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Advancing precision agriculture: a case study of open source autosteering with AgOpenGPS and RTKbase

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Abstract. Precision agriculture increasingly relies on Real-Time Kinematic (RTK) services to perform highly accurate tasks in the field. Robotics are gradually entering farming, demanding precise and reliable correction signals. However, before widespread adoption of autonomous field robots becomes a reality, automated tractors will remain in use for a significant period, becoming progressively more advanced.
The market is currently filled with various manufacturers offering aftermarket autosteering systems, which incrementally bring farmers closer to the functionality of fully autonomous field robots. This study explores open-source solutions for cost-effective autosteering systems and RTK base stations. The project involved retrofitting a single farmer's tractor with an autosteering system and establishing an RTK base station.
As the pilot progressed, word of the implementation spread, leading to the creation of a dedicated communication channel for interested farmers. This platform has facilitated knowledge sharing and further adoption. Information about the project also reached other regions, inspiring similar initiatives that have significantly increased the number of RTK base stations in just two years.
The results of this project demonstrate a strong demand for alternative solutions. Many farmers lack the financial resources to invest in expensive, proprietary systems or are unwilling to commit to recurring subscription fees. The goal remains the same, regardless of the implementation method, agriculture is moving steadily toward smarter, more precise practices and the eventual adoption of field robotics.

Key words: AgOpenGPS, autosteering, open source, precision agriculture, RTK2Go, RTKBase.

INTRODUCTION

Agriculture is becoming increasingly robotized. Cheng et al. (2023) discuss as many as fourteen different agricultural robots, illustrating that field robotics is just one part of the broader spectrum of agricultural automation. In this context, automating tractors serves as an ideal starting point, offering a valuable opportunity for skill development before the arrival of more advanced robotic systems. Many of these robots will also require precise navigation, making the construction of a local RTK base station a cost-effective and accurate solution.

The future of agriculture will involve multiple technological development sectors, such as robotics and artificial intelligence, but localization and navigation will remain core components among other advancements, as Kisliuk et al. (2023) discusses. This observation supports the idea that developing an autosteering system is not only beneficial for immediate use but also lays the groundwork for future data collection and data-driven decision-making processes.

The market is filled with commercial autosteering solutions, which signals the significant market potential recognized by industry players. However, open-source alternatives provide a cost-effective option, particularly for farmers who prefer a do-it-yourself approach or whose investment budgets are already allocated elsewhere.

Currently, agriculture in Finland is struggling with profitability, making efficiency improvements vital for sustainability. Autosteering systems can contribute to this by reducing overlap during fieldwork, minimizing unnecessary turns, and allowing farmers to focus more optimizing the work machine (Bora et al., 2012).

As automation increases and the variety of agricultural equipment expands, precise positioning will be crucial for new applications, such as drones. Agricultural drones are becoming as common as traditional machinery, used for tasks such as spraying crops, detecting invasive species, and generating NDVI maps (Linna et al., 2024; Lipping et al., 2020).

This paper focuses on a case study of a farmer-led implementation of a retrofitted open-source autosteering system AgopenGPS (AgOpenGPS, 2025a) and an RTKbase (RTKbase, 2025) base station, demonstrating the feasibility and broader implications of these solutions. The study highlights both the technical and practical challenges encountered throughout the process.

MATERIALS AND METHODS

Method

Case studies play an important role in the development of farming systems and agribusiness research, as highlighted by Klein & Knight (2005) and Vanclay et al. (1998). This research is an engineering case study that combines constructive research with empirical field experiments. The study investigates open-source solutions for implementing a retrofitted autosteering system and the necessary RTK base station for correction signals.

We hypothesize that open-source solutions can offer a competitive alternative to commercial systems, thereby enabling a transition to precision agriculture with lower investments. If this hypothesis holds true, more farms will be able to adopt precision agriculture. While some users may eventually shift to commercial solutions and new users will join the open-source community, the overall use of open-source technologies is expected to increase the adoption of precision farming practices on Finnish farms. This outcome aligns with the primary objective of the study.

