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REPORT ON REMOTISATION AND SIMULATION TOOLS

2023-12-22

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Abstract

AgriFoodTEF is a network of test and validation infrastructures in Europe that supports Agri-Food technology companies to do near product development of their AI and Robotics solutions in real-world facilities. The overall aim is to close the gap between excellent research in these fields and actual products that support an efficient and sustainable agriculture, while meeting stringent usability and economic requirements of their end-users. AgriFoodTEF foundations are solidly rooted in existing experimental farms and facilities for AI and Robotics in Agriculture, already operational in various regions highly representative of European Agri-Food production. These have been clustered to build scale and further enhance the EU role in guaranteeing world food security with testing and validation facilities that will engage all relevant stakeholders with the best experts in the AI and Robotics technology domains. While each TEF-node will promote independent operations with a sustainable business model that will be optimized for the specialties and territorial needs, all TEF-nodes will share common guidelines, standards and support each other with services that can be offered across the different regions represented by nodes and satellites.

The agrifoodTEF digital infrastructure is the set of digital resources used to provide digital testing services which can be remotely accessed and are not tied to a physical facility. This report concerns a subset of these resources and provide an initial catalogue of the agrifoodTEF remotisation and simulation tools, which are software applications that enable the creation, visualization, and manipulation of virtual models of agrifood systems, as well as the remote control and monitoring of real-world devices and processes. This report describes a mix of tools and tool chains that is currently in use by the partners, and it finishes with a discussion of the results and future work. The report will be updated and extended in the following years, as the project progresses, and new results are obtained.

Introduction

Background

AgriFoodTEF is a network of test and validation infrastructures in Europe that supports Agri-Food technology companies to do near product development of their AI and Robotics solutions in real-world facilities. The overall aim is to close the gap between excellent research in these fields and actual products that support an efficient and sustainable agriculture, while meeting stringent usability and economic requirements of their end-users. AgriFoodTEF foundations are solidly rooted in existing experimental farms and facilities for AI and Robotics in Agriculture, already operational in various regions highly representative of European Agri-Food production. These have been clustered to build scale and further enhance the EU role in guaranteeing world food security with testing and validation facilities that will engage all relevant stakeholders with the best experts in the AI and Robotics technology domains. Furthermore, standards for dataset creation, data sovereignty, algorithm or benchmark interoperability will be based on GAIA-X as the ambassadors of different GAIA-X agricultural-domains in Europe are part of the proposal. While each TEF-node will promote independent operations with a sustainable business model that will be optimized for the specialties and territorial needs, all TEF-nodes will share common guidelines, standards and support each other with services that can be also offered across the different regions represented by nodes and satellites. The final aim is to help Europe achieve leadership in fostering top quality, technology driven and massive adoption of innovative solutions for Agri-Food, bringing primary production to new levels of efficiency akin to what was achieved by the Green Revolution.

The agrifoodTEF digital infrastructure is the set of digital resources used to provide digital testing services which can be remotely accessed and are not tied to a physical facility. This report concerns a subset of these resources and provides an initial catalogue of the agrifoodTEF remotisation and simulation tools.

Purpose

This report is the first annual report of the agrifoodTEF project, and it aims to showcase the outcomes of the work done on the simulation and remotisation tools during the first year of the project. The report is part of deliverable 2.4, which corresponds to task 2.3 of the project. The report will cover the following aspects:

The description of the simulation and remotisation tool identification method, the existing simulation and remotisation tools most of which are used by the AgrifoodTEF partners, including software applications that enable the creation, visualization, and manipulation of virtual models of agrifood systems, as well as the remote control and monitoring of real-world devices and processes. The tools will be continuously designed and developed according to the specifications and needs of the end-users and the technical partners and they will be integrated into a common platform that facilitates their interoperability and accessibility in accordance with work from Task 2.1 and 2.2. The end-users are the stakeholders from the agrifood sector, such as farmers, processors, distributors, and consumers, who benefit from the use of the tools for improving their productivity, quality, and sustainability. The technical partners are the organizations from the research and innovation sector, such as universities, research institutes and companies, who are responsible for developing, testing, and deploying the tools.

The report intends to provide a comprehensive overview of the simulation and remotisation tools of the agrifoodTEF project, as well as to demonstrate their value and potential for enhancing the efficiency, sustainability, and resilience of the agrifood sector. This will mainly be done by collecting information and statistics from the infrastructure that will be provided by task 2.1. The report will be updated and extended in the following years, as the project progresses, and new results are obtained.

