INCREASING THE RESILIENCE AND PERFORMANCE OF AI-BASED SERVICES THROUGH HYBRID CLOUD INFRASTRUCTURES AND THE USE OF MOBILE EDGE IN AGRICULTURE

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Abstract.

Agriculture, as an essential part of food production, belongs to the Critical Infrastructures (CRITIS). Accordingly, the systems used must be designed for fail-safe operation. This also applies to the software used in agricultural operations, which must meet security and resilience criteria. However, there is an increase in software that requires a permanent Internet connection, i.e., a stable connection to servers or cloud applications is required for operation. This represents a significant vulnerability in terms of resilience and can lead to significant problems in the event of a telecommunications infrastructure failure. With developments from the field of Resilient Smart Farming (RSF), we show how data storage can be designed according to the offline-first principle. A central building block here is Resilient Edge Computing (REC) and the developed HofBox: a mini-server that handles data management on the farm and implements it using innovative open source-based container technology (Open Horizon). This will make further use cases within the agricultural production and value chain realistic and feasible in the future through public-private partnership models. For the first time, we can manage and deploy containerized software not only on local computers and servers (Raspberry Pi) but also on mobile edge such as smartphones. This can have a positive impact on the performance of AI-based models, especially when internet availability is poor.

An innovative new feature is therefore management and deployment of containerized software on mobile devices. This significantly increases the flexibility for the use of containerized applications. Administration of the software used on servers, HofBoxes and mobile devices is made much easier.

This makes it very flexible to use this software on different end devices across the entire hybrid cloud infrastructure. The scalability and flexibility within a hybrid cloud infrastructure is significantly increased through the use of AI tools. The ability to distribute the computing power individually according to the needs of the applications opens up a wide range of possible applications for AI in agriculture. We can show that complex AI-based models work in containerized software, e.g. for image recognition of weeds on mobile devices, and will significantly influence future developments.

Keywords.
Edge Computing, Resilience, AI, Hybrid Cloud, Mobile Edge

1. Introduction

The process of agricultural production is undergoing continuous digitalization, especially in industrialized countries, which is referred to as digital farming or smart farming (DLG 2019), i.e. the proportion of software-supported tools and purely software-based processes such as planning tasks is demonstrably increasing steadily (Dörr and Nachtmann 2022, Bitkom 2020, Bartels 2020). In times of various crises such as the Ukraine war, the COVID-19 pandemic, cyberattacks and climate change, it is more evident than ever that agriculture is exposed to multiple risks and will have to focus more on crisis and disaster preparedness in the future. The intensive use of regional sensor data in smart farming provides agriculture with an improved basis for decision-making and opens up new scope for action for the administrative bodies responsible for environmental and climate protection (Dörr and Nachtmann 2022).

The Experimental field project EF-Suedwest builds on the results of GeoBox-Project and focuses on the experimental development and testing of a practical prototype for decentralized data storage based on the offline-first principle. The aim is to implement the concept of a standardized and resilient GeoBox infrastructure. The central question here is: (How) can decentralized data storage with a hybrid IT infrastructure be implemented while supporting the economic and ecological benefits of applications in smart farming and increasing resilience? To this end, a concept was developed and implemented using agile methodology, so that a software prototype is now being used to determine the practicality, advantages and disadvantages of decentralized data management in agriculture. We expect the solution to be less susceptible to attacks on central infrastructure and blackout scenarios.

Resilient Smart Farming (RSF) is a concept for the use of digital technologies and applications with a focus on increasing resilience in digital agriculture. The central concept here is resilience as the desirable state of a resilient digital infrastructure in critical infrastructure agriculture (food sector) (BMI 2016, BLE 2020). Because of the importance of agricultural primary production for the functioning of the community the federal government has issued a legal basis for the protection of critical infrastructures (BSI 2021). There are major interdependencies between the agriculture as part of the food sector and other critical infrastructure sectors. Examples include the energy, water, transportation and traffic, information and communication technology

In the context of technical systems, resilience is often defined by three capacities: Absorption, Recovery and Change. In order to meet these capacities, the following technical requirements have arisen for the data management project in the agricultural context: (1) offline capability, (2) data security and (3) integration and compatibility with (open) data standards.

Offline capability describes the ability to use essential services even without an active connection to other computers (servers). Even if an Internet connection is not available for a longer period of time, the overall system should continue to be functional. This results in absorption of disruptions in the Internet infrastructure. This requirement can be implemented using different strategies. A software-hardware combination that does not require network technology, as is the case with classic desktop applications, often fulfills the requirement here. However, cloud applications can also use clever caching and synchronization mechanisms to allow a longer-term network failure without data loss. However, these are associated with higher requirements on the part of the software architecture.

