energies

MDPI

Article

BelBuk System—Smart Logistics for Sustainable City Development in Terms of the Deficit of a Chemical Fertilizers

Maciej Grunt [1], Andrzej Błażejewski [2,*], Sebastian Pecolt [2] and Tomasz Królikowski [2]

[1] BELBUK sp. zoo., Boh. Warszawy 28, 78-400 Szczecinek, Poland; maciej.grunt@epm.com.pl
[2] Department of Mechatronics and Automation, Faculty of Mechanical Engineering, Koszalin University of Technology, Śniadeckich 2, 75-453 Koszalin, Poland; sebastian.pecolt@tu.koszalin.pl (S.P.); tomasz.krolikowski@tu.koszalin.pl (T.K.)
* Correspondence: andrzej.blazejewski@tu.koszalin.pl; Tel.: +48-94-34-86-541

Abstract: ***Purpose***: This paper presents an aspect of asset tracking and storage conditions. This paper aims to fill the gap in the development of Industry 4.0 in terms of fully digital asset tracking to be implemented by medium and large-size manufacturing and logistics facilities. The article presents an innovative technology for the remote monitoring of chemical raw materials, including fertilizers, during their storage and transport from the place of manufacture to the local distributor or recipient. ***Methods***: The method assumes the monitoring and identification of special transport bags, so-called "big-bags," through embedded RFID tags or LEB labels and monitoring the key parameters of their content, i.e., temperature, humidity, insolation, and pressure, using a measuring micro-station that is placed in the transported raw material. ***Results***: The automation of inference based on the collected information about the phenomenon in question (the distribution of parameters: pressure, temperature, and humidity), and expert knowledge, allows the creation of an advisory system prototype indicating how to manage the measuring devices. ***Conclusions***: No similar solution in the field of monitoring environmental parameters has been implemented in the Polish market. The developed system enables the monitoring of 10,000 pieces of big bags in at least 30 locations simultaneously.

Keywords: monitoring of environmental parameters; smart logistics; sustainable storage; RFID technology; Internet of Things

check for updates

Citation: Grunt, M.; Błażejewski, A.; Pecolt, S.; Królikowski, T. BelBuk System—Smart Logistics for Sustainable City Development in Terms of the Deficit of a Chemical Fertilizers. *Energies* **2022**, *15*, 4591. https://doi.org/10.3390/en15134591

Academic Editor: Daniele D. Giusto

Received: 28 April 2022
Accepted: 20 June 2022
Published: 23 June 2022

1. Introduction

The growing human population makes it necessary to create and then connect intelligent and sustainable systems in increasingly urbanized areas. This applies to both the transportation of people and the transportation of goods. The need to combine smart mobility with the concept of sustainable smart city systems has emerged [1,2]. What is necessary to call cities intelligent is the ability to function as an integrated organism. Therefore, a smart city is one that maintains internal balance while integrating all components (functional organs), such as infrastructure elements, with the services they provide. Smart cities are connected into a coherent whole by intelligent monitoring and control devices called sensors. Their proper operation affects the functioning of the above-mentioned elements, i.e., infrastructure and services. Sensing is essential for smart cities' infrastructures as they can monitor themselves and act on their own intelligently. Using sensors to monitor and control infrastructure enables a more efficient use of resources. Real-time monitoring eliminates the need for regular human actions and inspections, therefore reducing costs and energy consumption. The data that were collected by these sensors allow for accurate forecasting and appropriate action, in order to avoid undesirable system states or become more system efficient. The theoretical background in this area and the roles of sensors as the nerves of smart cities are presented in the work [3]. Making cities smart represents an excellent potential for sustainable development in which both quality of life and the economy are improved. However, implementing new and efficient solutions in a smart city involves a large spectrum of factors that are related to the size and complexity of this type of project [4–6]. Eliminating unnecessary traffic and road congestion and optimizing routes with reduced environmental footprints are some of the fundamental factors of smart mobility. What makes the term smart appear in these efforts is the Internet of Things (IoT), Artificial Intelligence (AI), Blockchain technology, and Big Data guiding the main directions and fundamental pillars for the emergence of new innovative solutions that will change the existing paradigm of smart cities and their inhabitants. It is also often said that the smart city concept is moving towards a sustainable city concept, i.e., one in which resource conservation concerns both the environment and economic, social, and spatial aspects.

This article highlights other significant opportunities and challenges of smart logistics to counteract the disruption of the aspects that are mentioned above. It is essential to keep in mind that a properly growing city contains a human population that requires food. In fact, a feature of a sustainable city is to support urban farming, which aims to reduce the environmental impact of the agriculture supply chain. Still, it is not able to satisfy all the needs in this area. Therefore, food production occurs primarily outside of urban areas, which requires a supply system to be activated, albeit with fertilizers, to maintain high productivity. This, in turn, triggers huge, energy-intensive logistics processes that also require smart and sustainable approaches [7]. The technology that is the subject of this article makes it possible to increase the percentage of rescued materials in the chemical industry from destruction, resulting from the detection of the wrong conditions in which they are located. Data have been obtained stating that the complaint rate is 2–3% in the cited industries. The proposed system gives a 95% probability of capturing anomalies in transport and location at the distributor.

Due to the special scope of the work, to show its place and thematic relationship with the published works of other authors, the following literature review is carried out.

2. Literature Review

2.1. Smart City Manufacturing

The manufacture of products and goods for the public has gone through many stages of development, leading now to the pattern of Industry 4.0. The main goal of Industry 4.0, the largest European research project on the digital industry to date [8], is to achieve an improvement in the digitization of the European industry through electronics and information and communication technologies (ICT) [9]. The three main pillars of the systems approach in Industry 4.0 are digital manufacturing, supply chain networks, and product lifecycle management, which interact and influence each other. Real-life cases of this approach are presented in work [10], showing results where digital manufacturing resources, distributed by supply chain network (including warehousing and logistics tasks) [11], and product lifecycle stages can also be monitored through its digital footprint [12]. Within the above pattern, paradigms such as Sustainability, Manufacturing Networks, Smart Manufacturing, the Internet of Things, and Digital Twins have formed [13–16]. The characteristics of this type of manufacturing, also called urban, are manufacturing and service companies operating in buildings that are located in residential areas to rationalize the use of urban areas and solve transportation problems [17]. This solution does not deny the development of traditional industrial areas, i.e., manufacturing enterprises that are located outside the residential area of the city in industrial zones or industrial and technological parks [18]. The purpose of urban manufacturing is to meet the needs of city residents, as well as the needs of urban businesses and technology development centers (hereafter referred to as advanced technology and education parks (ATEPs)), by providing goods and services within a sustainable development framework [19]. However, the remoteness of production centers from the final destination is associated with the problem of transporting this production, as mentioned above [20].

2.2. Smart Logistics

Huge costs have been incurred for the improper storage and uncontrolled tracking of material flows in manufacturing facilities [21]. The foregoing is particularly true in the production and storage of bulk materials, such as artificial chemical fertilizers and cereals. As a result of their improper storage, contractors cause the loss of their physical properties [22,23]. As a result of complaints, they often demand a new delivery from manufacturers at their expense. Therefore, there is a need for a system to remotely monitor the physical and chemical parameters, distribution and storage, and identify contractors improperly handling such products. The traceability and accuracy system is related to real-time communication and feedback. Significant problems in the existing methods of identifying and tracking parts and products include part and product errors, schedule delays, delivery delays, and cost increases [24]. In fact, the use of appropriate technologies can improve the performance of monitoring and traceability, rather than just relying on human intervention and traditional methods, such as a barcode. Proper asset management can increase the productivity of a company. With advancements in the IoT, tasks such as tracking asset location and managing asset parameters can be carried out easily. Available asset management solutions use active or passive RFID tags [25]. For example, RFID tags have many advantages, more than barcodes. The paper [26] lists the benefits of RFID based on 10 case studies that are reported in the literature [27]. Unlike barcode technology, RFID has several advantages, such as multiple read rates of 1000 labels per second, which makes it a viable and cost-effective candidate for object identification and an important tool for providing visibility at different stages of the supply chain [28]. In fact, supply chains using RFID technology can generate 10 to 100 times more information than traditional barcode technology. Each RFID tag has a unique identification number and can have rewritable memory depending on the type [29]. Current asset tracking technologies typically require supporting infrastructure (signal transponders) to communicate with active asset tags [30,31]. The continuous tracking of resources in external and internal spaces can be costly, and reliable reference points are needed to calculate their position accurately [32]. For objects of this type, an augmented reality (AR) technique combines (passive) fiducial markers, i.e., taken as a fixed basis of comparison with flexible spatial anchors. This approach, called SABIAT, continuously tracks the approximate location of an asset using spatial anchors and, if necessary, the exact location of that resource using reference tags. The SABIAT technique, described in [33], was used to build an AR-IPS demonstration system to show how to track and locate resources inside a large, multi-level building.

