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PotatoScanner – Transmission of wireless sensor data for Smart Farming application illustrated by the determination of drought stress of potato plants

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Sustainable management of agricultural land requires the accurate collection of information about the condition of plants and the environment in which they grow. The term "Smart Farming" refers to technologies that can collect, evaluate and apply this information. In the following the PotatoScanner is presented which is able to collect and evaluate environmental data in the field. As an application example, the surface temperature of plants is recorded. With this parameter a determination of the drought stress of plants can be performed. In addition, the PotatoScanner is able to retrieve and store measurement data from other sensors in the field. This allows the collection of sensor data of infield sensors without the availability of a suitable transmission link, e.g., by a cellular network. This situation is created by the lack of investment from German cellphone operators on building up and operating cellular networks in rural areas. The PotatoScanner is able to compensate for this deficit, which enables the use of sensor technology in areas where no cellphone network is available. After the description of the system, an evaluation over two seasons is presented. Furthermore, it is shown which possibilities for infield data transmission exist and which environmental influences have to be considered during operation.

Keywords
Smart Farming, wireless data transmission, surface temperature of leaves, drought stress, potatoes

In recent years, the digitization has increasingly influenced todays agricultural processes. It has the potential to be integrated in every individual work step, to monitor the quality of the produced food and to document the route of the goods from the producer to the consumer. On field, sensors can record various growth variables, such as temperature, soil moisture or water content of the soil and air humidity, and thus provide the farmer with information of growth factors for his field. This data opens up the possibility of supporting plant growth with targeted crop management measures. At the same time, prediction systems for the occurrence of pests can be developed which, for example, allow resource-saving plant protection by calculating the start of infestation and making recommendations for subsequent treatment dates.

For all these tasks, the broadest possible database is needed. The more detailed and precise the collected data is, the more meaningful are the resulting recommendations for action. In addition to the actual collection, the transmission of data from the field to a central server for their prompt evaluation is necessary. For this purpose, the use of a mobile phone network is most often considered.

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However, the expansion of these networks, especially in rural areas, is proceeding very slowly, since the respective network provider has to invest a lot of money, but the expected profits are only minimal due to the low population density.

The PotatoScanner described in this article is an approach to solve the two challenges just described, the collection of as much data as possible and its transmission to a central location for evaluation (backend).

The data is collected by means of stationary sensor nodes installed in the field, which record, for example, temperature and soil moisture. On the other hand, a field sprayer was equipped with temperature sensors to determine the surface temperature of the plants when driving over the field.

The transfer of all collected data is also done by the sprayer. It functions as a mobile data node to which the measured data of the stationary sensor nodes are transmitted by radio while driving over the field. The data stored in this way on the field sprayer can be transmitted to the central evaluation point via the WIFI network when returning to the farm.

In the following section the complete system of the PotatoScanner will be sketched to give an overview. Afterwards the single components are explained, starting with the hardware of the stationary sensor nodes. This is followed by a description of the software used and a more detailed analysis of the communication and the plant temperatures measured by the PotatoScanner in the growing seasons 2018 and 2019.

Overview

The PotatoScanner consists of a number of different independent systems, which are able to exchange data beyond their system boundaries. Figure 1 shows the complete system of the PotatoScanner. The labeling follows the data flow, starting with the small sensor nodes on the field (a) to the data sink on the yard (e). On the field, you can also see a tractor with a field sprayer, which has been modified to be able to record the surface temperature of the plants. The individual components have the following tasks:

(a) **Small sensor nodes**: The red dots on the field represent small sensor nodes, which are approximately the size of a potato. These nodes are able to continuously measure various variables (air temperature, air humidity, soil moisture or water content of the soil). The collected data is not stored locally on the node, but is transmitted by radio to the "collecting nodes" described in (b). The small sensor nodes are buried and distributed over the field.

(b) **Collecting nodes**: Within the communication range to the small sensor nodes are so-called collecting nodes. The measured values of the smaller sensor nodes are transmitted to these larger nodes, which are equipped with solar cells and rechargeable batteries. The larger size and energy budget enables persistent storage of all measured values. From here, an automatic transmission of the data to the field sprayer is possible if it is within range. In an emergency, the data can also be retrieved manually from the collecting node via a USB stick. The collecting nodes themselves can also be equipped with sensors, for example soil moisture sensors. Thanks to the available energy and storage resources, photos of the surrounding plants can also be taken to document their growth.