This case study was conducted on a mid-sized farm in western Finland, using a CASE 7220 series tractor without factory-installed autosteering capabilities. The farmer had a strong interest in precision farming and aimed to develop the farm cost-effectively by investing personal time and effort into the process. The project was initiated independently and carried out during the 2022–2024 seasons, with support from peer networks and publicly available open-source resources. The implementation included building an RTK base station and integrating an AgOpenGPS-based autosteering system tailored to the farm's specific operational needs. The case represents a realistic example of how individual farmers can adopt precision agriculture tools with limited budgets and technical resources.

Searching and analyzing material

The research began with collecting relevant material on the topic. The primary sources were the AgOpenGPS websites (AgOpenGPS, 2025a; 2025b; 2025c) and other related documentation. While some additional sources were consulted, their overall significance was minimal. One particularly valuable practical resource was YouTube videos, which provided examples of various implementations. RTKbase material was mainly from Github account (RTKbase, 2025).

One of the biggest challenges was the inconsistency of available information. The software of AgOpenGPS was in an intense development phase, leading to numerous conflicting instructions and implementations. As a result, forming a comprehensive understanding of the system took considerable time in the beginning. This can, on the other hand, be seen as typical of open-source solutions, where the implementation process has not been given the same level of attention as in commercial systems.

Orders and building

After defining the implementation plan, printed circuit boards (PCBs) were ordered from circuit board manufacturing (JLBPCB, 2025) factory. Their delivery took some weeks, after arrival, there were plenty of boards for testing. Ordering individual components proved to be a complex process. Since no single supplier carried all the necessary parts, they had to be sourced from multiple vendors.

Additionally, there were significant supply chain issues with the Raspberry Pi due to global production challenges, likely caused by COVID-related manufacturing disruptions. Eventually, all the required hardware was successfully acquired, although a few incorrect components were ordered, and in some cases, there was an excess of certain parts.

Once all components were available, the soldering of the circuit boards began.

Software tools

After assembling the circuit boards, the software configuration phase began. This phase also took a considerable amount of time, as multiple software components and settings had to be studied, some of which were dependent on specific hardware versions.

The required software included:

- u-Blox (u-Blox, 2025) – Used to install the software and configure settings for the GPS module.
- Command Prompt (Terminal) – Used for installing RTKBase.
- Raspberry Pi Imager (Raspberry Pi Foundation, 2025) – Used to install the operating system onto the Raspberry Pi's memory card.
- Arduino IDE (Arduino, 2025) – Used to upload software and configure settings for the board.

- RTKBase (RTKbase, 2025) – The software running on the RTK base station.
- RTK2go Service (RTK2go, 2025) – Used for distributing the correction signal.
- AgOpenGPS Software (AgOpenGPS, 2025a) – The autosteering program. Contained all the necessary files for the autosteering system and related hardware configurations.

RTKBase - RTK base station

With the circuit boards assembled and the necessary software and configurations in place, the actual construction process began with the simplest task, building the RTK base station. The required components included the simpleRTK2 GNSS board with the u-blox ZED-F9P GNSS module (ArduSimple, 2025), Raspberry Pi and GNSS antenna.

The installation was relatively straightforward. The components were connected, the memory card was inserted into the Raspberry Pi, and the device was powered on. A connection to the Raspberry Pi was then established using the command prompt, where the following commands were executed:

- wget https://raw.githubusercontent.com/Stefal/rtkbase/master/tools install.sh -O install.sh
- chmod +x install.sh
- sudo ./install.sh --all release

This command sequence installed the RTKBase software, which serves as the main base station program. The installation also created a web-based configuration page, allowing users to monitor the system status, including the number and signal strength of satellites. Additionally, the page provided settings for defining services such as the NTRIP service.

We used RTK2go (RTK2go, 2025), a free service for distributing correction signals, which allows anyone to publish their own RTK signal and access publicly available signals. The registration details for the RTK2go service were entered into the base station configuration.

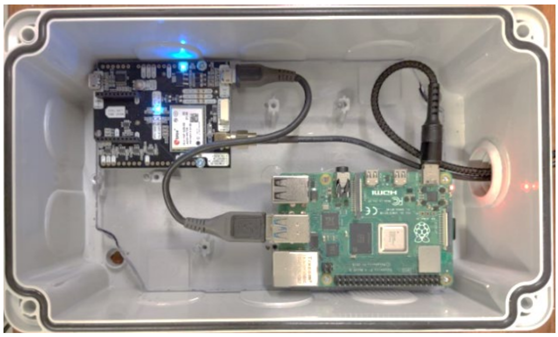

Figure 1. The layout of the RTK base station.