2.3. Sustainable City Manufacturing

In the case of Industry 4.0, the movement of raw materials, semi-finished products, parts, etc. [34–36] has a significant influence on all the areas that are connected to manufacturing, as well as logistics and supply chain management (SCM), which are often defined as Logistics 4.0 and SCM 4.0 [37]. Smart production focuses mainly on the Cyber-Physical CPS System, which means trends in digitization, and logistics—especially in resource planning and warehouse management. SCM can also benefit from a combination of physical and digital planes. The concept of CPS-based warehouses, which includes autonomous transport, means moving different materials from one location to another and receiving data from separate parts of the supply chain to realize deliveries in the system of a just-in-time and just-in-sequence. Each asset is fully identifiable via its Digital Twin counterpart, so the amount and quality of the resources are updated automatically [38,39]. There are many automation systems with subsystems in the industry at once which depend mainly on the scale of the company, but traceability has always been a key element of a product or asset. This includes physically tracking assets on the factory premises (e.g., production halls and warehouses) and, for fertilizers, tracking their life cycle, and updating and managing their statuses.

2.4. Smart Agriculture

Applications of the intelligent approach in agriculture include the use of many types of sensors to monitor and control various environmental and production parameters, such as temperature, humidity, soil quality, pollution and quality of air, surface and groundwater, sunlight and many more [40]. This is to maximize harvest as well as other agricultural production. Currently, intelligent agriculture uses advanced technologies from the field of AI. It has been proven that such technologies increase the yields by appropriate assessment of the quality [41–45], and then classification of the yields, which significantly influences the optimization of production [46–50]. The use of intelligent sensors [51–57] and advanced techniques of artificial intelligence [55,58] enable the planning [59–61] and analysis of agricultural production. This approach creates integrated monitoring systems in plant production, as well as in animal husbandry [62]. Smart sensors and IoT turn conventional farming into smart farming. Consequently, great importance is attached to the optimal use of artificial fertilizers.

As the literature review shows, it is possible to indicate many specific problems that relate to the topic of the work, but due to limited editorial possibilities, they are only discussed in a general way. However, from the general scope of the subject, a specific aim of the research is introduced.

3. Materials and Methods

The general scope of this article focuses on the aspect of asset tracking and storage conditions. This article aims to fill the gap in the development of Industry 4.0 in terms of fully digital asset tracking to be implemented by medium to large-size manufacturing and logistics facilities.

The specific scope, which is presented in the paper, is the innovative technology for the remote monitoring of chemical raw materials, including fertilizers, during storage and transport from the place of their manufacture to the local distributor or recipient. The system assumes the monitoring and identification of special transport bags, so-called "big-bags," using RFID tags ("pastilles") or LEB labels that are sewn into them, as well as monitoring of the critical parameters of their content, i.e., temperature, humidity, insolation and pressure, using a measuring micro-station that is placed in the transported raw material. RFID systems are modern solutions for the identification of various objects using radio waves. Their broad applicability, durability, and convenience of use caused the application of this solution. Additionally, this solution is supported by the fact that methodologies are being developed to optimize the system of tracking resources by a limited number of RFID readers. Methods for maximum location coverage are being improved along with new metrics for analyzing the critical number index, and the optimal placement of a limited number of RFID readers is being determined. The proposed methodology is already implemented in a healthcare facility where the RFID coverage increased by 72%, compared to the previously used reader-placement strategy based on expert knowledge and heuristics [39].

The proposed system enables the central management of quality tests and the disclosure of cases of improper transport or the storage of raw materials and materials. In particular, it enables an accurate analysis of the product lifecycle from the moment of loading in the factory to the handover to the end-user. Thanks to the built-in mechanisms of machine learning and data analysis, the system uses a minimum number of measuring stations to ensure the system's statistical significance and effectiveness. The built-in application (interface) allows, among other things:

- Monitoring the movement of big bags from production to distribution centers and wholesalers;
- The ability to identify a specific production run during remote measurement;
- Real-time monitoring of environmental parameters;
- Aggregating and analyzing data coming from the big bags;
- Automatic targeting of consecutive big bags for testing.

As a result, the system replaces the typical random inspection of handling points, manual sampling for parameter testing, and the manual measurement of environmental conditions. Additionally, it provides monitoring of the transport bags themselves. Currently, no environmental-parameter monitoring solution offers such capabilities.

To meet the above requirements, many components must be integrated. Therefore, the proposed system in its integral parts (hardware and software) is as follows.

4. The proposed System

4.1. Functional Structure of the System

To achieve proper functionality, an innovative technology of the remote monitoring of chemical raw materials, such as fertilizers, during storage and transport from the place of manufacture to the local distributor or customer was developed (Figure 1). The system provides for the monitoring and identification of special transport bags, the so-called big bags, using sewn-in RFID chips or LEB labels, as well as monitoring of the critical parameters of their content, e.g., temperature, humidity, pressure and other parameters required by potential users, e.g., UV radiation, using a measuring MicroStation that is placed in the transported raw material. The system enables the central management of quality tests and the disclosure of cases of improper transport or storage of raw materials. Thanks to the built-in mechanisms of machine learning and data analysis, the system uses a minimum number of measuring stations, ensuring statistical significance and efficiency. It enables an accurate analysis of the product lifecycle from the moment of loading at the producers until delivery to the end-user. The system uses solutions from the field of microelectronics, embedded systems, and Service-Oriented Architecture.

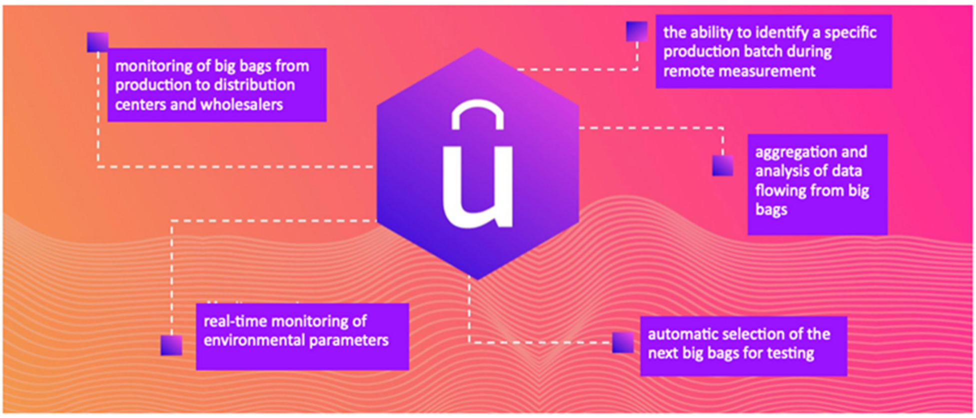


Figure 1. Functional structure of the system.

4.2. A Proposed System Architecture

The hardware structure of the system is based on Belbuk technology (Figure 2). Belbuk devices are robust structures in the form of measuring probes in a sealed enclosure, which transmit wirelessly measured physical quantities in real-time in the form of encrypted data transmission to the aggregation server. The autonomy and wireless operation of the measuring module are based on wireless communication standards. The complete Belbuk measurement station solution consists of a measurement module in the form of a measurement probe in a sealed enclosure sending data to the server. According to the Internet of Things (IoT) methodology, the aggregation of data that is obtained from the measurement modules can be sent to dedicated servers (Figure 2) using GSM LTE, 3G (UMTS, HSPA), LTE-M, and NB-IoT technologies (standards with the highest potential from the point of view of energy efficiency and coverage). When local infrastructure and WiFi wireless networks are available (within a compatible frequency, such as 2.4 GHz), it is possible to minimize the operational costs of installation and communication with servers. WiFi wireless radio networks provide a range of up to 70 m indoors and up to 250 m outdoors. The supported wireless communication standards are also complemented by an implemented module for receiving the Global Positioning System (GPS) signal, operating on the 1575.42 MHz and 1227.6 MHz carrier frequencies.