(c) **Field sprayer and mobile sensor node**: The field sprayer fulfils two functions. On the one hand, leaf surface temperatures can be recorded to estimate plant stress. On the other hand, the data stored on the collecting nodes (measured data of the small sensor nodes and measured data of the collecting nodes) can be automatically retrieved. The automatic transmission has the advantage of the data being reliably transmitted while passing the collecting nodes, thus minimizing human interaction with the system. This simplifies the use of the system and also ensures reliable and regular transmission of sensor data even if no mobile radio is available in the field. The sprayer was equipped with a GPS positioning system for the precise assignment of the measured leaf surface temperature to a plant location. During operation in practice, existing systems on the tractor itself could be used for this purpose (GPS is usually already available).

(d) **Tablet**: The tablet in the tractor is used to control the system and provides an additional data storage. On the tablet the measurement of the leaf surface temperatures is started by the driver. While driving, the system records the measured data and displays it visually on the tablet for the user. This makes it easy for the user to follow the progress of the measurement. However, an exact evaluation of the data is only done later, after the data has been transferred from the tablet to a backend service. In addition to storing the temperature data, the tablet also records the data received from the collecting nodes.

(e) **Farm**: The farm is the target of all data collected in the field. When the field sprayer arrives at the farm, the tablet automatically connects to the available WIFI network and uploads the data via the Internet to a backend server for further evaluation.