Data security refers to the property that stored data is not lost. Classic methods for this are the creation of deliberate data redundancies, such as through RAID systems and backups. However, decentralized data distributions also often have the positive property of distributing the data across several data carriers through their use. It is important here that redundant data can also be used for data recovery. In the event of (intentional) data duplication on mobile end devices, it should also be possible to (re)mirror these to other systems. This makes it easier to recover from crisis events, for example by replacing defective devices and quickly restoring them to a usable state with the old data.

Integration and compatibility with (open) data standards allow a high degree of flexibility in dealing with larger software ecosystems and thus the ability to react to changing - possibly unforeseen - circumstances. This also makes it possible to adapt the entire system after a crisis event - for example, if other software-hardware systems appear more suitable based on the findings of the crisis event.

Cloud computing generally refers to the outsourcing of computing and data capacities to remote data centers. Edge computing, on the other hand, refers to the relocation of computing capacities back to the end user, for example to minimize transport routes and times in the network. As latencies and aspects of data sovereignty as well as economical use of the network infrastructure play a role for more and more applications, edge computing will also become established for various agricultural applications in the short to medium term. This is due, among other things, to the increasing possibilities in the field of sensor technologies in the context of the Internet of Things (IoT) for agricultural purposes. The strong increase in collected data is increasingly becoming a problem for approaches based on classic server applications in central data centers (cloud computing) - both due to technical limitations on the part of the network infrastructure, as well as social and regulatory requirements, e.g. due to more sensitive data protection and an increased need for confidentiality and privacy. Edge computing as the next stage in the field of network-based data processing will increasingly come to the fore. This paradigm supports the management of decentralized and offline-capable edge devices. If these framework conditions are taken into account, this leads to resilient smart farming (RSF), which can subsequently strengthen the resilience of digital systems in agriculture. Resilience is particularly relevant in systems that are actually stable. This is made clear not least by the vulnerability paradox: "To the extent that a country is less susceptible to disruptions in its supply services, the greater the impact of any disruption" (Eberz-Eder 2021).

The objective of this work is the application-oriented development of possible scenarios for the introduction of innovative and resilient edge computing in agriculture. These new technologies for decentralizing and securing Internet-based applications shift data storage back to the farms and thus serve the data sovereignty of the farmers.

Resilient Edge Computing (REC) focuses on the resilience and reliability of agricultural production as demanded by the Conference of Agriculture Ministers, among others. The GeoBox infrastructure serves as the basis and will be expanded to include resilient edge computing. The introduction of 5G communication networks in agriculture and their importance for agriculture in the future reinforce the need for local computing processes in edge devices. The open source software "Open Horizon", managed by the Linux Foundation, provides the infrastructure with an edge framework that enables the automation of software installation and data synchronization on thousands of edge devices (e.g. “HofBox”- miniservers).

Such a resilient infrastructure for decentralization and regionalization must be coordinated and introduced nationwide in the CRITIS "Food and Agriculture" for reasons of failure and supply security. For such a scenario, a public-private partnership could be a possible instrument for making the infrastructure robust and diverse.

The significant increase in developments in the field of GenAI, following the release of ChatGPT by OpenAI in 2022, resulted in a significant increase in the consumer market (Kanbach et al. 2024). Initial analyses indicate that white-collar tasks, such as administrative support, are more susceptible to automation than manual labor-related functions, such as those required in construction or manufacturing, which are less prone to automation (Eloundou et al. 2023).

2. Goals

Agriculture is confronted with a multitude of economic, ecological and technological challenges. The transformation of agriculture with regard to digital technologies enables the implementation of new processes to optimize production and conserve natural resources (Dörr et al. 2022).

A significant number of digital applications are dependent on one or more central server applications and a stable, permanent internet connection, also known as cloud computing. The use of cloud technology is associated with a number of advantages, including cost reduction, high scalability and simple administration. A serious disadvantage is the inadequate functionality of the infrastructure or the limited usability of the applications in crisis situations such as a blackout scenario or a hacker attack (DDoS) on the central IT systems. In these cases, increasing dependence on central software applications could significantly increase the security risk. The concept of Resilient Smart Farming (RSF) was developed with the objective of minimizing the risk and simultaneously limiting the restrictions on use for the user.

The experimental development and testing of a prototype of a decentralized data storage system based on the offline-first principle (RSF) is the focus. The goal is to implement the concept of a standardized and resilient digital infrastructure (in Rhineland-Palatinate, so called GeoBox infrastructure). The central question here is: (How) can decentralized data storage with hybrid decentralized data storage with a hybrid IT infrastructure be implemented while maintaining the economic and ecological benefits of applications in smart farming and increasing the resilience of the digital infrastructure in agriculture.

The goal is to emphasizes the necessity for decentralized systems that prioritize security and data sovereignty. By employing open-source software, developers can ensure that these systems are not only secure but also accessible and maintainable by farmers and other agricultural stakeholders. Therefore our goal is to create a future orientated and flexible open source based framework for managing workloads. Therefore it should be able to deploy software on different hardware architectures.