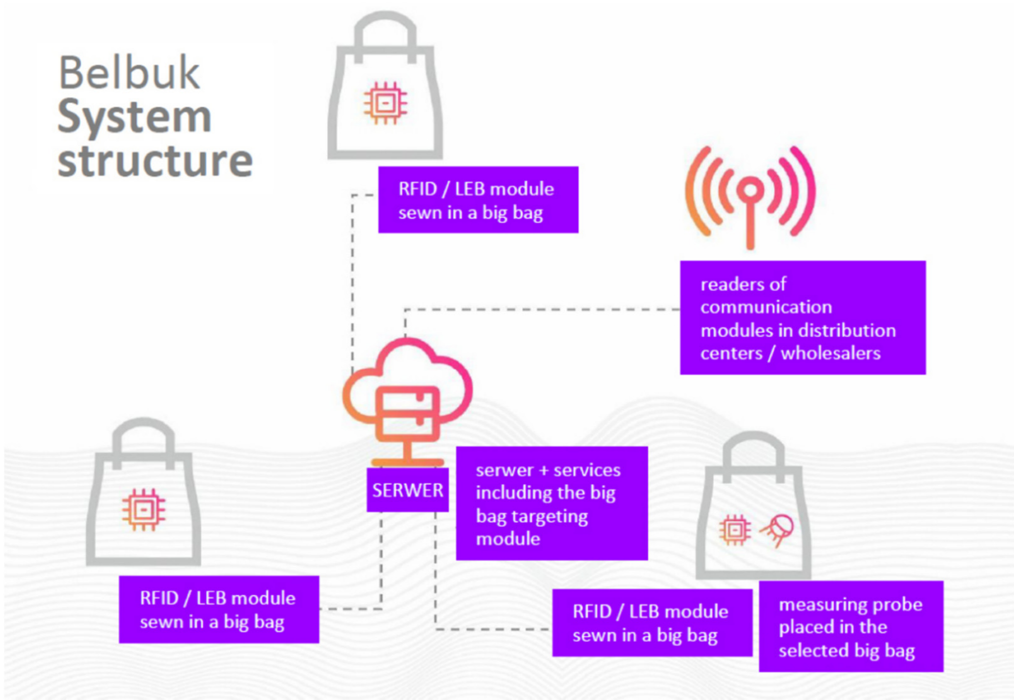


Figure 2. Structure of the Belbuk system.

Measurement interval: defines the frequency of receiving measurements from connected sensors. The value depends on the technical capabilities of the individual sensors and the characteristics of the physical and climatic parameters. Logging interval: defines the frequency of converting the received measurement data into the minimum, average and maximum values that have been aggregated over a given period. Data transmission interval: defines the frequency of sending recorded data to the Belbuk server. Belbuk devices are robust structures in the form of measurement probes in a sealed enclosure that wirelessly transmit measured physical quantities in real-time as encrypted data transmission to the aggregation server. The autonomy and wireless operation of the measurement module are based on wireless communication standards. The Belbuk system is based on measuring probes that allow measuring of the following parameters:

- The humidity content of the calcium fertilizer (a method with minimal risk of electrical discharge or potential for ignition of calcium compounds);
- Temperatures;
- The pressure scaled for quantitative evaluation of the vertically stored big-bag type bags of fertilizer;
- The relative humidity and air pressure (around the device).

The probe chip (Figure 3) can record data and send them to an aggregation server using GSM, NB, IoT, and LTE communications. In addition, if there is no communication, the data should be stored locally until they are read. The system is optimized to allow uninterrupted battery or rechargeable battery operation for six months from startup, assuming the measurements are taken every 15 min and the data are sent to the aggregation server once a day. This is unprecedented on the market and is a significant competitive advantage of the solution. The finished device in the form of a measurement probe is shown in Figure 4.

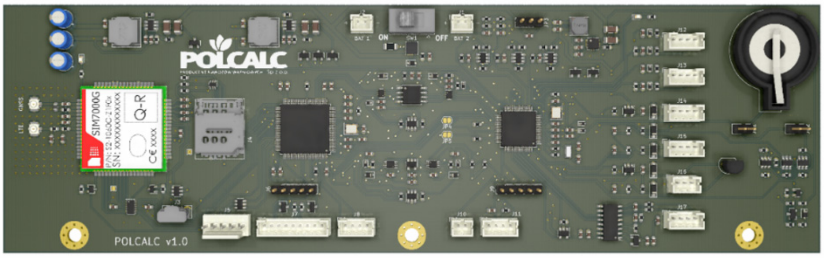


Figure 3. Central unit of the measurement module.

Figure 4. The measuring probe—general view.

4.3. Software

The software is designed to achieve maximum optimized performance and flexibility. A processor with minimized energy consumption was chosen as the central unit. It is designed to carry out the activities that are necessary for the functioning of the entire system (management and supervision of the power supply system) and to perform measurements. The system also has the function of switching into sleep mode for a set time (between successive measurements).

JSON, bootstrap, HTML 5, and PHP technology were used to implement the interface. The process itself was implemented based on Mockups (mockups) and Wireframes (sketches) that were developed in Adobe Illustrator CC 2018 and Adobe Photoshop 2018. The following development tools were used:

- Docker—used to build an application environment;
- Apache Kafka—system architecture;
- Kibana—data analysis;
- R studio—statistics;
- Azure Machine Learning Studio—statistics;
- Microsoft SQL—system database implementation;
- GRAPHQL—description of the data in API;
- HTML 5—used for several applets of the central application;
- Adobe illustrator—for preparing the wireframe of the central application;
- Eclipse Studio—server services, measurement probe software.

After the entire packet of measurement data is completed, serialization (to optimize the amount of transmitted data) and encryption (to further secure them) are performed.

The output information packet that is prepared in this way is sent via the NB IoT module to the server. An important parameter from the metrology point of view is the frequency of measurement execution and reporting. Due to the need to modify these parameters during the system operation, the system was programmed in such a way as to configure them based on a specific client command that was sent from the server.

The software also allows for remote updating—OTA (Over-The-Air). The device periodically checks the server, and when a new software version is available, it downloads the update file. Then, at a convenient moment, the device switches into bootloader mode and performs the update. With such functionality, the device entirely fits into the Internet of Things concept, allowing for complete remote management of the system and making any changes to the software without any hardware interference. The software architecture, based on the above tools is presented in Figure 5.