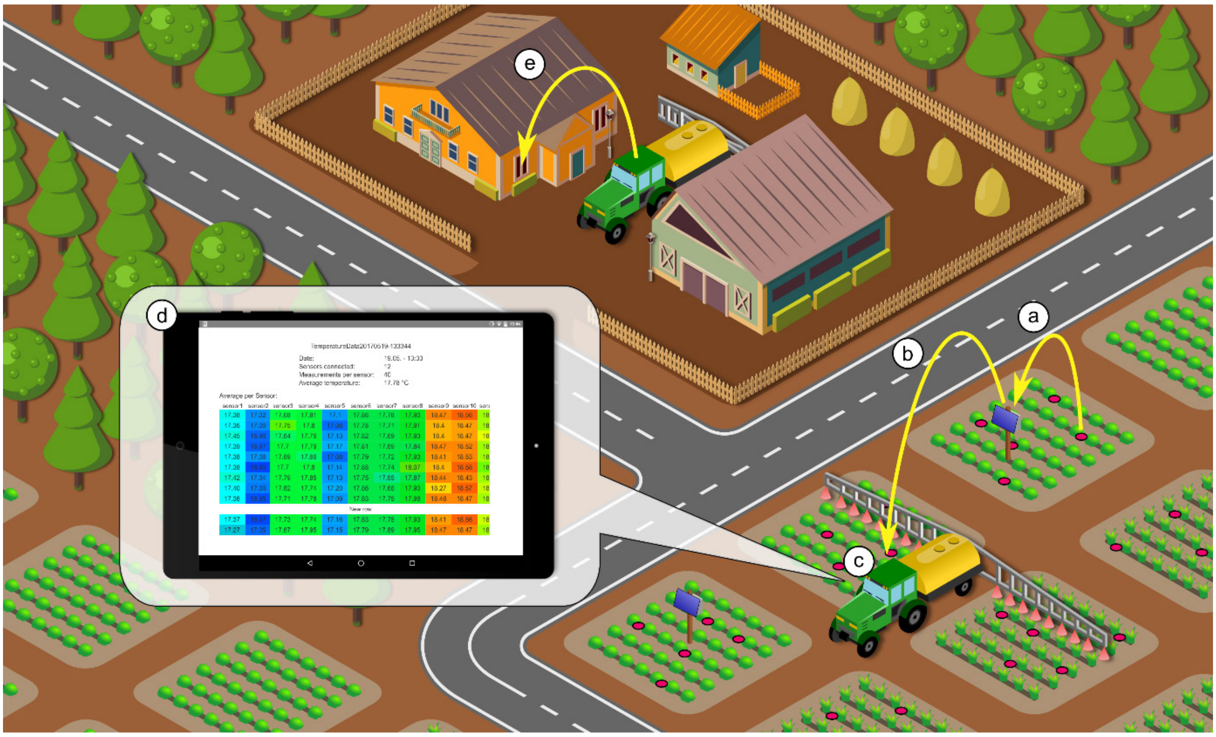

Figure 1: PotatoScanner overview: Data is collected at the small sensor nodes and transmitted to the collecting nodes as a first step (a). The measured values will be forwarded to the mobile sensor node, if the field sprayer with the mobile sensor node is in range (b). The field sprayer measures the leaf temperature of the potato plants (c). The collected leaf temperature is shown to the driver in real time (d). Upon reaching the farm all sensor data (including the data collected by the stationary nodes) is transmitted to a backend server by the tablet (e).

Hardware

Different hardware systems are used for the PotatoScanner. Each system is specially adapted to the respective tasks and should solve them as energy efficient and robust as possible. For the first step (a), the measurement of temperature and soil moisture, the INGA platform (Büsching et al. 2012) was used. The INGA is a small sensor node developed at the Institute for Operating Systems and Computer Networks (IBR) at the TU Braunschweig and has been modified for use in the field. Besides the microcontroller, it contains a real-time clock (RTC), a temperature and humidity sensor (SHT21, Sensirion, Switzerland) and a 433 MHz radio (RFM69HW, HopeRF, China). This made it possible to reduce the power consumption compared to the original INGA. The adjustment and the resulting reduction of energy consumption was necessary to allow the node to be used over a whole growing season. The RTC is used to wake the node up from its energy-saving stand-by state at regular intervals, so that the node can collect the measured data and transmit it to one (or more) collecting nodes.

The collecting nodes (b) consist of two parts, a low-power microcontroller and a Raspberry Pi (a single board computer developed by the Raspberry Pi Foundation, UK), which has a higher power consumption. The split allows the Raspberry Pi to be powered up selectively when more computing power is required by the node. Normally, however, this sub-component of the collecting node is switched off in order to reduce the power requirement. A charge controller is connected to the microcontroller, which can be used to charge a battery via an existing solar panel. In this way, the collecting node can be operated autonomously. Detailed information about the collecting node can be found in (Rottmann et al. 2016).

Two measurements of the small sensor nodes per hour were specified for the field tests. To ensure the transmission of the measured values to the collecting nodes, the Raspberry Pi was switched on for 5 minutes every 30 minutes. The small sensor nodes were woken up with a 2.5-minute offset to the start of the Raspberry Pi. This offset of the times is necessary to compensate for the increasing drift of the RTCs from real time. The RTCs and crystals were calibrated before the test setup, so that the offset is only about one second per week. This allows the clocks to drift from each other by up to 150 seconds, ensuring reliable operation throughout the season. The problem could also be solved by regularly synchronizing the clocks. A corresponding mechanism for time synchronization has been implemented for future experiments.

Figure 2 shows the mobile sensor node (c) mounted on the sprayer. This has a GPS, a Raspberry Pi and a battery for power supply. The Raspberry Pi is equipped with two additional WIFI antennas. One of them is used to establish a connection to the collecting nodes. The second antenna provides the tablet with a WIFI, which can be used to transmit control commands to the mobile node and exchange measurement data between the mobile node and the tablet.

To measure the leaf surface temperature, infrared temperature sensors (MLX90614, Melexis, Belgium) were mounted on one side of the 6 m long sprayer boom at a distance of 35 cm to each other. They measure the temperature at a frequency of 2 Hz. The data is collected on the mobile node of the sprayer and stored together with the GPS position on the mobile node.

The tablet (d) connects to the mobile node on the field sprayer as described above. In this way, control commands (start/stop of a measurement) can be transmitted to the mobile node. From the node itself, the tablet receives the measured leaf surface temperature data of the plants and also all the data retrieved from the collecting nodes. This means that the tablet stores all data collected in the field. For a successful transfer of these data to a backend, which automatically evaluates the measured data and makes it available to the farmer, only the tablet has to be taken along. A manual (and therefore error-prone) copying is not necessary. Alternatively, a direct transmission of the data from the tractor to the backend is possible, if the tractor connects to the WIFI network after reaching the farm.

Figure 2: Mobile node on the field sprayer. It contains a GPS, a Raspberry Pi, a rechargeable battery for power supply and a connection for the temperature sensors attached to the sprayer‘s traverse.