The hybrid cloud infrastructure tested in the agricultural sector aims to enable efficient management of the software for the numerous edge devices (HofBoxes).

3. Methods and Materials

3.1 Resilient Smart Farming

The focus of German agriculture is particularly on the precise and sustainable management of the soil. Digitalization offers a wide range of opportunities to counteract the ongoing structural change in agriculture. Intelligent systems can relieve the burden on farmers by supporting operational work or decisions. Smart farming involves automation technologies and the collection, processing and analysis of data in real time.

In the future, smart farming should enable the collection and analysis of process and sensor data. The services and products currently available on the market are characterized by the functionality of cloud computing. This means that data is no longer stored on site, but is outsourced to servers in data centers. In agricultural practice, internet-dependent and high-performance applications in particular are often limited by insufficient bandwidths and high latency times. One possible countermeasure to address the risks of cloud computing would be to set up at least a partially decentralized network (e.g. "HofBox"). The point of such an "offline-first" system is to ensure that programs can always be used without an Internet connection (Eberz-Eder et al. 2023). We are trying to implement this approach with resilient smart farming (RSF) (Kuntke 2024).

The use of edge computing can offer new accents and opportunities, particularly in agricultural production and farm management. Edge computing gives farms, even those with lower internet bandwidth, the opportunity to calculate computationally intensive parts of applications locally on site. We understand resilience not only as crisis management but also as a preventive and foreseeing concept. The goal of resilience is the regular continuity of the system under every circumstance (Kuntke et al. 2022, Eberz-Eder et al. 2021).

In agriculture, precision and smart farming are important for the future, as they offer a number of technical production and economic advantages (Dörr and Nachtmann 2022) The focus when using resilient edge computing (REC) should be on the decentralized use of smart farming applications (Eberz-Eder et al. 2021, Reuter et al. 2019). Data and decisions are to be processed as far as possible in real time using Internet of Things (IoT) processes. These processes will be or are already of great importance in agriculture. Edge computing now offers the opportunity to be used in agriculture with a suitable digital infrastructure (such as the GeoBox infrastructure). The connection of various IoT sensors to a decentralized network opens up new possibilities for direct information gathering in agriculture

Agricultural businesses are market-based companies whose most valuable asset in today's world is their operational geo-referenced data. In order to do justice to data sovereignty, the GeoBox infrastructure with its decentralized data storage provides a digital opportunity through edge computing in the form of a HofBox, in which some of the entire computing power can be used locally (Eberz-Eder et al. 2023, 2022, 2021 and 2019).

3.2 Edge Computing

Shi et al- 2016 define edge computing as data processing at the "edge" of the Internet, i.e. data processing between the end devices and the large data centers. The technical reason for this development compared to cloud computing is primarily the efficiency advantage when data processing takes place close to where the data is generated. Before edge computing, there were already other efforts to detach data processing from the cloud, including cloudlets and fog computing. In their work, Shi et al. 2016 highlight three reasons in favor of edge computing:

1) Detachment from cloud services: Performing computations in the cloud is appealing, but network capacities have not increased at the same rate as the increasing computing power of data centers to process accumulating data. Due to the enormous increase in data that can be generated per second, network connections are now the bottleneck. Apart from the strain on the network infrastructure, applications are also disadvantaged by high response times due to a lack of bandwidth. 2) The pull effect of the Internet of Things (IoT): Almost every category of electrical device would become part of the IoT and consequently produce data. This would give rise to several requirements, including the requirement for data protection, which is an obstacle to processing IoT data in the cloud. 3) Shift from data consumer to producer: In the paradigm behind cloud computing, end devices are typically consumers, e.g. smartphones that play YouTube videos. However, users' devices are also producers of data, e.g. when videos are created and uploaded to YouTube. In such cases, the pre-processing, including compression of the data, could already be done by edge computing and not in the cloud, which in turn reduces the load on network resources (Eberz-Eder et al. 2021).

The advantages of edge computing include (1) the reduction of network resources if the data to be transmitted is already filtered or compressed before transmission, (2) a possible reduction in energy consumption due to a lower load on the network technology of the end devices, and (3) increased data protection if data is processed and depersonalized directly before it is transmitted and stored in the cloud, or if the data does not have to be distributed further in the network at all (Shi et al. 2016).

The disadvantages of edge computing are due to the more complex structure and include (1) higher initial costs due to expansion of the infrastructure, (2) increased requirements for care and maintenance of the overall system, and (3) a larger attack surface for malicious attackers.

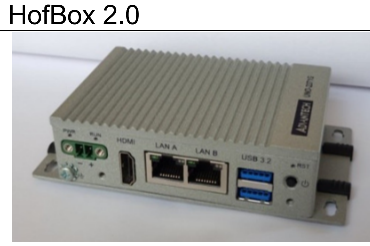
The term Resilient Edge Computing (REC) is the composite of the terms resilience (in the sense of resistance/adaptability) and edge computing as a system architecture approach (Eberz-Eder et al. 2022).