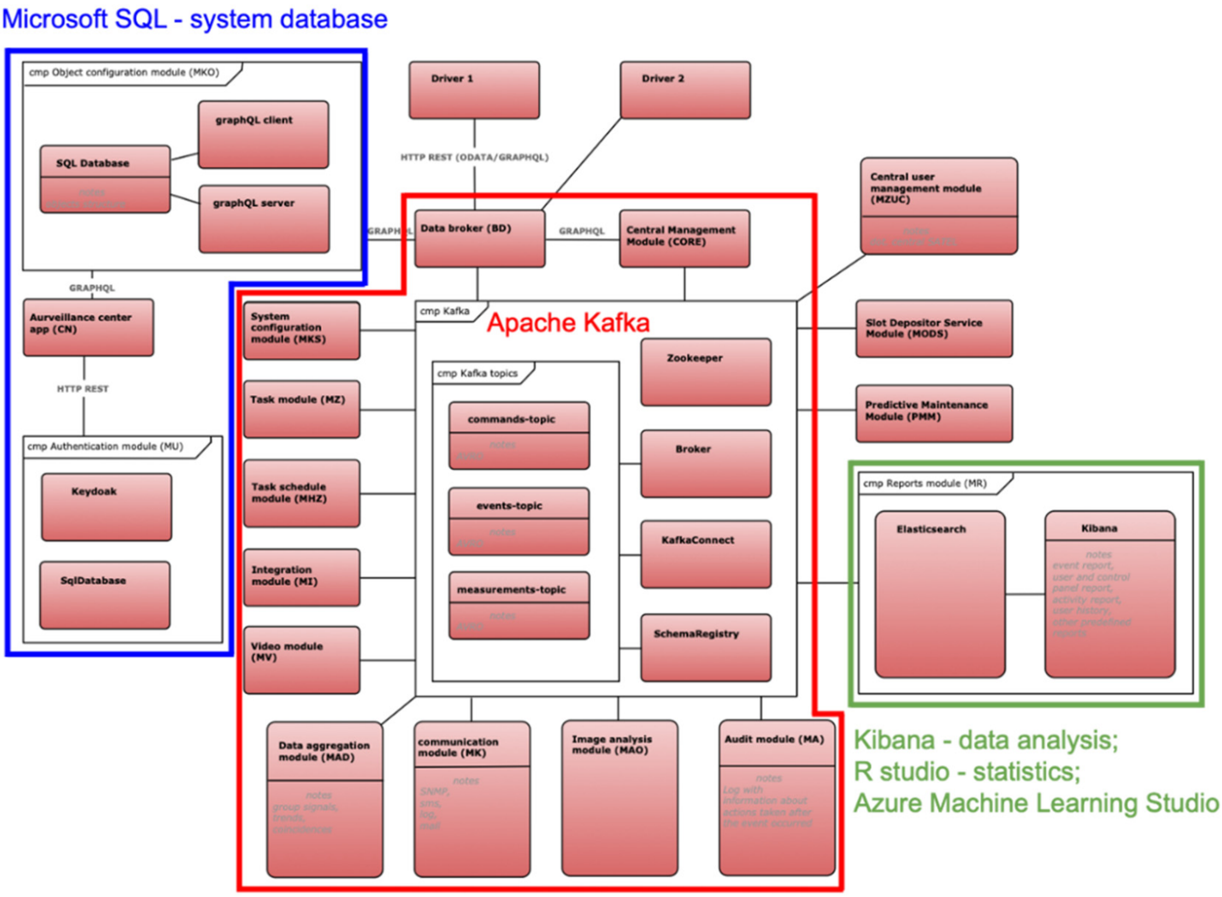


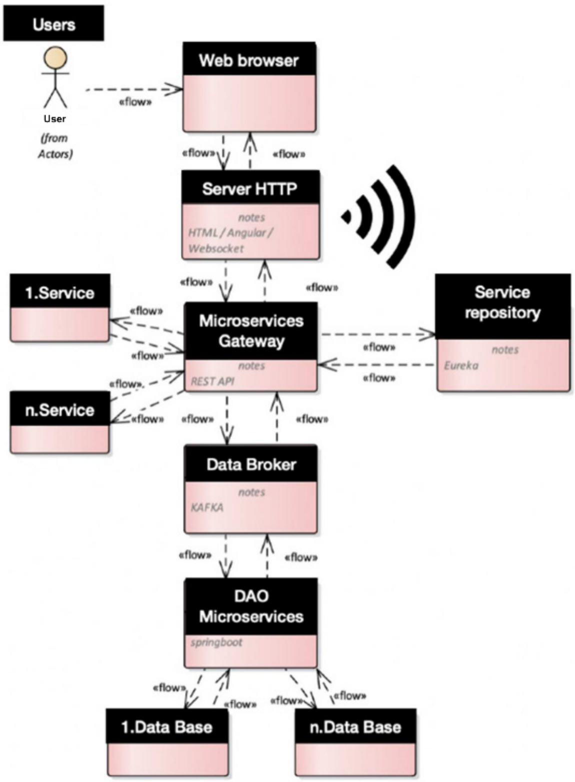
Figure 5. Software architecture of the proposed system.

4.4. System Algorithms

The system key algorithms were developed, including a big bag targeting algorithm for a probe placement (Figure 6), a probe data-acquisition algorithm, and the reader localization algorithm based on communication modules.

The measurement probe is integrated with the software system by wireless connection. It allows to send the measurement to the server or receive updates from the server. Figure 6 shows the integration between the hardware and software modules.

Ultimately, all the above-mentioned elements are integrated to create a fully functional prototype of the system. Then begins the last stage of research, i.e., testing the prototype. The tests and evaluation of the obtained measurement results were as follows, as presented in the Sections 5 and 6.



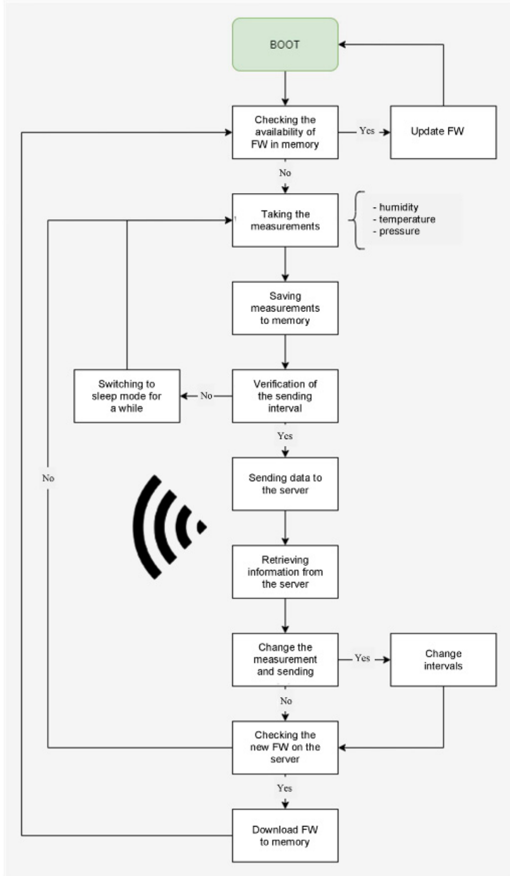


Figure 6. Algorithm for the operation of the central unit of the measurement module.

5. Results

As part of the system tests, the required backend services were implemented, and communication with external services, including Microsoft Azure, was ensured. The task also included the implementation of big bag targeting algorithms and integration tests. The data come from a pilot study based on a single prototype measurement device used multiple times in transport sets at different contractors between June and September 2021. A total of 26-time series were collected, i.e., the prototype was placed in 26 different transport sets for two consecutive days. The prototype recorded parameters like humidity, pressure and temperature every 15 min during this period. The 26 sets were carried out by five contractors. The primary goal of performing the pilot study was to confirm the possibility of collecting actual data in non-laboratory conditions and, on their basis, to describe (build the characteristics of) the issue quantitatively. The resulting global descriptive statistics are presented as box plots. To show precise values, the table form is introduced, apart from box plots. Table 1 and Figures 7–9 show the global values of selected parameters. On the other hand, Table 2 and Figures 10–12 show selected parameters for individual contractors.

Table 1. Summary statistics for temperature, humidity and pressure globally for all 26-time series.

	Temperature [°C]	Humidity [%]	Tension [Pa]
Minimum	6.50	15.03	10,295,001
1st quartile	16.98	18.86	10,297,708
Median	19.25	20.04	10,300,330
Mean	20.13	20.12	10,319,435
3rd quartile	21.73	21.26	10,302,964
Maximum	46.38	25.98	10,803,336

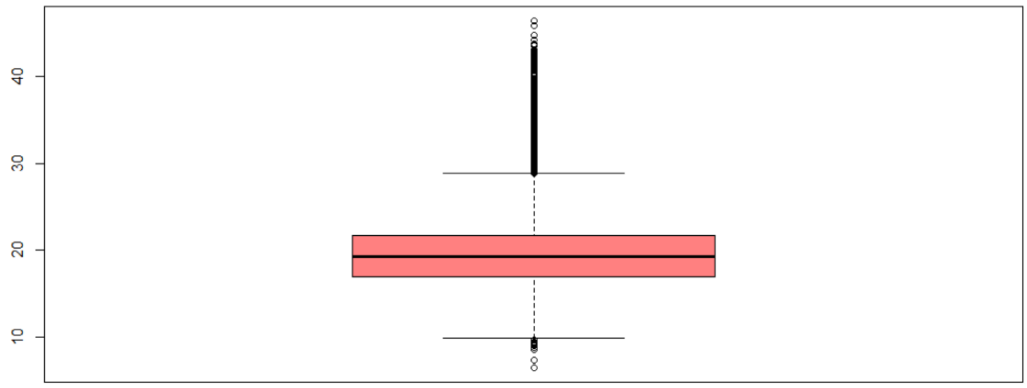


Figure 7. Box plot for temperature (degrees Celsius) globally (for all 26 time series). Temperatures in (°C): minimum 6.5, 1st quartile 16.98, median 19.25, mean 20.13, 3rd quartile 21.73, maximum 46.38.