Accurately determining the base station's location is essential for transmitting correct correction signals. The base station included a feature for logging GNSS signals over a specified period. In our case, signals were logged for 24 hours to ensure accuracy. The resulting RINEX file was uploaded to the Canadian Geodetic Survey's GSRS-PPP service (Natural Resources Canada, 2025), which calculated the precise coordinates of the base station. These coordinates were then entered into the base station configuration. After this step, the NTRIP service was activated, and the base station began transmitting RTK correction signals to the RTK2go service, making them publicly available for use. The base station is ready for wall installation, as shown in Fig. 1

AgOpenGPS - Retrofitting Autosteering

After setting up the base station, the more challenging part began: connecting the autosteering components, installing the necessary software, configuring the system, and conducting field tests.

The key components included a steering angle sensor for measuring the wheel position, GNSS antenna and its circuit board, hydraulic control unit, Windows-based laptop, USB hub and main control module.

Installing the steering angle sensor proved structurally challenging, as it needed to measure the angle of the front wheel accurately. The sensor was mounted on the front axle to measure the angle of the left wheel joint. For protection, a 3D-printed housing was used as seen in Fig. 2.

Figure 2. The angle sensor with protective case.

The GNSS antenna was mounted on the edge of the tractor's roof, as close to the tractor's center as possible along both the length and width axes.

Several options were available for controlling the steering wheel, including using a roller motor on the wheel, a center motor on the wheel, an electronic orbital steering unit, or a custom hydraulic control system. We chose the hydraulic solution, due to its technical benefits and alignment with our implementation goals. This setup involved cutting the hydraulic hoses between the orbital valve and the wheels and inserting a custom-made hydraulic control unit (Fig. 3). The box received control signals from the AgOpenGPS control unit.

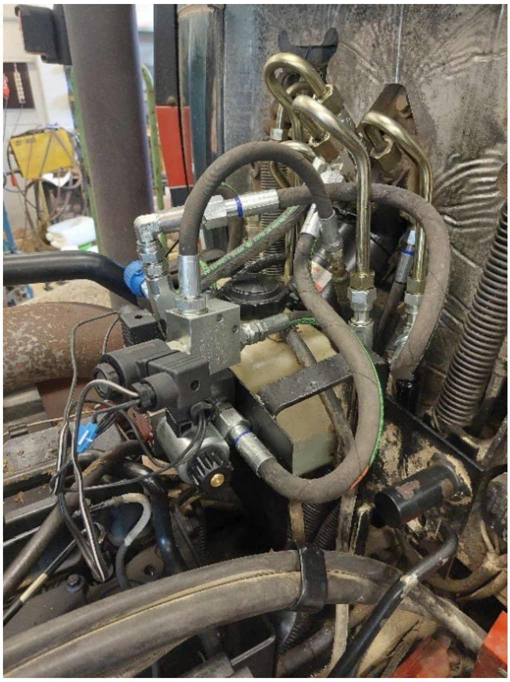

Figure 3. The hydraulic control unit in this research case.

Nowadays, ready-made electronic hydraulic control units are also widely available (Fig. 4).

After completing the hydraulic system, the most challenging tasks were building the main control box and GNSS box. For the GNSS box, the u-blox configuration utility was used to install the firmware and configure the necessary settings for the simpleRTK2 board. The firmware for the control box was installed on the Teensy board using the Arduino IDE. This process required installing the correct drivers for the Teensy and ensuring the right software version was selected in the Arduino IDE. Initially, there were significant communication issues between the GNSS board and the control box due to an incorrect baud rate, which prevented data transmission. Once the configurations were completed, the devices were connected to the Windows laptop via a USB hub. At this stage, the software and hardware setup were fully operational (Fig. 5).

Next, tractor-specific configurations were completed in the field, such as adjusting the turning radius and calibrating the system to match the tractor's characteristics. After several steps and fine-tuning, the system was successfully operational.

During practical use, issues began to arise with the USB connection, which would occasionally disconnect unexpectedly. It was discovered that the COM connection via USB experienced small, intermittent disconnections for unknown reasons. Similar issues had been reported by other users of the same implementation model.