Software

The PotatoScanner consists of different subsystems which interact with each other and exchange data. One requirement of the system is a robust and reliable functionality. Therefore, the exchange of data must be as reliable as possible. Otherwise, for example, if not all data can be retrieved from the collecting nodes, the accuracy of the evaluation would be reduced. The recording of the measured leaf surface temperatures must also be ensured.

The data should be transmitted wirelessly between the individual components. However, such transmissions are error prone due to various interferences from other sources. For example, simultaneous transmissions influence each other. Multipath propagation, reflection and refraction make it difficult or even impossible for the receiver of the transmission to decode data from the receiving radio signal. Environmental influences change transmission characteristics and can reduce the range of the transmission.

For a reliable system, it is therefore necessary to minimize the effects of the mentioned (and possibly other) sources of error and to create mechanisms that take corrective action when errors occur. For the implementation of the PotatoScanner, therefore, delay tolerant network architectures, in the following referred to as “Delay Tolerant Networking” (DTN), (RFC4838 (Cerf et al., 2007)) and especially the bundle protocol (RFC5050 (Scott and Burleigh 2007)) was used. The bundle protocol can be used in networks in which no continuous end-to-end connection between subscribers is possible. It uses the so-called “Store-Carry-Forward” principle to transmit information to the destination by means of one or more intermediate stations (e.g. other sensor nodes). The data is stored at the respective intermediate station until a connection to the next station can be established. Particularly in very dynamic networks, where physical movement is present, which means that the subscriber does not know at which time which connections exist, data can still be transmitted from the transmitter to a receiver in this way. In relation to the scenario presented here and shown in Figure 1, the tractor with the sprayer and the tablet represents the dynamic component in the system. The data is first transferred to the collecting nodes where it is stored until the field sprayer comes into reach. From there the data is transferred to the field sprayer and is also stored on it until the data can be transmitted via a WIFI network to the backend when it arrives at the farm. The reliability of the system was further increased by redundant storage of the data on various collecting nodes.

IBR-DTN (Doering et al. 2008; Schildt et al. 2011) was used to transfer data from the collecting nodes to the field sprayer and from the field sprayer to the backend. IBR-DTN is an implementation of the bundle protocol, which was developed at the Institute for Operating Systems and Computer Networks (IBR) at the Technical University of Braunschweig. For example, the Android implementation was used on the tablet and the Linux implementation used on the sensor nodes.

User interface

The measurements of the sensor nodes and the transmission to the collecting nodes works automatically and does not need to be monitored by a user. The frequency of the measurements, here every 30 minutes, can be set by the user before the nodes are deployed. The collecting nodes automatically ensure the storage and provision of the data for the field sprayer.

This scenario differs from the measurement of the leaf surface temperatures, which requires more user interaction. The tablet is located on the tractor and can be used to start the measurement. By doing this, the tractor and the sprayer are first brought into position on the field. The used temperature sensors (MLX90614, Melexis, Belgium) have an opening angle of 72°. This means, that the distance between the temperature sensors to the surface of the plants needs to be about 30 cm in order to record the leaf surface temperature without gaps. The traverse must therefore be raised accordingly before starting the measurement. The start must be indicated to the system by pressing the corresponding button in the application. Afterwards the temperatures are recorded twice per second and stored in a database together with the GPS position of the field sprayer. When the end of the row is reached, the driver needs to press the corresponding button in the application. Afterwards the tractor can be turned and the measurement is continued for the next row. This is repeated until the area to be measured is completely recorded.

Figure 1 shows the evaluation of the measurement on the tablet (step d). For each sensor, the respective measured temperature is displayed and color-coded. The color coding makes it possible to quickly detect deviations and locate areas with, for example, increased leaf surface temperatures.

The measured values are stored in a database and transferred to a backend for further evaluation with the help of IBR-DTN as soon as the tablet is near the farm‘s WIFI and an Internet connection is available. In our case, the data from the Dethlingen Experimental Station (VSD) were transferred to the Technische Universität Braunschweig, where it was evaluated and made available to the VSD. Transmission, evaluation and provision were fully automated.