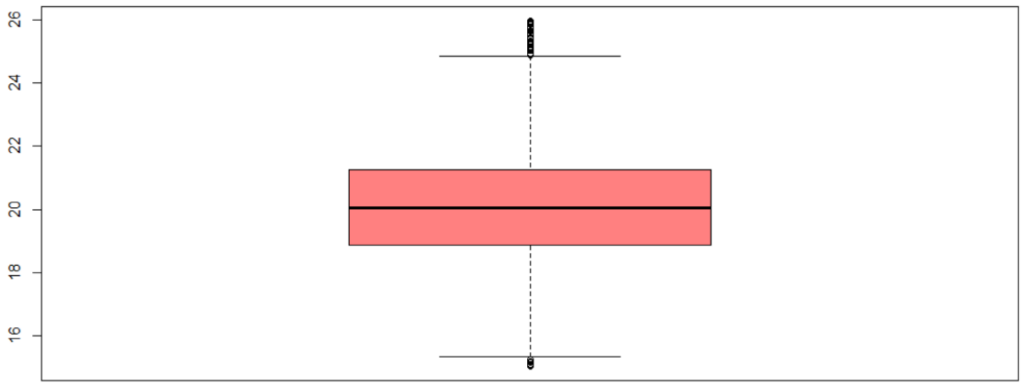


Figure 8. Box plot for humidity (%) globally (for all 26 time series). Humidity in (%): minimum 15.03, 1st quartile 18.86, median 20.04, mean 20.12, 3rd quartile 21.26, maximum 25.98.

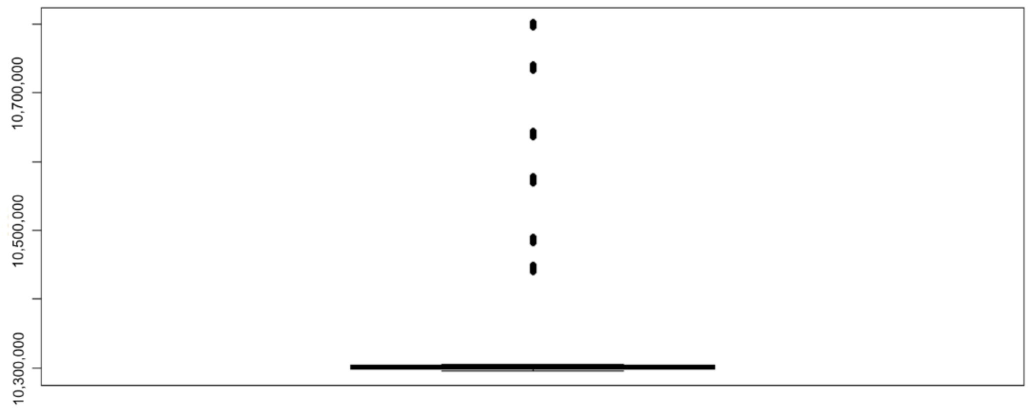


Figure 9. Box plot for pressure (Pa) globally (for all 26 time series). Pressure in (Pa): minimum 10,295,001, 1st quartile 10,297,708, median 10,300,330, mean 10,319,435, 3rd quartile 10,302,964, maximum 10,803,336.

Table 2. Summary statistics for temperature, humidity and pressure for the different contractors (kontr).

	kontr_1	**kontr_2**	**kontr_3**	**kontr_4**	**kontr_5**
			Temperature (°C)		
Minimum	8.52	10.02	9.12	a.l.w.	6.50
1st quartile	16.89	17.04	16.91	16.65	17.82
Median	19.17	19.43	18.63	19.48	19.98
3rd quartile	21.55	21.60	20.79	22.10	22.55
Maximum	41.07	46.38	38.35	32.41	43.53
			Humidity (%)		
Minimum	a.l.w.	a.l.w.	15.03	25.98	a.l.w.
1st quartile	18.20	19.03	19.06	19.17	18.97
Median	19.41	20.21	20.12	20.26	20.08
3rd quartile	20.84	21.46	21.14	21.52	21.16
Maximum	b.u.w.	25.98	b.u.w.	b.u.w.	b.u.w.
			Tension (Pa)		
Minimum	a.l.w.	a.l.w.	a.l.w.	a.l.w.	a.l.w.
1st quartile	10,298,662	10,298,217	10,298,851	10,289,864	10,294,439
Median	10,301,026	10,301,277	10,301,153	10,300,994	10,302,083
3rd quartile	10,302,364	10,305,138	10,302,319	10,304,735	10,307,376
Maximum	b.u.w.	10,741,059	10,446,672	10,803,336	10,666,239

b.u.w.—below upper whisker boundary of the box plot; a.l.w.—above lower whisker boundary of the box plot.

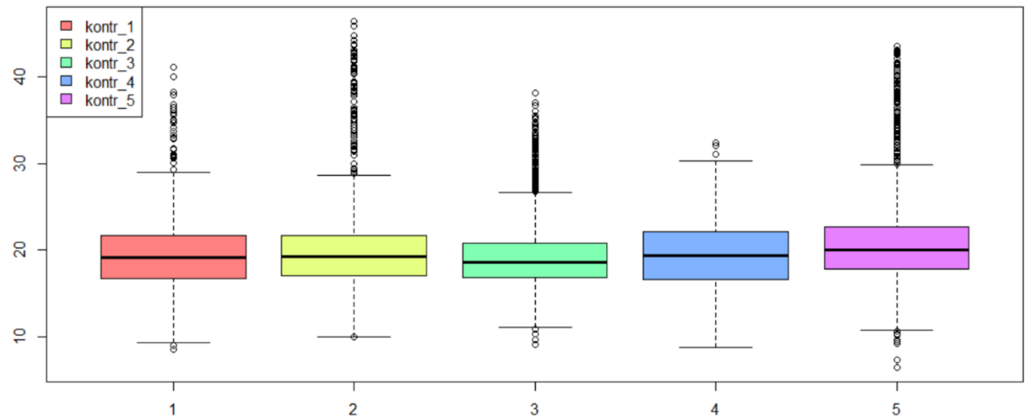


Figure 10. Temperature by contractor.

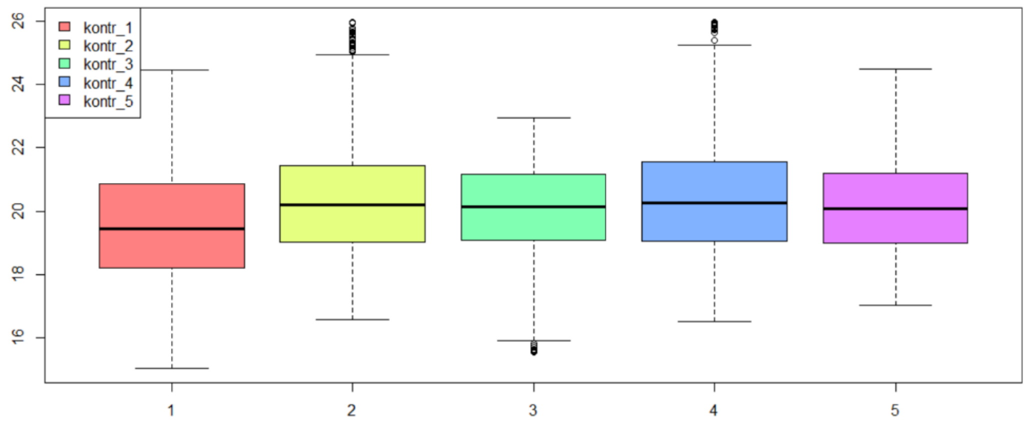


Figure 11. Humidity content by contractor.