To address this, the control box was replaced with an all-in-one board solution that used Ethernet connectivity instead of USB. The new all-in-one board integrated the GNSS functionality, eliminating the need for a separate GNSS board. The ZED-F9P GNSS module and the position sensor were both directly integrated into the new board (Fig. 6). Although it required learning a new implementation, the installation was completed relatively quickly. The new setup proved more reliable and streamlined, making it a significant improvement over the initial configuration.

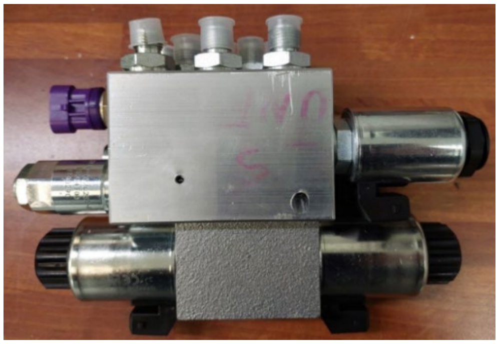

Figure 4. The commercial hydraulic control unit.

Figure 5. On the left is the 2nd version with All-in-One board including also GNSS. In the middle is the 1st version of board. On the right is the 1st GNSS board and hydraulic electronic control which is linked with Fig. 3 hydraulic control unit.

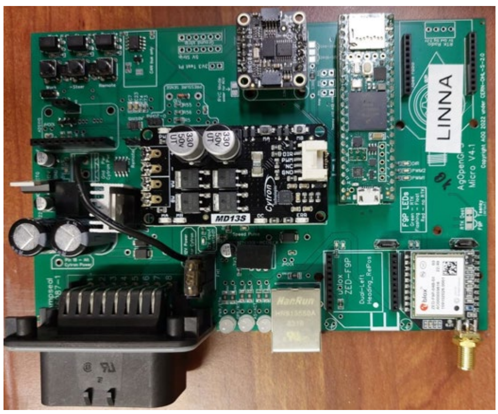

Figure 6. The All-In-One board.

RESULTS AND DISCUSSION

The project successfully resulted in a fully functional retrofitted autosteering system integrated with an RTK base station connected to the RTK2Go service. The system achieved centimeter-level accuracy, enabling precise field tasks.

As the pilot progressed, word of the implementation spread through dedicated communication channels, primarily among farmers interested in low-cost precision agriculture solutions. There is significant expansion of the RTK base station network, in 2023/2, approximately 23 base stations and by 2024/4 (Fig. 7), this number had increased to 60 stations and 2024/10 about 70. One farmer involved in the network began selling custom-built hardware kits, enabling broader access to autosteering solutions. The project's success inspired similar implementations in neighbouring regions, contributing to the wider adoption of open-source precision agriculture technologies.

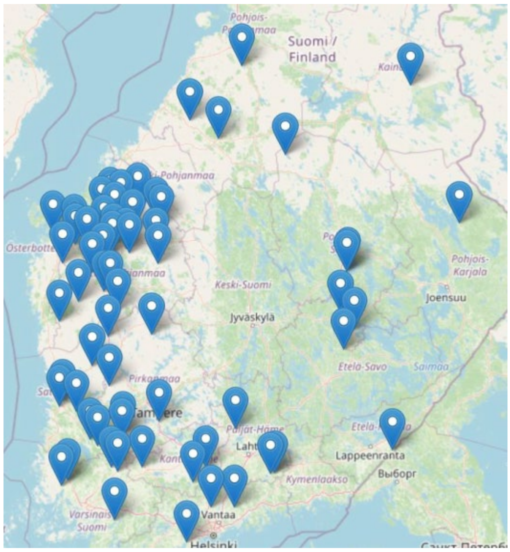

Figure 7. The RTK base stations in Finland in RTK2go-service at 2024/4.

Despite the challenges, the project demonstrated that open-source solutions are viable alternatives to commercial autosteering systems, especially for farmers seeking affordable and customizable options. The availability of almost ready-to-use kits has significantly lowered the barrier to entry over the past two years. As open-source solutions continue to evolve, they are expected to complement and even accelerate the adoption of commercial technologies, further promoting agricultural automation. Farmers purchasing tractors or harvesters have become more likely to install autosteering systems at the time of purchase due to the growing availability of open-source and hybrid options. Open-source implementations, when supported by knowledge-sharing networks, contribute to broader technological advancements in the agricultural sector.