Evaluation of the sensor network

The results presented here are from the 2018 growing season and were carried out on the experimental fields of the Dethlingen research station. Two collecting nodes were installed on the field (Figure 3). Node 19 was in the irrigated part of the field, node 24 in the non-irrigated part. The tractor together with the field sprayer started from the starting position, made a turn at the end and drove back to the starting position. Thus, the sprayer passed the collecting nodes twice. The smaller nodes for measuring soil moisture and soil temperature were placed north and south of the collecting nodes.

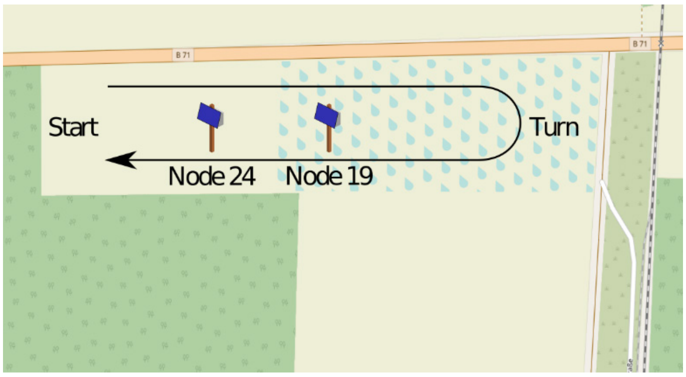

Figure 3: Overview of the test for determining the communication range. The signal strength indicator (RSSI) to nodes 19 and 24 was measured at the two points "Start" and "Turn" on different days. The results are shown in Table 1. (Source of background image: OpenStreetMap)

Influence of the plants on node connectivity

Even if the setup on the field appears static, as the nodes are fixed, the connections of the small measuring nodes to the collecting nodes are not constant over the season. Figure 4 shows on the left side an open collecting node at the middle of the 2018 growing season and on the right side at the end of the season.

Figure 4: The figures show two different environmental conditions for the collecting nodes on the field. In the first picture the node is almost enclosed by leave of the potatoes, in the second one the node is standing freely in the field.

Due to the height of the potato's leaves (up to 1m) the small sensor nodes are strongly shielded of by the leaves. Fresh potato leaves can have a water content of more than 90% (Schreiber 1961), which creates a high attenuation of the radio signal. In this case the small sensor nodes are only able to reach one collecting node. At the end of the season, when the potato leaves are increasingly dying and collapsing, further collecting nodes are reached by the absence of the potato leaves.

Nodes 19 and 24 were 51.4 m apart from each other. The small sensor nodes were between 3.5 m and 5.3 m away from the collecting nodes. They were buried about 15 cm in the ground, so that the signal had to travel through the soil and through the potato leaves to reach the collecting node. At these distances, the small sensor nodes were able to reach the nearby collecting node at any time and transmit the measured sensor data. Due to the dying potato leaves, reaching the collecting node further away was only possible at the end of the season. Since the experiment was not set up until the middle of the season, when the leaves of the potato plants had already grown noticeable high, no reliable statement can be made about the beginning of the growing season. It can be assumed, however, that in the case of small plants the accessibility of both collecting nodes would be given and that this would gradually decrease with the size of the of the potato plants.

Communication range of the collecting nodes

The transmission of data from the collecting nodes to the sprayer is crucial for the robust operation of the system. It is important for the field sprayer to be within communication range of the collecting nodes for as long as possible to ensure the transmission of the DTN bundles. Therefore, the radio range of the collecting nodes should be as high as possible. As already mentioned, the range is influenced by the leaves of the plants. Therefore, when installing the collecting nodes, care was taken to keep the antennas above the leaves of the potatoes. The collecting nodes were installed in a height of 1.2 m (Figure 4), which should minimize the influence of the above-ground plant parts on the communication between collecting nodes and field sprayer.