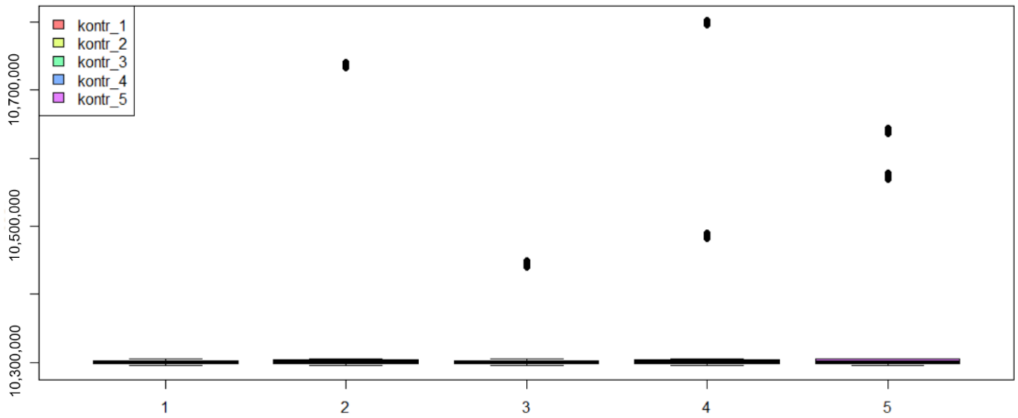


Figure 12. Pressure by contractor.

The resulting global descriptive statistics are presented as box plots. The mean temperature that was recorded in the shipping bags (Figure 7, Table 1) was 20.13 degrees Celsius, with the measurement showing a fairly small scatter around the mean (1st and 3rd quartiles were 16.98 and 21.73, respectively).

Figure 8 shows many deviating values for measurements above 30 degrees Celsius. From the information that was provided by the expert, it is known that it is extremely dangerous to expose big bags to temperatures exceeding 40 degrees. Below (Figure 8, Table 1), a similar graph for humidity is presented. The average humidity oscillated around 20%. There were no abnormally high extreme cases in the range of humidity measurements.

According to the obtained expert knowledge, a moisture content of 26% is acceptable. In contrast to the previously discussed parameters, the measured pressure significantly exceeds the standards. Figure 9 (Table 1) shows the distribution of measurements for pressure. The mean value and the first and third quartiles are very close (at 10.3 MPa) to the outliers (between 10.5 MPa and 11 MPa). A significant outlier for a pressure measurement could mean that the pressure was measured when another shipping bag was placed on top of the shipping bag with the prototype. This type of arrangement is often used by companies but is very detrimental to the quality of the raw material being transported.

Table 2 presents statistical data from the collected measurements for individual contractors. From their base, the anomaly in the process of storage can be identified.

Figure 10 shows the box plots by contractor. Similar to the global statistics, the outliers do not strongly deviate from the central tendencies' values. However, it can be noted that the (minor) deviations, if any, are characteristic of only two counterparties, i.e., 2 and 4.

Regarding the temperature by contractor (Figure 11), two, in particular, should also be considered, i.e., the second and fifth contractors have significantly more temperature measurements in the ranges above 30 or even 40 degrees Celsius. As has been already mentioned, high temperature is the factor that causes the deterioration of raw material quality.

In the case of pressure (Figure 12), only contractor 1 did not have a significant overpressure. The remaining partners must have transported or stored the bags in a non-compliant manner, with contractors 5 and 4 doing so twice.

Automation of conclusions based on the collected information about the studied phenomenon (distributions for parameters, such as pressure, temperature, humidity) and the obtained expert knowledge allow the creation of an advisory system prototype indicating how to manage measuring devices.

6. Discussion

The analysis of the obtained results and their interpretation was supported by expert knowledge that was provided by the quality control employee. His heuristic knowledge allowed him to interpret the measured values of selected parameters. The average temperature recorded in the transport bags (Figure 7, Table 1) was 20.13 degrees Celsius, and the measurement had a fairly small dispersion around the mean (respectively, the first and third quartiles were 16.98 and 21.73). The best condition for storing fertilizers is a warehouse with adequate ventilation, where the temperature inside is in the range of 5 to 20 degrees C. The outliers are the temperature values above 30 degrees Celsius. According to the information that is provided by the expert, it is extremely dangerous to expose big bags to temperatures above 40 degrees. It follows that many contractors do not comply with the temperature storage requirements of fertilizers, instead keeping the wrong temperature in the warehouse. A similar diagram is presented for humidity in Figure 8 and Table 1. The requirements for warehouses with controlled air humidity require keeping the air humidity below 50%. This allows to avoid the growth of bacteria and the formation of lumps in the big bag. The average humidity fluctuated around 20%. In terms of humidity measurements, there were no cases of abnormally high, extreme values. According to the expert knowledge, a humidity of 26% is acceptable. Contrary to the previously discussed parameters, the measured pressure significantly exceeds the norm. Figure 9 (Table 1) shows the distribution of pressure measurements. The mean value and the first and third quartiles are very similar (at 10.3 MPa) to the outliers (between 10.5 MPa and 11 MPa). A significant outlier for the pressure measurement may indicate that the pressure was measured when another shipping bag was placed on top of the probe shipping bag. Double big bags with fertilizer weighing more than 500 kg should be stored in one layer at most. Nevertheless, this type of storage system is often used by companies but has a very negative effect on the quality of the transported raw material. In the case of detailed analyzes of individual contractors, the system also offers the possibility of assessing the quality of storage. In the case of the fertilizer storage temperature by individual contractors (Figure 10), two of them, in particular, should be taken into account, i.e., contractors 2 and 5, where many more temperature measurements were recorded in the range above 30 or even 40 degrees Celsius. As already mentioned, high temperature is a factor causing the deterioration of the raw material's quality. Figure 11 presents humidity box plots for individual contractors. As in global statistics, the outliers do not differ significantly from the values of central tendencies. However, it can be seen those (slight) deviations, if any, are specific to only two counterparties, i.e., 2 and 4. In the case of pressure (Figure 12), only contractor 1 had no significant overpressure. The other partners had to transport or store the bags in a non-compliant manner, with contractors 5 and 4 doing so twice.

Based on the obtained detailed measurement results of the indicated parameters proving the quality of transport, storage and warehousing by contractors of fertilizers, general conclusions were formulated, as presented below.

7. Conclusions

The obtained characteristics are to be used to determine the principles of detecting undesirable phenomena in general and the potential fraud of individual contracts; for example, those who would like to extort additional deliveries, e.g., as part of a complaint, and who store the materials incorrectly. This gives the opportunity to estimate trends in the activities of the fertilizer supplier, optimize contracting, transport, etc. The next step is to automate the inference based on the collected information about the phenomenon under study. The distribution of parameters, such as pressure, temperature, humidity and successively obtained expert knowledge allow for the creation of a prototype of a consulting system that shows how to manage the transport of materials, not only fertilizers, in the future.

There is no similar solution implemented in the Polish market in terms of monitoring environmental parameters. The possibility of simultaneously monitoring 10,000 big bags in at least 30 locations is competitive on the global markets, where, for example, tracking a fleet of delivery vehicles (a service that is offered by Elatec RFID System) comprises a maximum of several hundred cars simultaneously (however, in this case, it is not monitoring of the big bags themselves, but only their means of transport). Another example is the AssetGather solution from the US, which monitors the inventory by placing RFID sensors on it. The system has no indicated limitation of the number of monitored sensors, but it is in one physical location (without the possibility of tracking packages "on the move"). This technology also makes it possible to increase the percentage of big bags in the nitrogen industry (Anwil S.A.) and calcium industry (Polcalc sp. z o.o.) that are "saved" from calcification and destruction, resulting from the detection of unacceptable conditions to which they are exposed. It was found that in the mentioned industries, the complaint rate is 2–3%. The presented system gives a 95% probability of detecting anomalies in transport and location at the distributor.

Other successful competitive advantages that are achieved include:

1. Autonomy—fully autonomous operation without external power sources or wired communication;
2. Modularity—the ultra-compact design; the rich, versatile equipment, and interface configuration; and the autonomous operation allow the creation of flexible measurement systems while maintaining all the key features of professional measurement stations;
3. IoT (Internet of Things)—compliance with all leading IoT standards allows to select the optimal wireless communication depending on customer needs and local conditions of the system;
4. Data security—data encryption in radio communication is based on the AES-256 standard, which means a 256-bit encryption key, virtually unbreakable by today's computers.