Outline

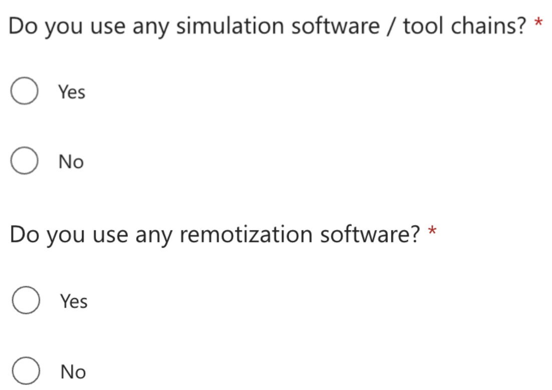
This document gives an overview of the task and purpose of the report. It details the work done around simulation and remotisation tools in T2.3 including the AgrifoodTEF simulation and remotisation tool survey conducted by RISE to identify simulation and remotisation tools currently being used by the AgrifoodTEF partners. It then goes through the different categories of simulation and remotisation tools descriptions and short analysis that are mostly identified through the survey process and is made available through the agrifood TEF. It finishes with a discussion of the results and future work.

As part of the activities to identity simulation and remotisation tools in T2.3, RISE conducted a *'simulation and remotisation survey'* to understanding the current landscape and future potential of simulation and remotisation tools as key enablers in agricultural technology. The survey was designed to gather valuable insights from the partners, focusing on evaluating the effectiveness, challenges, and reusability opportunities of the tools. The primary objectives of the survey were to:

- **Assess application areas:** What are the application areas where simulation and remotisation tools are currently being utilized within agrifood technologies?
- **Evaluate adoption rates:** How widely have these tools been adopted by the partners and to what extent integrated into their existing agricultural practices?
- **Determine impact:** What is the impact of these tools on improving efficiency, productivity, and sustainability in agriculture?

AgrifoodTEF simulation and remotisation tool survey methodology:

The survey was conducted using mixed methods for the survey questions by creating a mix of quantitative and qualitative questions designed to capture detailed feedback on current tool practices, relevant tool links, user experiences, number of tools already under use per partner, and main expert contacts for the simulation and remotisation tools. Some questions were made mandatory to answer 'yes' or 'no' (e.g., 'do you use any simulation/remotisation software?' as shown in Figure 1) to understand the current state of simulation/remotisation tools usage followed by some more specific questions (not mandatory) if answered 'yes' to gain additional information about the specific tools. We also kept some questions open ended not only to identify types of simulation tools used but also to gain information about any new types of simulation and remotisation tools available to collect feedback based on partner experiences. Moreover, there were questions to understand various other aspects such as the extent of remote operation integration, benefits realized, tool preference on a scale of 1 to 5, tool accessibility, and understand partner plans with the tools.


Do you use any simulation software / tool chains? *

Yes

No

Do you use any remotization software? *

Yes

No

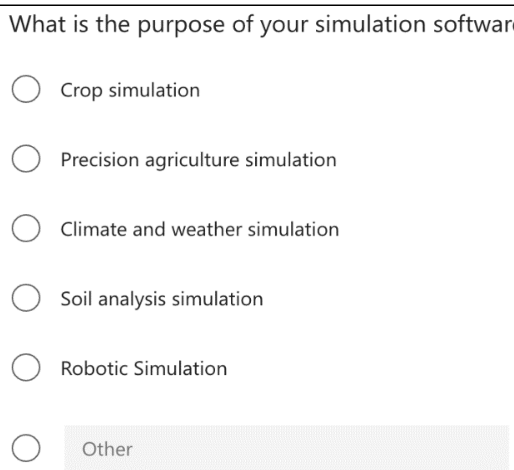


Figure. 1 Survey question to identify the different purposes of simulations in AgrifoodTEF.

The survey link was forwarded to a diverse group of partners working in the agrifood sector, including researchers and industry experts, to identify partners' current use of simulation and remotisation tools. The intention for us this year is to identify tools that are *already in use by partners* to determine suitability for remote experiments in the agricultural landscape. The survey findings provided us with a bigger picture for understanding how simulation and remotisation tools are practically used in the agrifood sector, guiding strategic decisions to enhance efficiency, cost reduction, productivity, and sustainability in agricultural practices.