Table 1: Measured RSSI values from start area to node 24 and turn area to node 19

Date	**22.5.**	**28.5.**	**4.6.**	**11.6.**	**15.6**	**18.6.**	**25.6.**	**2.7.**	**9.7.**	**16.7.**	**23.7.**	**30.7.**	**6.8.**	**13.8.**	**27.8.**	**3.9.**
Node 19	-74	-75	-79	-79	-84	-80	-81	-83	-82	-85	-64	-80	-77	-80	-79	-79
Node 24	-79	-78	-79	-80	-80	-81	-74	-80	-72	-66	-72	-77	-78	-77	-73	-78

Values in dBm

The Received Signal Strength Indicator (RSSI) is used to evaluate the quality of the radio link between the communication partners. The lower it is, the lower the reception quality. According to the data sheet, the WIFI chips used in this test (BCM43143, Infineon, Germany) can receive a signal down to -97 dBm. Experience has shown that this value is lower in real world applications compared to desk setups. Table 1 shows the measured RSSI values from the starting area to node 24 (74 m) and from the turning area to node 19 (195 m). The data were recorded during the passage of the sprayer to the leaf surface temperature measurement. The sprayer passes collecting nodes 19 and 24 twice (Figure 3). The measured RSSI values for both nodes are between -64 dBm and -85 dBm. If one considers the height of the leaves of the potato plants, it can be seen that this had no influence on the signal quality between the collecting node and the field sprayer in the respective areas. It is also evident that the field sprayer can communicate with the nodes over a distance of up to 195 m. Unfortunately, the test field was not large enough to determine the maximum communication range. In addition, these observations are highly dependent on the setup used. WIFI in the 2.4 GHz range was used for communication.

Influence of soil moisture on RSSI values

Figure 5 shows the influence of the water content in the soil on the RSSI value, measured at a collecting node. The small sensor node was located at a distance of 3.6 m from it. The graph shows a section of the measured data from 5-8-2019 to 8-16-2019. During this period, it rained on the test field on three different days. The graphs of the other nodes show a similar course, because all nodes were buried at the same depth and have a similar distance to the collecting node.
On August, 9th 2018 it rained 7 mm per m2 on the test field. The RSSI value deteriorated by 8 dBm. In the evening of August 13th, the precipitation was 9 mm per m2 and the following morning it rained another 6 mm per m2. The RSSI value worsened again by 8 dBm. After August 14, with decreasing soil moisture saturation, an improvement of the RSSI values can be observed.

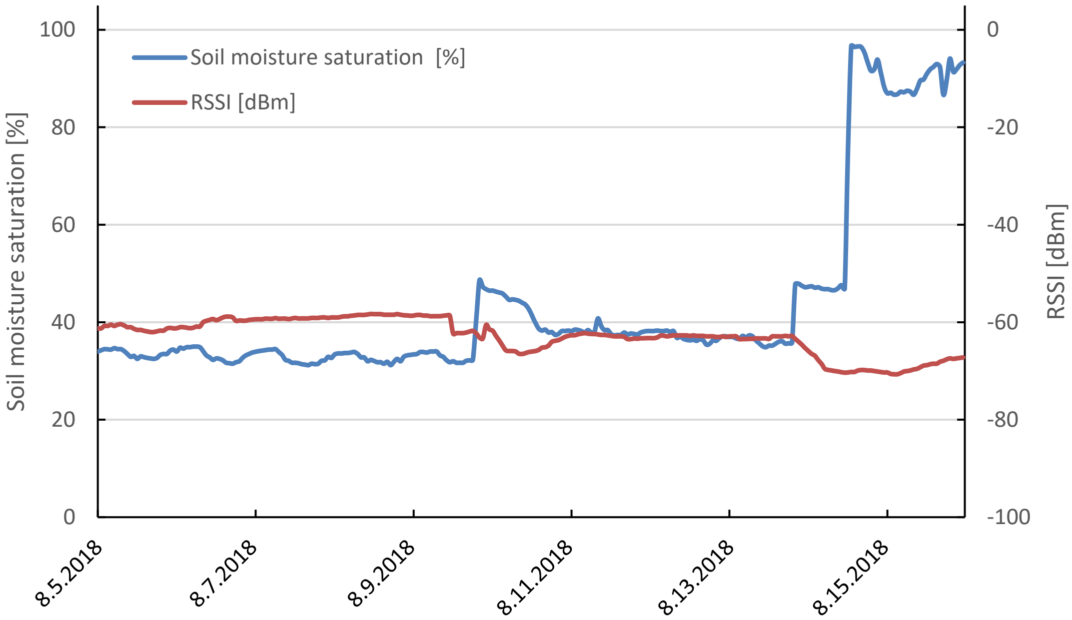

Figure 5: Influence of soil moisture saturation on the RSSI. The indicator decreases when the amount of water in the soil increases, such as on rainy days (August 9th and August 13th/14th).