Even though the project is dedicated to the chemical industry, especially fertilizers, the developed system structure is universal enough to enable the central management of quality tests and the disclosure of improper transport or storage of other raw materials and loose materials. Thanks to the built-in machine learning and data analysis mechanisms, the system uses the minimum number of measuring stations, ensuring statistical significance and model effectiveness. The system enables an in-depth analysis of the product life cycle from loading at the factory to hand-over to the end-user. The system also replaces the common random checks of transshipment points and manual sampling for parameter testing, and the manual measurement of environmental conditions. In addition, it provides monitoring of the transport bags themselves. Such a set of functionalities does not currently exist in any solution in the field of monitoring environmental parameters.

Author Contributions: Formal analysis, A.B. and S.P.; Methodology, M.G.; Software, M.G.; Supervision, M.G. and A.B.; Visualization, M.G.; Writing—review & editing, T.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by grant in accordance with the Project implemented under the Smart Growth Operational Programme 2014–2020, Measure 1.3: R & D works financed with the participation of capital funds, Sub-measure 1.3.1: Support for research and development projects in the preseed phase by proof of concept funds–BRIdge Alfa.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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

References

1. Clerici Maestosi, P. Smart Cities and Positive Energy Districts: Urban Perspectives in 2020. *Energies* **2022**, *15*, 2168. [CrossRef]
2. Ahvenniemi, H.; Huovila, A.; Pinto-Seppä, I.; Airaksinen, M. What are the differences between sustainable and smart cities? *Cities* **2017**, *60*, 234–245. [CrossRef]
3. Hancke, G.P.; Ce Silva, B.D.; Hancke, G.P., Jr. The Role of Advanced Sensing in Smart Cities. *Sensors* **2013**, *13*, 393–425. [CrossRef] [PubMed]
4. Perić, K.; Šimić, Z.; Jurić, Ž. Characterization of Uncertainties in Smart City Planning: A Case Study of the Smart Metering Deployment. *Energies* **2022**, *15*, 2040. [CrossRef]
5. Patrão, C.; Moura, P.; de Almeida, A.T. Review of Smart City Assessment Tools. *Smart Cities* **2020**, *3*, 1117–1132. [CrossRef]
6. Sharifi, A. A critical review of selected smart city assessment tools and indicator sets. *J. Clean. Prod.* **2019**, *233*, 1269–1283. [CrossRef]

7. Dudek, T.; Dzhuguryan, T.; Wiśnicki, B.; Pędziwiatr, K. Smart Sustainable Production and Distribution Network Model for City Multi-Floor Manufacturing Clusters. *Energies* **2022**, *15*, 488. [CrossRef]
8. Productive 4.0. Available online: https://productive40.eu/about/ (accessed on 1 July 2020).
9. Strulak-Wójcikiewicz, R.; Bohdan, A. The concept of an e-platform cooperation model in the field of 3D printing during the COVID-19 pandemic. *Procedia Comput. Sci.* **2021**, *192*, 4083–4092. [CrossRef]
10. Halme, J.; Jantunen, E.; Hästbacka, D.; Hegedu, C.; Varga, P.; Björkbom, M.; Mesiä, H.; More, R.; Jaatinen, A.; Barna, L.; et al. Monitoring of production processes and the condition of the production equipment through the internet. In Proceedings of the 6th International Conference on Control, Decision and Information Technologies (CoDIT), Paris, France, 23–26 April 2019; pp. 1295–1300.
11. Kozma, D.; Varga, P.; Hegedu, C. Supply Chain Management and Logistics 4.0—A Study on Arrowhead Framework Integration. In Proceedings of the 8th International Conference on Industrial Technology and Management (ICITM), Cambridge, UK, 2–4 March 2019; pp. 12–16.
12. Soós, G.; Kozma, D.; Janky, F.N.; Varga, P. IoT device lifecycle—A generic model and a use case for cellular mobile networks. In Proceedings of the 2018 IEEE 6th International Conference on Future Internet of Things and Cloud (FiCloud), Barcelona, Spain, 6–8 August 2018; pp. 176–183.
13. Lom, M.; Pribyl, O.; Svitek, M. Industry 4.0 as a part of smart cities. In Proceedings of the 2016 Smart Cities Symposium Prague (SCSP), Prague, Czech Republic, 26–27 May 2016.
14. Kusiak, A. Smart manufacturing. *Int. J. Prod. Res.* **2018**, *56*, 508–517. [CrossRef]
15. Ivanov, D.; Tang, C.S.; Dolgui, A.; Battini, D.; Das, A. Researchers' perspectives on Industry 4.0: Multi-disciplinary analysis and opportunities for operations management. *Int. J. Prod. Res.* **2020**, *59*, 2055–2078. [CrossRef]
16. Frazzon, E.M.; Agostino, I.R.S.; Broda, E.; Freitag, M. Manufacturing networks in the era of digital production and operations: A socio-cyber-physical perspective. *Annu. Rev. Control.* **2020**, *49*, 288–294. [CrossRef]
17. Dzhuguryan, T.; Deja, A.; Wiśnicki, B.; Jóźwiak, Z. The Design of sustainable city multi-floor manufacturing processes under uncertainty in supply chains. *Sustainability* **2020**, *12*, 9439. [CrossRef]
18. Lorenzen, M.; Frederiksen, L.; Cooke, P.; Lazzeretti, L. Why do cultural industries cluster? Localization, urbanization, products and projects. In *Creative Cities, Cultural Clusters and Local Economic Development*; Edward Elgar Publishing: Cheltenham, UK, 2013; pp. 155–179.
19. Deja, A.; Dzhuguryan, T.; Dzhuguryan, L.; Konradi, O.; Ulewicz, R. Smart sustainable city manufacturing and logistics: A framework for city logistics node 4.0 operations. *Energies* **2021**, *14*, 8380. [CrossRef]
20. Sarkis, J.; Zhu, Q. Environmental sustainability and production: Taking the road less travelled. *Int. J. Prod. Res.* **2018**, *56*, 743–759. [CrossRef]
21. Zulkifli, C.Z.; Abdulla, R.M.; Ismail, W.; Rahman, M.G. Wireless mesh network in integrated web base monitoring systems for production line automation. In Proceedings of the First International Joint Conference, SPIT 2011 and IPC 2011, Amsterdam, The Netherlands, 1–2 December 2011; Springer: Berlin/Heidelberg, Germany, 2011; pp. 7–15.
22. Martín, M.P.; Asensio, C.M.; Nepote, V.; Grosso, N.R. Improving Quality Preservation of Raw Peanuts Stored under Different Conditions During a Long-Term Storage. *Eur. J. Lipid Sci. Technol.* **2018**, *120*, 1800150. [CrossRef]
23. Zhelobkova, M.O.M.; Stankevych, G.N. Practical questions for silo bags grain storage technology. *Grain Prod. Mix. Fodd.* **2019**, *19*, 10–16. [CrossRef]
24. Matičević, G.; Lovrić, T.; Čičak, M. *Using ERP System to Improve Internal Supply Chain Coordination*; University Osijek, Mechanical Engineering Faculty: Slavonski Brod, Croatia, 2011; Volume 4, pp. 11–21.
25. Gandhewar, R.; Gaurav, A.; Kokate, K.; Khetan, H.; Kamat, H. Cloud Based Framework for IIOT Application with Asset Management. In Proceedings of the 3rd International Conference on Electronics and Communication and Aerospace Technology (ICECA), Coimbatore, India, 12–14 June 2019. [CrossRef]
26. Zare-Mehrjerdi, Y. RFID and its benefits: A multiple case analysis. In *Assembly Automation*; Emerald: Bingley, UK, 2011; Volume 31, pp. 251–262.
27. Liukkonen, M. RFID Technology in Manufacturing and Supply Chain. *Int. J. Comput. Integr. Manuf.* **2015**, *28*, 861–880. [CrossRef]
28. Lee, D.; Park, J. RFID-enabled supply chain traceability: Existing methods, applications and challenges: Sustainable radio frequency identification solutions. In Proceedings of the INTECH 2010, Prague, Czech Republic, 14–16 September 2010; pp. 51–68.
29. Gandino, F.; Montrucchio, B.; Rebaudengo, M.; Sanchez, E.R. Analysis of an RFID-Based information system for tracking and tracing in an agri-food chain. In Proceedings of the IEEE 1st Annual RFID Eurasia, Istanbul, Turkey, 5–6 September 2007; pp. 1–6.
30. Yoo, S.; Kim, S.; Kim, E.; Jung, E.; Lee, K.H.; Hwang, H. Real-time location system-based asset tracking in the healthcare field: Lessons learned from a feasibility study. *BMC Med. Inform. Decis. Mak.* **2018**, *18*, 80. [CrossRef]
31. Tan, G.; Fang, Y.; Meng, Y. Research on the remote monitoring system for chemical raw materials in storage tank based on ARM embedded system. *Chem. Eng. Trans.* **2017**, *62*, 757–762. [CrossRef]
32. Lee, C.K.M.; Ip, C.M.; Park, T.; Chung, S.Y. A bluetooth location-based indoor positioning system for asset tracking in warehouse. In Proceedings of the IEEE International Conference on Industrial Engineering and Engineering Management 2019, Macao, China, 15–19 December 2019; pp. 1408–1412. [CrossRef]
33. He, W.; Xi, M.; Gardner, H.; Swift, B.; Adcock, M. Spatial anchor based indoor asset tracking. In Proceedings of the IEEE Virtual Reality and 3D User Interfaces (VR), Lisboa, Portugal, 27 March–1 April 2021; pp. 255–259. [CrossRef]