There were some challenges. The initial USB connection instability due to COM port interruptions was a major hurdle. This was mitigated by switching to the Ethernet-based control unit, which streamlined communication and eliminated frequent disconnections. Incorrect baud rates initially caused communication problems, which were resolved through careful reconfiguration. The RTKBase system's limited reliability was attributed to external factors like power supply issues and Wi-Fi connectivity problems. Potential improvements include using a more robust power source and wired connections.

To approximate the effort required for setting up an RTK base station, the process can be divided into two components: technical installation and preliminary research. The preliminary phase, consisting of information gathering, hardware selection, and community engagement, can be significantly more time-consuming. The latter varies considerably depending on the user's technical background and access to peer support. Therefore, in our analysis we focus on the concrete installation time, while acknowledging the challenge of quantifying the research phase.

Mounting the components into the enclosure typically takes 1 to 2 hours, or longer if the case lacks pre-drilled cable entry points or suitable mounting locations for boards. Installing the software on the Raspberry Pi takes approximately 30 minutes. Setting up the RTKbase application also takes around 30 minutes. Installing the base station in a suitable location may require drilling holes, building an antenna mount, or routing cables such as power lines. In this estimate, we assume that the antenna can be easily screwed into place and that both power and Ethernet are readily available. Under these conditions, physical installation can be completed in about 2 hours.

Following the hardware setup, a series of configuration steps are required: starting position logging about 10 minutes, using an online positioning service such as the Canadian Spatial Reference System Precise Point Positioning (Natural Resources Canada) service about 15 minutes, and importing the calculated coordinates to the base station about 15 minutes. Finally, setting up RTK information sharing, (e.g., registering the station on the RTK2Go service) entering service details into the base station configuration, and starting the correction data broadcast takes around 1 hour. All the above assumes an optimal setup. In practice, each phase may take significantly more time if any challenges arise.

The total estimated installation and configuration time for the RTK base station is approximately 6 to 7 hours under optimal conditions.
The total hardware cost for a self-built RTK base station ranges from approximately 380 € to 530 €, depending on the selected components. The GNSS receiver (SimpleRTK2b) and the computing unit (Raspberry Pi) constitute the majority of the cost. Although prices vary slightly depending on the supplier and specific models used. The listed estimate does not include labor or research time required to understand the setup process. The table below presents the prices of components.

Table 1. RTK base station components

Component	Price
SimpleRTK2b (with u-blox F9P)	180
GNSS antenna	50–100
Raspberry Pi	100–200
Cables, box, and charger	50
	380–530 €

As in the base station analysis, our focus for the AgOpenGPS-autosteering system is on the concrete installation and configuration steps. The time required for background research is difficult to estimate precisely, as it depends heavily on the desired implementation method and the specific tractor model and equipment used.

In our first case, we built a custom experimental hydraulic control unit between the orbital steering valve and the steering cylinder. Its installation took approximately 20 hours. Based on this, installing a ready-made hydraulic unit can be estimated to take around 10 hours. In another tractor, we implemented steering using a motor mounted on the steering wheel. This installation took approximately 5 hours, including 3D printing, welding, and mechanical attachment of parts. For steering wheel control, there are also ready-made solutions available, for example, steering wheel center hub motor kits, which can be installed very quickly, in about 1 hour.

The first autosteer PCB assembly required substantial manual effort. All components were hand-soldered, which took about 4 hours. The components had to be ordered from different suppliers, and the selection process required considerable effort. In a later implementation, we used a so-called All-in-One board, which was significantly easier. When ordering the board, a parts list and installation instructions are also provided on the AgOpenGPS download site. It is essential to ensure that all components are available from the chosen vendor, to avoid manual soldering and rework. The result is a high-quality, factory-assembled PCB board. Placing the order takes about 1 hour, and no soldering or wiring is required after that.

Electrical wiring, including power supply, safety relays, and connections to the steering controller, adds approximately 2 hours. Installing and connecting the wheel angle sensor and GNSS antenna may take an additional 2 to 4 hours.

Software configuration, including installing AgOpenGPS on a PC, sensor calibration, and device communication setup, can take 2–4 hours under optimal conditions. Initial field calibration takes another 1 to 2 hours and includes practical testing of turning radii and steering performance.

