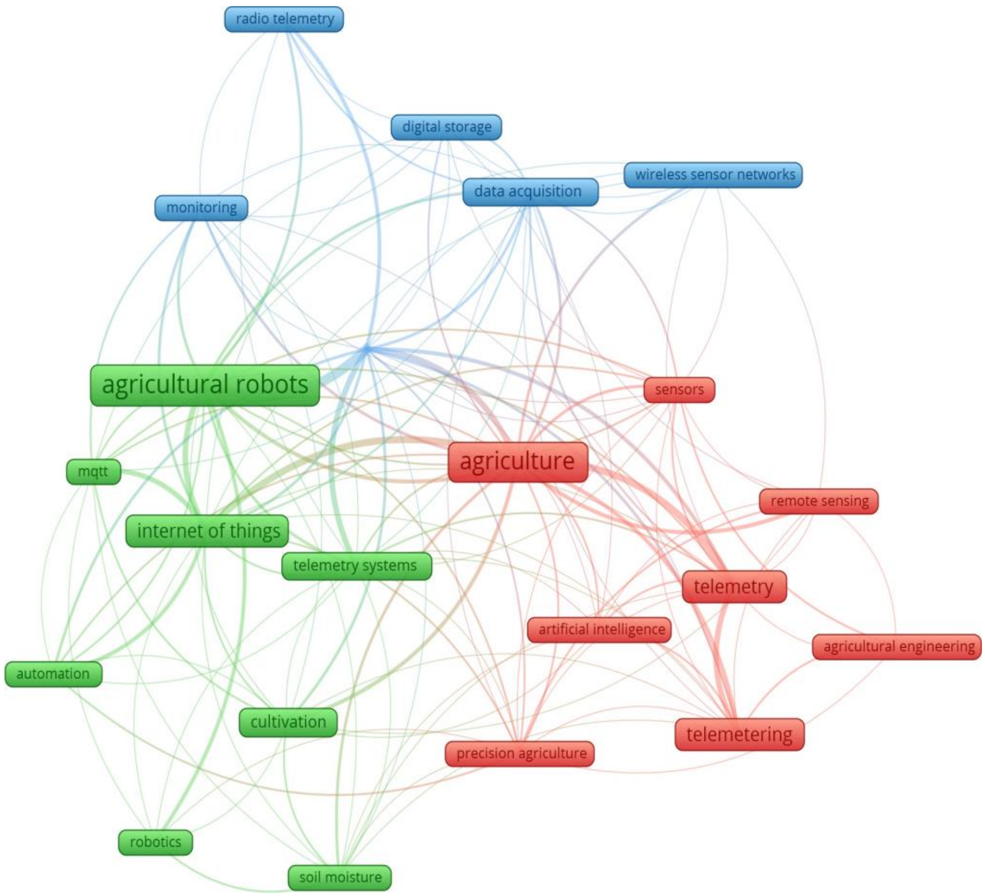

Figure 9. Map generated from the analysis of the most repeated keywords in articles published between 2000 and 2021 in the Scopus previewer and Web of Science databases on agricultural machinery telemetry. Different colors represent the diversity of thematic clusters found with the associated keywords: red (group 1), green (group 2), blue (group 3), and yellow (group 4) and links between keywords.

It is still possible to observe that the keywords that stand out the most in the network visualization map due to their high occurrences and total link strength are agriculture, agricultural robots, and telemetry. As in S1, there is a strong trend in the relationship between agriculture and robotics, and agriculture and telemetry. In this research, new terms such as the internet of things, artificial intelligence, and precision agriculture refer to the technological evolution and the trend of new technologies entering agriculture. In this way, the keyword terms were found to represent the technological evolution of data sent to the cloud and used for precision agriculture and robotic processing.

The researcher who published the most articles referring to agricultural*AND telemetry*, with nine articles published, was George Suciu, an engineer and author or co-author of more than 60 journal articles and scientific papers presented at several international conferences. In second place, Ioana Marcu published some articles with George Suciu, while the other researchers published between one and three articles related to the topic. The most published institutions, with 7% of the publications each, were the Polytechnic University of Bucharest and Beia Consult International.

It was observed that, with the two analyses, S1 served to assemble the state of the art, since it directed the terms related to the research and delimited the contents of the state of the art and the evolution of studies in the area. As for S2, as it is a more comprehensive and refined research with the requirements of engineering, agriculture, and computer sciences, with the reading of titles and separation of related research, and, later, the reading of selected articles, it was observed that it was optimized for the assembly of the main technologies and innovations applied in the area.

8. Final Remarks

The present study described agricultural machinery telemetry, which collects and shares data that are sent remotely and become information. In this way, it makes it possible to monitor, manage, and diagnose equipment applied in the agricultural environment.

It was observed that the evolution of research in telemetry showed high growth in the last decade, and the main country that made more quantitative contributions to scientific work in this area was the U.S.A. in both analyses.

The presented analyses showed that equipment telemetry provides a wide range of areas and has several fields that need research. Thus, agricultural machine telemetry consists of a migration of technology, which began in industry and promotes the evolution of the agricultural system to a new level called agriculture 4.0.

Recent research has placed great emphasis on trying to reduce data-processing time. The main difficulties encountered are related to the delay in the reception time and their respective errors in the GSM and GNSS data.

Telemetry has been applied to robotic systems and has stood out in the market for new agricultural equipment.

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