Simulation Software

Simulation software serves as a platform for creating virtual models and environments for testing, training, and analysis purposes. These tools allow for the replication of real-world scenarios within a controlled digital space, facilitating experimentation, design, and training without the constraints or risks of physical testing. Common applications include engineering simulations, flight and driving simulators, medical training, and 3D modeling. Simulation software often includes realistic physics engines, graphical interfaces, and support for data analysis, catering to various industries like aerospace, automotive, healthcare, and entertainment. The versatility of simulation software enables users to refine designs, train personnel, and conduct research in a cost-effective and safe manner.

Crop simulation

Unity

Unity is proprietary software that offers free versions for individuals and companies. The Unity Perception package[unity-perception2022] provides a toolkit for generating large-scale datasets for computer vision training and validation. The package is open-source and licensed under Apache License Version 2.0.

EV ILVO uses Unity for Sim2real flower detection towards automated Calendula harvesting. More information can be found in the paper by Vierbergen et al [Sim2real]. The paper presents a pipeline to generate synthetic data of agricultural processes with photogrammetry and a game engine. A Calendula flower detector based on a convolutional neural network is trained on synthetic data and validated on a test set of real Calendula images (sim-to-real transfer). This flower detector, combined with stereo vision, enables the localization of the flowers to automatically adjust the height of harvesters to increase harvest efficiency. All collected and generated data is made available on Zenodo.org [Sim2real dataset] as a contribution to future research on precision agriculture. The synthetic dataset follows the Synthetic Optimized Labeled Objects (SOLO) Dataset Schema, as defined in the Unity Perception package. For completeness, the data scheme is also included in the upload.

Tool Assessment:

- **Used by:** EV ILVO
- **Link to the website:** https://unity.com/
- **Tool effectiveness:** Unity is effective for creating realistic simulations and generating synthetic datasets for training computer vision models. Its use in the Sim2real flower detection project demonstrates its capability to bridge the gap between simulated and real-world agricultural data, achieving an F1 score of up to 86% on test sets of real data. The detection model determined the 3D positions of flowers with an average error of 6 ± 5.1 mm in predicting flower height. Using the tool, it took only 20 minutes to generate a training set of 15,000 synthetic images on a laptop with an Intel i7-8550U CPU and a Radeon Pro WX 3100 GPU. EV ILVO gave a score of 5 in the survey question of how likely they would recommend Unity on a scale of 1 to 5 where 1 means 'not at all' and 5 means 'very likely'.
- **Integration strategies**: Unity integrates with various machine learning frameworks and tools. It can be used to generate labeled datasets that can be used to train and validate machine learning models, enhancing its applicability in precision agriculture.
- **Cost analysis**: Unity is propriety, but it offers a free version for individual users and small companies. The major costs involve the initial setup and any potential licensing fees for advanced features (e.g., high resolution 3D objects, map integration with GAIA).
- **Assumptions:** Access to high-performance computing resources to handle extensive processing required for simulation and data generation. It also requires basic understanding of game engine operations, computer vision and basic machine learning principles.
- **Skill requirement:** Technical skills in game engine operations, scripting and understanding of computer vision and machine learning concepts. There is available documentation and community support available.

Robotic simulation

Webots

Webots, developed by Cyberbotics, is an open-source, general purpose simulation software for robotics used by UniMi (University of Milan). It provides an environment for modeling, programming, and simulating robots, designed for professional use in industries, education and research featuring GUI, a physics engine (ODE fork) and an OpenGL 3.3 rendering engine. The software supports programming in C, C++, Python, Java, MATLAB, and ROS, offering a simple API for basic robotics needs.

Tool Assessment:

- **Used by:** UniMI, WUR
- **Link to the website:** https://cyberbotics.com/
- **Tool effectiveness:** Webots is a general-purpose simulation software for robotics. UniMi and WUR give an average score of 4 in the survey question of how likely they would recommend Webots on a scale of 1 to 5 where 1 means 'not at all' and 5 means 'very likely'.
- **Integration strategies:** Webots can be integrated into existing project workflows by using its APIs to connect with software and hardware tools making it versatile for both project and research activities. It supports various programming languages including C, C++, Python, Java and Robot Operating System (ROS).
- **Cost analysis:** Webots is free and open source.
- **Assumptions:** Access to compatible computer hardware capable of running the software.
- **Skill requirement:** Webots require basic understanding of robotics concepts and programming languages required for the simulation environment. Tutorials and user guides are available online.