3.3 Hardware

For the practical implementation of Resilient Smart Farming in the form of Resilient Edge Computing, a so-called HofBox was used as a miniserver with the hardware of a Raspberry Pi 4, 4GB with LoRa board in the first step. This simple and commercially available hardware could be manually integrated into the Open Horizon infrastructure. The LoRa board is used as a gateway for an autonomous sensor network on the farm. In the second prototype, a HofBox 2.0 with x86 and Secure Device Onboarding (SDO) was used for automated deployment of software containers.

In further developments, we have upgraded the hardware and used a standard but powerful Intel NUC with expandable and flexible 16 GB RAM and a powerful GPU to make the HofBox “AI-ready”. The aim is to test different scenarios regarding the use of AI software in online, offline and hybrid form for agricultural use cases.

Table 1. Three different HofBox hardware were used

HofBox 1.2	description	HofBox 2.0	description
	Our first usable prototype of HofBox 1.2 was based on a Raspberry Pi 4 with 4 GB RAM and an extension of a LoRa-Board		The second usable prototype of HofBox 2.0 is a x86 with a secure device onboarding (SDO)
HofBox 3.0 (HofBoxAI)	description		
	HofBox 3.0 is based on a Intel NUC with expandable and flexible RAM (16, 32) and GPU. Possibility to integrate FDO.		

At the infrastructure level, Resilient Edge Computing is deployed via the open source framework Open Horizon [3,4] at the professional level as IBM Edge Application Manager. The software used to deploy software containers in the project is open source software in the first step, such as Libre Office, MQTT broker or the GeoBox-App. The Long Range Wide Area Network is supported, among other things, by its own gateways, which store the sensor data via the commnitiy-based and central platform The Things Network and make it available via APIs. You can see the different variants of the HofBoxes in (Table 1).

4 Results

4.1 From concept to practice – Resilient Smart Farming

Process of many years to develop an usable open source framework to support resilience in digital infrastructure with an easy way to adopt current and future technologies based on containerized software applications. The focus of the developments was on the design of an operational, productive and resilient infrastructure for agriculture (Reuter et al. 2018, Reuter et al. 2019, Eberz-Eder et al. 2021, Eberz-Eder et al. 2023, Kuntke 2023). Edge computing refers to a system architecture in which basic data processing services (primarily CPU and storage capacity) are not provided by central cloud systems, but instead directly at the point of origin of the data. As part of the GeoBox projects, the REC was planned on two levels: the infrastructure level (1) and the application level (2) (Eberz-Eder et al. 2023).

The focus was on the use of existing open standards, open and international ontologies and the transferability of the technologies to other systems (Kadi et al. 2023). The application of the Open Horizon Framework for the realization of a resilient infrastructure according to the "offline-first" principle was a novelty and required far-reaching considerations regarding the structure of the framework. The development was guided by the goal of establishing a resilient and usable infrastructure that can meet the requirements of foreseeable future developments in the area of the Internet of Things (IoT) and the use of AI-based services.

4.2 Hybrid Cloud Infrastructure with Open Horizon as main framework

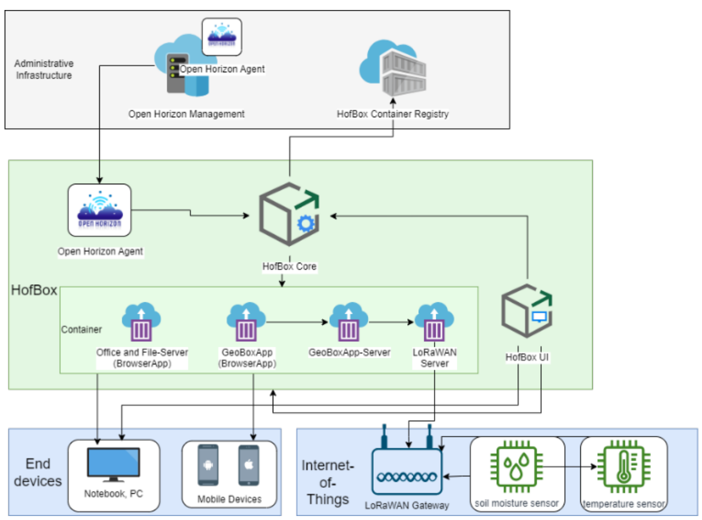


Figure 1 Open Horizon as main framework for managed containerized software at the edge in agriculture (Eberz-Eder et al. 2023)

The applications should be usable by means of a standard Internet browser, i.e. without additional software, accessible via a special start page on the HofBox and basically functioning without connection to the Internet. Furthermore, additional applications can be installed via the integration of an app store if desired by the user. To support the daily work, an (extendable) basic software (GeoBox app) is supplied as standard. The HofBox is a dedicated, self-contained, ruggedized compute server delivered to the farm, managed remotely, and providing localized workload ad data processing services to the farmer. In order to realize resilient smart farming into practiice, farmers data will be on the HofBox edge device. Only by agreeing, the data can be sent and stored elsewhere. The solution is fully resilient, because of a hybrid-cloud architecture which means that the solution is cloud agnostic.