In addition to the height of the potato leaves, the weather situation also has an influence on the communication quality of the data transmissions. When setting up a sensor network in the field, sufficient reserves for communication should therefore be provided to guarantee data transmission. Alternatively, mechanisms must be implemented that retain the data until they can be transmitted. As mentioned above, DTNs are suitable for this purpose, for example, which store the data locally until it can be successfully transmitted.

Analysis of the measured surface temperatures

After the tractor and sprayer were back on the premises of the Dethlingen research station, the data were automatically transferred to the Cloud (TU Braunschweig) via the WIFI network available there, whereupon the data were evaluated and made available to the user. The measurement data can be accessed at https:/www.ibr.cs.tu-bs.de/projects/potatoscanner/. The leaf surface temperatures recorded with GPS were plotted on a map. The result is shown in Figure 6 for measurements on 6-15-2018. The two tracks of the sprayer are clearly visible. Also, a temperature difference of the leaf surface between the western and eastern part of the field can be seen. In the western part the measured leaf surface temperature of the plants is between 35 °C and 40 °C, whereas the leaf surface temperature in the eastern part is between 15 °C and 20 °C. The reason for this is the artificial irrigation of the eastern part of the field. Due to the more watered soil, the plants were able to absorb more water, which was released via the leaves and contributes to the cooling of the leaf surfaces due to the resulting evaporative cooling.

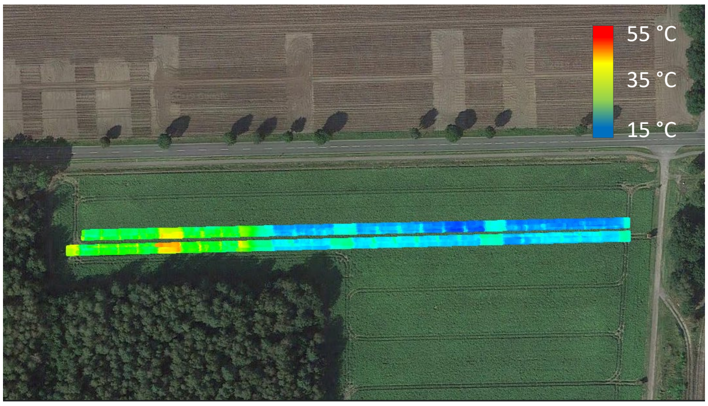

Figure 6: Visualization of the measured leaf surface temperatures (6-15-2018). The right part of the field was irrigated artifi-cially, where the left part was not irrigated. A clearly increased leaf surface temperature can be seen on the left compared to the right field section. (Source of the background image: Google Maps©)

Relevance of the measured data for agriculture

Within the scope of sustainable agricultural management, the improvement of the efficiency of plant cultivation measures such as fertilization, plant protection and irrigation are an essential component. In addition to breeding more environmentally stable crops, it is important to provide the plants with the mostly limiting growth factors, water and nutrients, in such a way that they can achieve the highest possible utilization level. By recording the plant temperatures during the passages with the field sprayer, up-to-date data can be obtained without additional effort, which above all provides information about the drought stress of the plants in different parts of the field. Higher leaf temperatures also indicate more intensive drought stress in potatoes (Prashar et al. 2013), which restricts both plant growth and nutrient consumption. An irrigation system, for example, which is oriented towards the driest areas of the field, allows irrigation to begin as needed and also saves water. At the same time, it is ensured that the nutrients applied are used by all plants to the maximum possible extent and undesirable losses are minimized. In addition, the temperature maps provide a further parameter which, together with the historical field data, facilitates a cause-related analysis of the current yield data.

With the targeted distribution of a larger number of sensor nodes on the field, it would be possible to expand the site-specific location knowledge. In comparable situations, this opens up the possibility of introducing targeted measurements that mitigate the expected effects and thus contribute to a more sustainable yield generation overall.

Conclusion and outlook

In this article the PotatoScanner was introduced. The system consists of several components, which are built on top of each other and which allow for the monitoring of agricultural areas. On the one hand local sensor nodes are used, which for example measure temperature and soil moisture. On the other hand, temperature sensors attached to a field sprayer enable the determination of leaf surface temperatures, which can be used to draw conclusions about the drought stress of plants.