Gazebo

Gazebo is an open-source 3D robotics simulator that incorporates the ODE physics engine, OpenGL rendering, and supporting code for sensor simulation and actuator control. It allows the use of various high-performance physics engines, with ODE being the default. Gazebo offers realistic rendering of environments, featuring high-quality lighting, shadows, and textures. Additionally, it can model a variety of sensors, including laser range finders, cameras (wide-angle included), Kinect-style sensors, and more. Politecnico di Milano uses Gazebo to develop and test robotic navigation algorithms that exploit multimodal sensor input like lidar and camera data in virtual vineyards before the robot is ready to navigate in the real world to arrive faster at an initial prototype. Moreover, the preliminary tests in a virtual environment allow increased safety and minimize the risk of costly damage to the robot and the plants when the algorithm is still in the early stages and potentially subject to unexpected outcomes and bugs.

Tool Assessment:

- **Used by:** Politecnico di Milano, WUR
- **Link to the website:** https://gazebosim.org/
- **Tool effectiveness:** Gazebo enables physical designs in realistic virtual environments with a variety of sensor streams. The tool provides advanced 3D graphics, precise physics engine and multimodal sensors. Gazebo makes it possible to test control strategies in a safe virtual environment. As an example, Politecnico di Milano uses Gazebo to develop and test robotic navigation algorithms, and gave a score of 4 in the survey question of ‘how likely they would recommend Gazebo’ on a scale of 1 to 5 where 1 means ‘not at all’ and 5 means ‘very likely’.
- **Integration strategies:** Gazebo can be integrated with software tools and robot operating systems (ROS) through its APIs and plugins to test robot operations in a safe virtual environment.
- **Cost analysis:** The tool is open source.
- **Assumptions:** Access to computer system with sufficient processing power and graphics capabilities to handle 3D simulations.
- **Skill requirement:** Gazebo requires a basic understanding of robotics and simulation principles. There is documentation available online and a community for support (https://community.gazebosim.org)

4D-Virtualiz / 4DV-SIMULATOR

4D-Virtualiz is a proprietary software used by LNE and Politecnico di Milano. The software simulates one or more robotic models into a 3D world. It has a physics engine which computes the world dynamics and produces accurate simulation of robot movements and its interactions with the environment. It can be used to assess the system robustness against challenging situations and produce stress tests, simulate sensor degradation, etc. Politecnico di Milano used the 4DV-SIMULATOR / 4D-Virtualiz during the FIRA 2024 Hackathon Competition. The competition concerned developing navigation and obstacle detection algorithms in a simulated farm. The Politecnico team participated in the challenge and had the opportunity to test their algorithms inside the 4DV simulator, which can simulate the real world with higher fidelity, like more realistic ground friction models or environmental conditions like rain. LNE is developing a platform named LEIA Simulation (purely numeric for virtual testing) to evaluate and assess agrifood robots using 4DV-Virtualiz to generate synthetic data of harsh environmental conditions such as foggy situations, and day/night images. A second infrastructure named LEIA Immersion was developed for hardware-in-the-loop mixed testing of AI physical systems and models in their environment.

Tool Assessment:

- **Used by:** LNE and Politecnico di Milano
- **Link to the website:** https://www.4d-virtualiz.com/

- **Tool effectiveness:** 4DV-SIMULATOR is a real-time 3D simulation platform used for the development of robotic systems like vehicles, robots and drones. The tool enables realistic 3D virtual representations of operational use-cases. Politecnico di Milano has used the 4DV-SIMULATOR/4D-Virtualiz for developing navigation and obstacle detection algorithms in a simulated farm. LNE and Politecnico di Milano give an average score of 4.5 in the survey question of how likely they would recommend 4DV-SIMULATOR/4D-Virtualiz on a scale of 1 to 5 where 1 means 'not at all' and 5 means 'very likely'.
- **Integration strategies:** 4D-Virtualiz integrates with various robotics software and hardware to support real-time data exchange and co-simulation with other platforms, making it suitable for diverse research and development projects.
- **Cost analysis:** 4D-Virtualiz requires a licensing fee. The cost varies based on the usage requirements and scale of the deployment. While the initial setup can be significant, the detailed simulations and robot testing capabilities can lead to cost savings by reducing the need for physical prototypes and minimizing risks in real-world testing.
- **Assumptions:** Access to high performance computing resources to handle complex simulations.
- **Skill requirement:** 4D-Virtualiz requires fundamental understanding of robotics, simulation principles and familiarity with programming. There is documentation and support available to assist practitioners.

ISAAC Sim

ISAAC Sim is an open-source, robotic simulation software built to address many of the most common use cases, including manipulation, navigation, and synthetic data generation for training data. It includes advanced physics simulation, photorealism and MDL (Material Definition Language) material definition support for physically based rendering. LNE explored other simulation tools such as the ISAAC Sim to setup a robot navigation in its controlled environment. Besides a huge graphical consumption, ISAAC Sim proposes a standardized format to import robots (URDF).