At the administrative level (1), the Open Horizon Management Hub is installed, through which the Management Hub takes over the administration of the HofBoxes. This is an edge computing framework whose objective is to facilitate the administration and orchestration of applications and services at the edge of the network, i.e. close to the data sources. Distributed application provisioning via a management hub on different servers represents a resilient way of administering the HofBoxes. In order to reduce the administration effort of software on a large number of HofBoxes, this is automated via Open Horizon. This means that countless HofBoxes (edge devices) can be administered and operated. The security and scalability of the applications provided is guaranteed by the technology. The OH Management Hub can be scaled via several server-side OH Management Hubs as the number of HofBoxes (edge devices) increases. On both the server and client side, the Open Horizon Framework is based on open source software and is characterized by open standards. Shifting the computing operation to the end of the network (edge computing) appears to be a sensible measure to improve data processing and latency in light of the increased use of IoT applications in agriculture.

The HofBox level (2) contains the Open Horizon Agent, which communicates with the OH Management Hub (1) and, once its identity has been established, receives authorization to install the available containers on the Management Hub. The HofBox UI enables intuitive use of the available applications by the end user (farmer) (see also section 4.3). In the HofBox network, it is possible to access the applications installed on the HofBox via browser applications. This can be done both via the classic computer and via mobile devices. Furthermore, the applications can also be run offline on the HofBox. The need for a permanent internet connection depends on the respective software application and its specifications for operating the software. The GeoBox app developed by us and its basic services (booking journal, map editor and field pass) are also fully operational offline. However, there are also software applications that require an internet connection to function properly. This applies, for example, to the Watson Assistant for crop protection management or the LoRa network connection to the TTN server.

The basic architecture offers the opportunity to implement our preferred "offline first" principle in order to increase the resilience of the infrastructure. A permanent internet connection to the management hub is not absolutely necessary during operation.

The Figure 2 shows the hybrid cloud infrastructure, with 1 the classic central cloud-based services, 2 the network infrastructures required for use and the integration of resilient edge computing via Open Horizon as resilient edge computing and the option of deploying external containerized software applications on edge devices.

Resilient smart farming thru resilient edge computing is a role model for critical infrastructures and is running on current hardware settings.

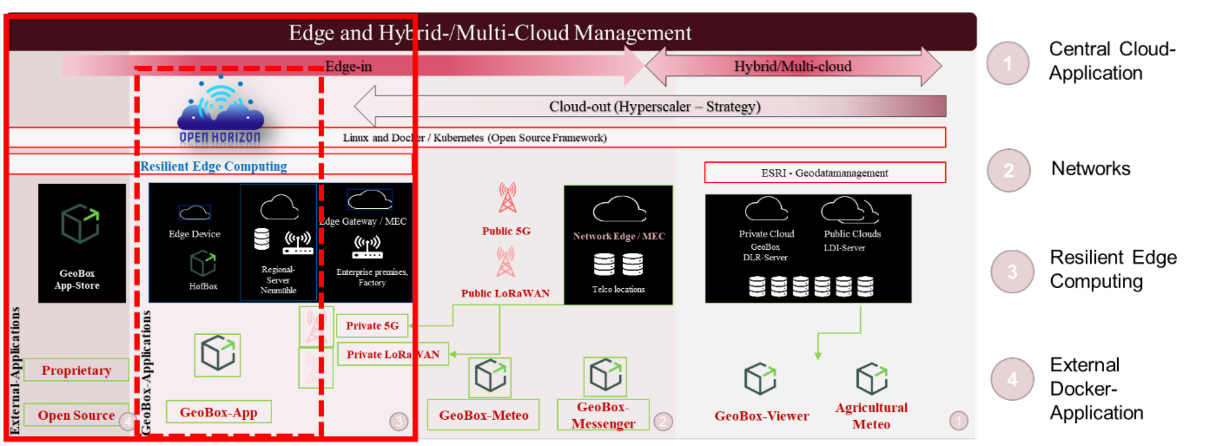


Figure 2 Hybrid cloud infrastructure with embedded resilient edge computing via open horizon

4.3 Containerized software applications

The HofBoxes are initialized, installed and updated without user interaction (zero touch) via the open source edge computing platform "Open Horizon". The application layer applications shall be containerizable to run in the data center, cloud-based or locally on the HofBox (Eberz-Eder

2023). In order to increase the user-friendliness of the software applications available in the Management Hub, the user (farmer) sees a clear dashboard with available information about the user, the software applications available in the Management Hub and the software applications already loaded via the IP address when starting the HofBox. It is possible to use both open-source and freely accessible (Libre Office,GeoBox-App, Streamsheets, Chirpstack, Snapdrop, FarmOS etc.) containerized software as well as proprietary containerized software on the HofBox (Table 2). This makes the solution very flexible, scalable and user-friendly. It also enables the active use of software that is already in use and will be used in the future.