The experiment shows that when installing sensor networks, it is important to consider possible influencing factors in advance. For example, weather and plant growth have an influence on the connection quality of the individual sensor nodes. Therefore, the resulting attenuation must be taken into account during the conceptual design in order to ensure a robust operation of the entire system. This also applies to the protocol used for transmission. In this test, DTN proved to be very robust, so that all data could be successfully transmitted from the collecting nodes to the modified field sprayer and from there to the backend. DTNs are able to deal with interrupted connections and ensure a robust data transmission. In the end, the system was easy to operate for the VSD staff due to its high degree of automation and did not require any special training.

With the exemplary collected data of the surface temperatures of the plants, the intensity of the drought stress could be differentiated and appropriate countermeasures could be initiated promptly, e.g. in the form of subarea specific irrigation. At the same time, temperature maps could be produced to support yield analyses. Targeted distributed sensor nodes also offer the possibility of recording the dynamics of the change process in the stand and soil and using this information for future crop cultivation measures to increase efficiency.

In the future, the small sensor nodes used will be further improved. A design in which the sensor nodes can be planted and harvested like potatoes would be desirable. This would further automate and simplify the design of a sensor network. It would also be conceivable to store the “harvested” sensor nodes in a warehouse, where the sensor nodes continue to monitor the environmental conditions of the potatoes. First successful experiments have already been conducted for this purpose (Gernert et al. 2018).

References

Büsching, F.; Kulau, U.; Wolf, L. (2012): Architecture and Evaluation of INGA - An Inexpensive Node for General Applications. Sensors, 2012 IEEE, S. 842 -845, https://www.ibr.cs.tu-bs.de/papers/buesching-sensors2012.pdf?lang=de%3C

Cerf, V.; Burleigh, S.; Hooke, A.; Torgerson, L.; Durst, R.; Scott, K.; Fall, K.; Weiss, H. (2007): RFC4838 - Delay-Tolerant Networking Architecture. Internet Engineering Task Force (IETF), pp. 1-35, https://tools.ietf.org/html/rfc4838

Doering, M.; Lahde, S.; Morgenroth, J.; Wolf, L. (2008): IBR-DTN: an efficient implementation for embedded systems. Proceedings of the Third Workshop on Challenged Networks, pp. 117-120, https://doi.org/10.1145/1409985.1410008

Gernert, B.; Schwartau, F.; Raabe, S.; Schoebel, J.; Schubert, K.; Rottmann, S.; Wolf, L. C. (2018): Evaluation of Suitable Radio Frequencies for Data Transmission in Potato Warehouses. IEEE 15th International Conference on Mobile Ad Hoc and Sensor Systems (MASS), pp. 220-227, https://ieeexplore.ieee.org/document/8567565

Prashar, A.; Yildiz, J.; McNicol, J.; Bryan, G.; Jones, H. (2013): Infra-red Thermography for Hight Throughput Field Phenotyping in Solanum tuberosum. PLoS ONE 8(6), https://dx.doi.org/10.1371%2Fjournal.pone.0065816

Rottmann, S.; Hartung, R.; Käberich, J.; Wolf, L. (2016): Amphisbaena: A Two-Platform DTN Node. International Conference on Mobile Ad Hoc and Sensor Systems (MASS). IEEE, pp. 246-254, https://www.ibr.cs.tu-bs.de/oa/Rottmann_MASS_2016.pdf

Schildt, S.; Morgenroth, J.; Pöttner, W.-B.; Wolf, L. (2011): IBR-DTN: A lightweight, modular and highly portable Bundle Protocol implementation. Electronic Communications of the EASST, Vol. 37, https://www.ibr.cs.tu-bs.de/papers/ibrdtn_architecture_wasangi2011_slides.pdf

Schreiber, K. (1961): Chemie und Biochemie unter besonderer Berücksichtigung qualitätsbestimmender Faktoren. In: Die Kartoffel - Ein Handbuch, Hg. Schick, R.; Klinkowski, M., Berlin, VEB Deutscher Landwirtschaftsverlag, S.191-352.

Scott, K.; Burleigh, S. (2007): RFC5050 - Bundle Protocol Specification. Internet Engineering Task Force (IETF), pp. 1-50, https://tools.ietf.org/html/rfc5050

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