All estimates assume optimal conditions and some prior familiarity with the hardware and software. In practice, any phase may take considerably longer if complications arise.

The total estimated installation and configuration time for the autosteering system is approximately 37 hours under optimal conditions, which is calculated our first case installation.

Table 2. AgOpenGPS components

Component	Price
Steering motor and mount	100
or hydraulic steering unit	600
or steering wheel hub	600
GNSS antenna	50–100
Autosteer PCB and connectors	300
u-blox F9P (micro)	200
Cables and enclosures	50
Wheel angle sensor	50–100 €
Windows tablet	300–1,000
	1,450–2,350 €

The hardware cost of an open- source autosteering system varies depending on the chosen implementation method and component availability. Based on our assessment, the total cost ranges from 1,450 € to 2,350 €. The Table 2 presents a typical breakdown.

CONCLUSIONS

This case study demonstrates that open-source solutions for autosteering and RTK base stations are viable, cost-effective alternatives to proprietary systems, offering farmers a pathway to adopting precision agriculture technologies without significant financial barriers. However, success with open-source implementations requires a willingness to experiment and access to a strong support network that can be relied on when challenges arise. While most problems encountered are minor, having someone to confirm or suggest a solution is often essential.

The goal of both open-source and commercial implementations is ultimately the same: to bring farmers closer to fully automated field robotics, where tasks become increasingly automated and optimized. Once farmers have experienced the benefits of systems such as autosteering and automated implement control, it becomes difficult to return to traditional methods. The adoption of such technologies represents a permanent shift in how farming is approached, driving the agricultural sector steadily toward greater efficiency and automation.

This study is a case-based investigation, limited to two self-built RTK base stations and a single implementation of autosteering. As such, the generalizability of the results is limited, particularly regarding the autosteering system, due to the diversity of tractors and the variety of possible implementation options. Additionally, the type of implements used may influence the chosen technical solutions. In contrast, the RTK base stations are significantly easier to replicate, as evidenced by the rapidly expanding RTK base station network in Finland.

Our next aim is to support farmers in adopting more precise and automated agricultural practices, while respecting their individual preferences. Some may be inclined to explore open-source solutions, while others prefer quick and easy commercial options. Ultimately, the goal is to shift the farmer's role from repetitive tasks toward data-driven decision-making.

The total hardware cost for a self-built RTK base station ranges between 380 € to 530 €, and the estimated installation and configuration time is approximately 6–7 hours. For the autosteering system based on AgOpenGPS, hardware costs vary from 1,450 € to 2,350 € depending on implementation (e.g., motor vs. hydraulic control), and installation time ranges from 7 to 13 hours. These figures include only the optimal technical installation, not the preliminary research or troubleshooting phases.

As a result of this study, setting up RTK base stations has become easier, as more guidance and documentation are now available. The threshold for building a personal base station may also have lowered as awareness of such setups has spread. In general, the installation of the base station was relatively simple to begin with. The software installation process has not changed significantly, nor has the required hardware, which has remained largely the same over the past few years. Unit costs have also remained fairly stable, as the core components have not undergone major changes. Therefore, the most significant change has been the growing viability of building a base station as an alternative to purchasing commercial correction signal services.

When compared to commercial alternatives, an RTK base station may not be needed at all, users can simply purchase an RTK subscription, typically costing around 600 € per year and usable anywhere in Finland. This option requires no installation time. It is sufficient to buy the license and configure the connection details into, for example, the tractor's autosteering device. An interesting emerging alternative is the Galileo High Accuracy Service (HAS), which eliminates the need for a local RTK base station altogether by providing correction data directly via satellite (Prol et al., 2024).

A wide range of commercial autosteering systems is available, with prices starting at approximately 5,000 € and extending significantly higher. The authors have not conducted commercial installations themselves, but according to product brochures and manufacturer claims, installation usually takes only a few hours at most.

Open-source solutions, while significantly cheaper, require intermediate-level proficiency in electronics, mechanical assembly, and software configuration. For example, the original PCB required hand-soldering, but newer All-in-One versions simplify the process considerably.

Despite the higher initial labor requirement, the open-source approach offers a viable alternative with substantial cost savings, especially for technically skilled users or those with peer support networks. In particular, the flexibility to tailor the solution to specific farm equipment and the absence of vendor lock-in are key benefits for early adopters.

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