Tool Assessment:

- **Used by:** LNE
- **Link to the website:** https://developer.nvidia.com/isaac-sim
- **Tool effectiveness:** ISAAC Sim is useful to generate synthetic data for training AI models, enhancing the development and validation process. It also provides useful simulation capabilities for robotic detailed manipulation and navigation tasks. LNE gave a score of 4 in the survey question of how likely they would recommend ISAAC Sim on a scale of 1 to 5 where 1 means 'not at all' and 5 means 'very likely'.
- **Integration strategies:** ISAAC Sim integrates with NVIDIA's ecosystem, including GPUs and deep learning frameworks. It supports ROS and other robotics middleware.
- **Cost analysis:** ISAAC Sim is freely accessible. However, optimal performance may require NVIDIA hardware, which could involve additional costs.
- **Assumptions:** Effective use of ISAAC Sim requires access to compatible NVIDIA hardware and an understanding of NDIVIA ecosystem.
- **Skill requirement:** Familiarity with robotics simulation, AI model training principles and NVIDIA's tools and platforms. There is documentation and community support available for practitioners.

Esmini

Esmini (Environment Simulator Minimalistic) is an open-source software tool to play "OpenSCENARIO" files. It is available both as a stand-alone application and as a shared library for linking with custom applications. In addition, some tools have been designed to support design and analysis of traffic scenarios. AstaZero uses Esmini to visualize scenarios where the tool CARLA is used as rendering and early proof of concept simulation engine when working with perception and robotics.

Tool Assessment:

- **Used by:** AstaZero
- **Link to the website:** https://esmini.github.io/
- **Tool effectiveness:** AstaZero uses Esmini to visualize automotive scenarios in combination with the tool Carla. They gave a score of 2 in the survey question of how likely they would recommend Esmini on a scale of 1 to 5 where 1 means 'not at all' and 5 means 'very likely'.
- **Integration strategies:** Esmini integrates well with other simulation tools such as CARLA to enhance visualization and scenario analysis.
- **Cost analysis:** Esmini is open source, eliminating licensing costs.
- **Assumptions:** Access to compatible hardware capable of running the simulations efficiently.
- **Skill requirement:** It requires knowledge of traffic scenario design, software developer and python knowledge. There is available documentation and community support to help users.

CoppeliaSim VREP

CoppeliaSim (formerly V-REP) is a robotics simulator. It has an integrated development environment and is based on a distributed control architecture.

Tool Assessment:

- **Used by:** ILVO
- **Link to the website:** https://www.coppeliarobotics.com/
- **Tool effectiveness:** CoppeliaSim is useful for research and development projects in robotics as it allows simulating complex robotic systems and processes. Its distributed control architecture allows for flexible and scalable simulations.
- **Integration strategies:** CoppeliaSim integrates with multiple programming languages including Python, C/C++, Java and robotics frameworks/ROS. It also allows seamless connectivity and data exchange with other tools and systems.
- **Cost analysis:** CoppeliaSim has both free and paid versions. The free version provides all basic capabilities, while the paid version offers additional features and support tailored to different user needs and budgets.
- **Assumptions:** Access to compatible hardware and stable development environment for optimal performance.
- **Skill requirement:** Familiarity with robotics simulation and basic programming skills. The platform provides documentation and tutorials to assist users.

Autonomous driving

CARLA (UE4)

CARLA is an open-source simulation software based on the game engine "Unreal Engine 4" to take advantage of the photorealistic rendering. It is mainly used for autonomous driving vehicle simulation, but it can also be applied on other domains where autonomy behavior relies on the perception of the environment through cameras.
CARLA supports development, training, and validation of autonomous driving systems. In addition to open-source code and protocols, CARLA provides open digital assets (urban layouts, buildings, vehicles) that were created for this

purpose and can be used freely. The simulation platform supports flexible specification of sensor suites, environmental conditions, full control of all static and dynamic actors, maps generation and more.
LNE used CARLA combined with Unreal Engine 4 to set up and integrate a robotic environment that includes various scenarios for autonomous driving. CARLA provides more photorealism for a better compromise of graphical resources needed than other evaluated tools.