The architecture of the GeoBox-App initially stores the necessary data locally on the mobile device and then synchronizes it against the operational HofBox (offline-first principle). The GeoBox-App local event store (Buchungsjournal) represents observations and actions taken as instances of formal activity ontology and transforms the documentation entries into a comprehensive operational knowledge graph based on RDF. The respective contents are formalized in a clear and machine-readable way by using terms from the AGROVOC Thesaurus of the Food and Agricultural Organization (FAO). A major advantage for the usability of the local event store is the use of existing open linked data standards. The linking of geo-based information from the state with operational land data and the production measures carried out on the land opens up new possibilities for optimization and information retrieval. This is done on the basis of semantic technologies and international ontologies.

3.1 HofBox-UI 3.2 GeoBox-App

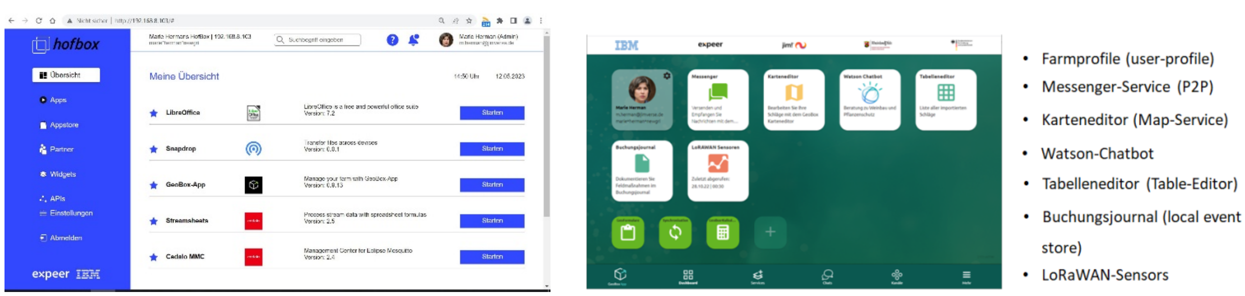


Figure 3 Basic software on HofBox, 2.1 HofBox-UI of usable containerized applications, 2.2 Screenshot of GeoBox-App

As part of the project, the deployment of various software applications relevant to agricultural practice was tested. Particular attention was paid to their suitability for use in the future. As part of the focus on Resilient Smart Farming (RSF), applications for implementing an “offline-first” principle and self-sufficient IoT networks were tested (Kuntke et al. 2022). We are using ChirpStack as an open-source LoRaWAN Network Server which can be used to setup LoRaWAN networks with HofBoxes. One possible application scenario for our development is to ensure the exchange of short messages during times of communication infrastructure failure in rural communities (Kuntke et al. 2023). The deployment of external containerized agricultural applications is shown in Figure 4. An open source farm management information system was installed there and used via the browser.

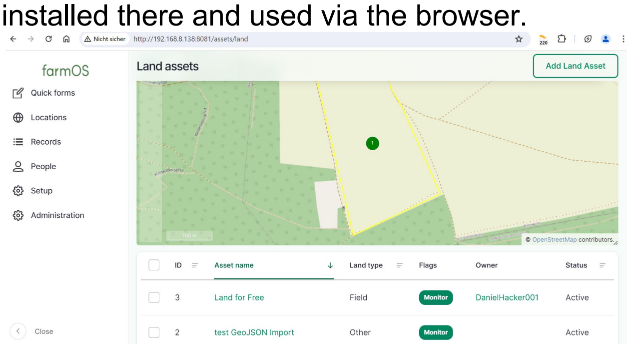


Figure 4 an example of a running containerized open source farm-management-information-system

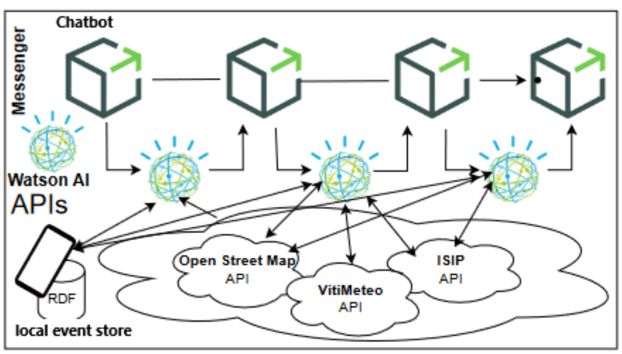
4.4 Solution for efficient and resilient AI-based services

The aim was to test different AI-based chatbot services in order to build a flexible, scalable hybrid cloud infrastructure that is necessary for the performance of the application.