34. Frankó, A.; Vida, G.; Varga, P. Reliable identification schemes for asset and production tracking in Industry 4.0. *Sensors* **2020**, *20*, 3709. [CrossRef]
35. DIN Standards. *Reference Architecture Model Industrie 4.0 (RAMI4.0)*; DIN SPEC 91345: Berlin, Germany, 2016.
36. Kozma, D.; Soos, G.; Varga, P. Supporting digital production, product lifecycle and supply chain management in Industry 4.0 by the arrowhead framework—A survey. In Proceedings of the IEEE International Conference on Industrial Informatics (INDIN), Helsinki, Finaland, 22–25 July 2019.
37. Barreto, L.; Amaral, A.; Pereira, T. Industry 4.0 implications in logistics: An overview. *Procedia Manuf.* **2017**, *13*, 1245–1252.
38. Perez-Guirao, M.D.; Kull, B.; Luediger, H. An ultra-wideband approach towards autonomous radio control and positioning systems in manufacturing & logistics processes. In Proceedings of the 4th Workshop on Positioning, Navigation and Communication, Hannover, Germany, 22 March 2007.
39. Asil, O.; Foad, M.P.; Dursun, D.; Leva, K.S. An RFID network design methodology for asset tracking in healthcare. *Decis. Support Syst.* **2010**, *49*, 100–109.
40. Ullo, S.L.; Sinha, G.R. Advances in IoT and Smart Sensors for Remote Sensing and Agriculture Applications. *Remote Sens.* **2021**, *13*, 2585. [CrossRef]
41. Ayaz, M.; Ammad-Uddin, M.; Sharif, Z.; Mansour, A.; Aggoune, E.-H.M. Internet-of-Things (IoT)-based smart agriculture: Toward making the fields talk. *IEEE Access* **2019**, *7*, 7, 129551–129583. [CrossRef]
42. Marcu, I.; Voicu, C.; Drăgulinescu, A.M.C.; Fratu, O.; Suciu, G.; Balaceanu, C.M.; Andronache, M.M. Overview of IoT basic platforms for precision agriculture. In *Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering*; Springer International Publishing: Berlin/Heidelberg, Germany, 2019; Volume 283, pp. 124–137.
43. Doshi, J.; Patel, T.; Bharti, S.K. Smart farming using IoT, a solution for optimally monitoring farming conditions. *Procedia Comput. Sci.* **2019**, *160*, 746–751. [CrossRef]
44. Arias, M.; Campo-Bescós, M.Á.; Álvarez-Mozos, J. Crop classification based on temporal signatures of Sentinel-1 observations over Navarre province, Spain. *Remote. Sens.* **2020**, *12*, 278. [CrossRef]
45. Nellis, M.D.; Price, K.P.; Rundquist, D. *Remote Sensing of Cropland Agriculture*; SAGE Publications: Thousand Oaks, CA, USA, 2013; pp. 368–382.
46. Syrový, T.; Vik, R.; Pretl, S.; Syrová, L.; Čengery, J.; Hamáček, A.; Kubáč, L.; Menšík, L. Fully printed disposable IoT soil moisture sensors for precision agriculture. *Chemosensors* **2020**, *8*, 125. [CrossRef]
47. Shafi, U.; Mumtaz, R.; García-Nieto, J.; Hassan, S.A.; Zaidi, S.A.R.; Iqbal, N. Precision agriculture techniques and practices: From considerations to applications. *Sensors* **2019**, *19*, 3796. [CrossRef]
48. Fisher, D.K.; Woodruff, L.K.; Anapalli, S.S.; Pinnamaneni, S.R. Open-source wireless cloud-connected agricultural sensor network. *J. Sens. Actuator Netw.* **2018**, *7*, 47. [CrossRef]
49. Lu, B.; Dao, P.; Liu, J.; He, Y.; Shang, J. Recent advances of hyperspectral imaging technology and applications in agriculture. *Remote Sens.* **2020**, *12*, 2659. [CrossRef]
50. Piikki, K.; Söderström, M.; Eriksson, J.; John, J.M.; Muthee, P.I.; Wetterlind, J.; Lund, E. Performance evaluation of proximal sensors for soil assessment in smallholder farms in Embu County, Kenya. *Sensors* **2016**, *16*, 1950. [CrossRef] [PubMed]
51. Elahi, H.; Munir, K.; Eugeni, M.; Atek, S.; Gaudenzi, P. Energy harvesting towards self-powered IoT devices. *Energies* **2020**, *13*, 5528. [CrossRef]
52. Hassan, R.; Qamar, F.; Hasan, M.K.; Aman, A.H.M.; Ahmed, A.S. Internet of Things and its applications: A comprehensive survey. *Symmetry* **2020**, *12*, 1674. [CrossRef]
53. Sinha, G.R. *Advances in Modern Sensors—Physics, Design, Simulation and Applications*; IOP Publishing: Bristol, UK, 2020.
54. Vasisht, D.; Kapetanovic, Z.; Won, J.; Jin, X.; Chandra, R.; Kapoor, A.; Sinha, S.N.; Sudarshan, M.; Stratman, S. Farmbeats: An IoT platform for data-driven agriculture. In Proceedings of the 14th USENIX Symposium on Networked Systems Design and Implementation (NSDI '17), Boston, MA, USA, 27–29 March 2017; pp. 515–529.
55. Aggarwal, N.; Singh, D. Technology assisted farming: Implications of IoT and AI. In Proceedings of the 1st International Conference on Computational Research and Data Analytics (ICCRDA 2020), Rajpura, India, 24 October 2020; IOP Publishing: Bristol, UK, 2021; Volume 1022.
56. Lakshmisudha, K.; Hegde, S.; Kale, N.; Iyer, S. Smart precision-based agriculture using sensors. *Int. J. Comput. Appl.* **2016**, *146*, 36–38. [CrossRef]
57. Suanpang, P.; Jamjuntr, P. A smart farm prototype with an Internet of Things (IoT) case study: Thailand. *J. Adv. Agric. Technol.* **2019**, *6*, 241–245. [CrossRef]
58. Zhang, D.; Wei, B. Smart sensors and devices in artificial intelligence. *Sensors* **2020**, *20*, 5945. [CrossRef]
59. Madushanki, A.R.; Halgamuge, M.N.; Wirasagoda, W.S.; Syed, A. Adoption of the Internet of Things (IoT) in agriculture and smart farming towards urban greening: A review. *Int. J. Adv. Comput. Sci. Appl.* **2019**, *10*, 11–28. [CrossRef]
60. Sishodia, R.P.; Ray, R.L.; Singh, S.K. Applications of remote sensing in precision agriculture: A review. *Remote. Sens.* **2020**, *12*, 3136. [CrossRef]
61. Lakhankar, T.; Krakauer, N.; Khanbilvardi, R. Applications of microwave remote sensing of soil moisture for agricultural applications. *Int. J. Terraspace Sci. Eng.* **2009**, *2*, 81–91.
62. Ruan, J.; Jiang, H.; Zhu, C.; Hu, X.; Shi, Y.; Liu, T.; Rao, W.; Chan, F.T. Agriculture IoT: Emerging trends, cooperation networks, and outlook. *IEEE Wirel. Commun.* **2019**, *26*, 56–63. [CrossRef]