Both online and offline scenarios with different AI-based services were to be tested. In recent years, AI-based services have also increased significantly in agriculture. As a result, various AI-based services were developed and tested during the implementation of the hybrid cloud infrastructure. Since 2021, an AI-based chatbot based on the Watson Assistant (IBM) has been available for the use case of pesticide application in viticulture. The service is a combination of external APIs from external providers and the advisory knowledge of the public viticulture advisory service in Rhineland-Palatinate. This is an internet-dependent chatbot (IBM Watson Assistant) integrated into the GeoBox-App with internet-dependent API services. The first development of an AI-based automated advisory service via messenger was intended to evaluate the feasibility and demonstrate the practical benefits.

The further development of the AI-based advisory service using a chatbot was implemented on the basis of the far more complicated resistance management in the cultivation of winter oilseed rape and its dependencies in the crop rotation. The flexible booking journal (local event store) based on AGROVOC ontologies was used for the first time as the basis for historical entries of measures. The GeoBox local event store documents agricultural observations and measures as formal instances of an activity ontology with reference to established vocabularies such as AGROVOC (Kadi et al. 2023). The modeling principles ensure maximum flexibility, extensibility, exchange and machine usability of the data. The resulting knowledge graph is used as an example in the chatbot for advice on resistance management in crop protection.

5.1 Workflow of AI-based Chatbot



5.2 Dialogue Chatbot

Figure 5 Workflow of AI-based Chatbot-II for resistance management in oilseed rape with local event store and third party APIs (source Kadi 2023)

In a further step, flexible and open-source-based software for the use of Large Language Models (LLM), the so-called Ollama[1], was set up and tested with the UI component OpenWebUI[2] using the Open Horizon Management Hub. The advantages of using this open source version of an AI-based chatbot are its high flexibility, independent adaptability, large selection of existing pre-trained models and community-based international further development by a large developer community.

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[1] https:ollama.com
[2] https:openwebui.com

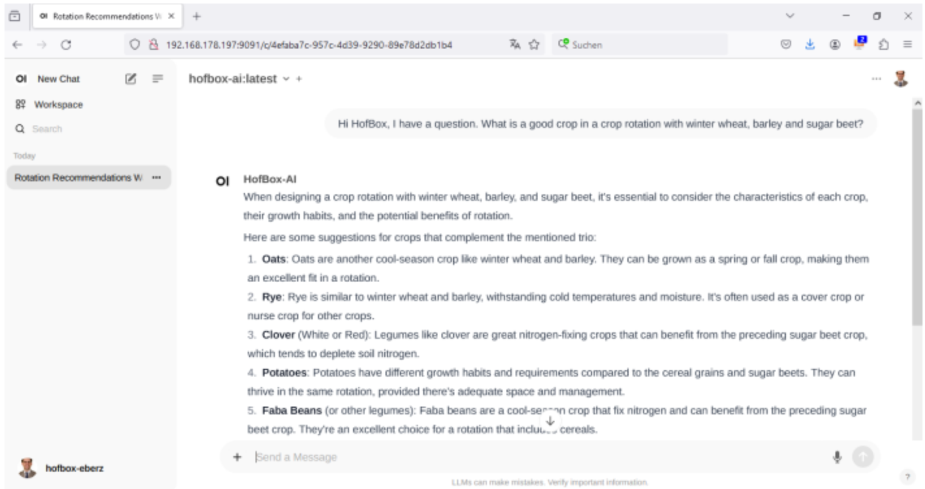

Figure 6 HofBox-AI a local open source based chatbot with Ollama and OpenWebUI

The current open source models like Llama3, Llama2, Gemma etc. available on the market have a comprehensive general training set. The aforementioned questions can be answered with a satisfactory degree of generality. But the relevant and time-critical information in the agricultural production process must be realized either by training own agricultural specific LLMs. From the practical tests carried out in recent weeks, it can be concluded that linking the RAG framework with common LLMs is a promising way to develop automated assistance systems for agricultural practice.

For the near future it is interesting to use local LLMs to run within a Retrieval-Augmented Generation (RAG) framework in order to use scientifically based and high-quality information in the background to help farmers through automated advisory communication via a chatbot (Lewis et al. 2020,).

4.5 Mobile edge as a technology in the near future

The performance of small computers and mobile computing systems such as smartphones and tablets has increased enormously over the last ten years. As a result, mobile devices are now able to process large amounts of data in a short space of time. Both the graphics processing unit (GPU) and the central processing unit (CPU) performance have increased significantly, as has the storage capacity. The increased use of mobile devices and applications in agricultural practice for various operations, such as pest monitoring, recording of area information and use of farm management information systems, has changed the shift in use from traditional computers to mobile devices (smartphones and tablets) in the last decade.

In this context, we wanted to test the Open Horizon software management system on mobile devices for the first time worldwide in order to determine the possibility of deploying containerized software on standard mobile Smartphone's. The mobile device (Smartphone) does not serve as a client with the corresponding application software, as is usually the case, but performs the server-side computing operations decentrally on the smartphone. The advantage of this is that the computing power and data storage takes place on the device at the point of origin. In the absence of an internet connection, this enables offline capability of the functionalities on the Smartphone acting as a server.

Our test deployment was on a SaaS solution of Open Horizon by IBM Edge Application Manager. Therefore workloads deployment and application lifecycle management capabilities embedded in Samsung industrial mobile devices are enhancing worker experience with AI-analytics and augmenting human productivity at scale and with cost efficiency. We'll also explore connectivity to other Edge workloads and private, public clouds for end-to-end distributed application connectivity with network as well as infrastructure and application observability. We deployed the containerized GeoBox-App (see Figure 3, 3.2 and Figure 7), which had already been tested on the HofBox, to the Smartphone via the management hub by Open Horizon and got it running. As a result, we were able to determine that the application could be executed without any noticeable performance problems for the user. In the near future it could be a possible solution to get more resilient mobile edge computing applications. This technology could potentially become a game changer in the future because it makes it possible to easily manage containerized software.

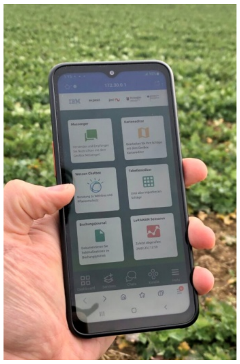

Figure 7 containerized agricultural software on smartphone

5 Discussion

In the current fast-paced and dynamic agricultural landscape, resilient smart farming is of paramount importance for ensuring food security and sustainability. By leveraging advanced technologies such as precision agriculture, IoT sensors, and machine learning, farmers can now respond rapidly to changing weather patterns, soil conditions, and crop health. This allows them to make data-driven decisions that minimize losses, optimize yields, and reduce waste. Moreover, resilient smart farming enables farmers to adapt to emerging challenges such as climate change, pests, and diseases, thereby ensuring the long-term viability of their operations. By embracing this innovative approach, agriculture can not only feed a growing global population but also contribute to a more sustainable and environmentally conscious food system for future generations.

The results shows that the development and testing of AI-based services, specifically chatbots, for agricultural use cases with different IT-architecture. Due to the rapid developments and the large international community, the basic developments have been developed on the basis of open source software. The benefits of using open-source solutions, such as Open Horizon as Management of workloads and LLM-Models such as Ollama, which offer high flexibility, independent adaptability, and a large selection of existing pre-trained models.

GenAI in combination with RAG in a hybrid cloud infrastructure can represent a good opportunity for rapid change in the area of automated advisory dialogs. A further step forward would be the development of an automated AI-based assistant that calculates critical and sensitive data from the farms on the local instance of the LLM on the HofBox and only needs to access web services for specific issues. Thanks to the synchronization mechanisms already developed, the data on the farm HofBox can be kept up to date.

As a milestone we are using mobile edge computing technology, where small computers and mobile devices can process large amounts of data in a short space of time. We test this technology by deploying containerized software on a standard mobile Smartphone using the Open Horizon software management system. They demonstrate that it is possible to execute the containerized GeoBox-App without any noticeable performance problems for the user.

By adopting a resilient approach to smart farming, RSF seeks to ensure that the benefits of digitalization in agriculture are not overshadowed by concerns about security and reliability. The concept has the potential to improve the overall efficiency, productivity, and sustainability of agricultural systems while minimizing the risks associated with their increasing dependence on technology. This approach acknowledges that no single solution can guarantee absolute security but rather focuses on creating a system that is highly resistant to failures and attacks.

This work showed that the Open Horizon Framework is suitable for deploying the containerized applications to the various edge devices (hardware) and managing the workloads, which was also implemented and tested on smartphones for the first time. The results also show that in times of increasing automation of processes in agriculture, AI-based advisory services can already be implemented. By using a hybrid cloud infrastructure, it is possible to run critical data and applications relevant in times of crisis resiliently according to the offline-first principle and to use cloud-based services in normal operation. This also shows that the hybrid cloud infrastructure can contribute to strengthening resilience and increasing the performance of different applications. We have to highlight the significance of standardized interfaces and open standards for improving the acceptance of such tools among farmers and industry. Thanks to its open architecture, it offers both public administration and the private sector the opportunity for joint further development.

The technical feasibility of using hybrid cloud infrastructure to increase resilience and performance was demonstrated. In addition, numerous practical tests must be carried out to determine the extent to which the infrastructure is able to function under practical conditions on farms with different requirements in terms of technical equipment and application knowledge. The topic of usability will play a greater role here.

The results so far show the opportunities of edge computing in conjunction with hybrid cloud management in agriculture.

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