Tool Assessment:

- **Used by:** LNE, AstaZero
- **Link to the website:** https://carla.org/
- **Tool effectiveness:** Carla is mainly used for autonomous driving vehicle simulation. LNE and AstaZero give an average score of 3 in the survey question of how likely they would recommend Carla on a scale of 1 to 5 where 1 means 'not at all' and 5 means 'very likely'.
- **Integration strategies:** Carla integrates with machine learning frameworks and supports ROS, with extensive customization and integrations with other tools and systems.
- **Cost analysis:** Carla provides open-source code and open digital assets (urban layouts, buildings, vehicles) that can be used freely.
- **Assumptions:** Access to high-performance computing resources capable of handling detailed simulations.
- **Skill requirement:** Basic understanding of autonomous driving principles and simulation techniques. There is documentation and community support to help troubleshoot issues.

Farm simulation

Digital Future Farm

This digital twin represents the nitrogen cycle of an arable farm or a dairy farm. It comprises of existing process-based and new data-driven models fed with real farm data to mimic reality. It can be used by farmers and researchers to reduce the nitrogen surplus of a farm while maintaining crop yields.

Tool Assessment:

- **Used by:** WUR
- **Link to the website:** https://www.wur.nl/en/research-results/research-funded-by-the-ministry-of-lnv/soorten-onderzoek/kennisonline/digital-future-farm-dff-1.htm
- **Tool effectiveness:** Digital Future Farm is useful in modelling and simulating the nitrogen cycle within a farm. It provides insights into nitrogen use efficiency, helping to identify opportunities for reducing nitrogen surplus while ensuring optimal crop yields. WUR uses the tools as part of their design process. The tool employs modular components, representing a biophysical aspect of the farm (e.g. soil, crops, animals). Each component can be made custom to a farm and linking these components results in a full-inclusive farm-specific digital twin. A machine learning approach is discussed to be used for the twinning process.
- **Integration strategies:** Digital Future Farm integrates with data sources, including sensors and IoT devices to collect real-time data from the farm. It can also be connected with other farm management software to provide a comprehensive overview of farm operations. It also provides integration opportunity with other farm databases and external data sources.
- **Cost analysis:** Digital Future Farm is a research institute funded project leveraging existing infrastructure and open-source models to minimize costs. The primary costs involve the setup and maintenance of sensors and IoT devices, as well as data processing and analysis. The ongoing operational costs are relatively low compared to the benefits in terms of improved nitrogen management and crop yields.

- **Assumptions:** Access to accurate and reliable data from sensors and IoT devices. Adequate computational resources are required to run the models and simulations.
- **Skill requirement:** Basic understanding of the nitrogen cycle and its impact on crop production. Also, familiarity with data collection technologies. There is training and support available through WUR to help users interpret the data and implement recommendations on the simulation results.

Summary

The above-mentioned software packages, currently in use by our partners UniMi, Politecnico di Milano, WUR, ILVO AstaZero and LNE, offer unique features tailored to specific types of simulation, ranging from robotic movement and interaction to autonomous driving and crop simulation. In the survey, LNE also mentioned that they have several other simulation capabilities such as MATLAB/Simulink: Embedded solution testing without 3D Rendering (Licensed) and SCANeR Studio: Close to CARLA Sim (Licensed). Universitat de Lleida uses ExtendSim to prototype and interact with end-users developing discrete event simulation models. ExtendSim is a general-purpose discrete event simulation tool.

Remotisation Software

Remotisation software and tools enable work from a remote location and include software and interfaces for remote access to desktops, networks and tools. Remotisation software and tools could enable remote sensing, remote monitoring, remote operation, remote tests in physical and simulated environments, remote dataset creation, or other remote services.

Remote desktop access

VNC (Virtual Network Computing) for AI Model training

VNC is a remote desktop software that enables users to access and control a computer from another device regardless of the location. This feature is beneficial for various applications, including AI model training offering secure and convenient remote access to computational resources. VNC implementations used by EV ILVO are open source but there are also proprietary versions available.

Tool Assessment:

- **Used by:** EV ILVO
- **Link to the website:** https://www.realvnc.com/
- **Tool effectiveness:** VNC is effective in providing remote access to computational resources required for resource intensive AI model training. EV ILVO give a score of 5 in the survey question of how likely they would recommend VNC on a scale of 1 to 5 where 1 means ‘not at all’ and 5 means ‘very likely’.
- **Integration strategies:** VNC can be integrated with various operating systems and platforms. It can be used alongside other remote access tools and software to create a robust remote working environment.
- **Cost analysis:** The open-source versions of VNC are free.
- **Assumptions:** Access to stable and fast internet connection to maintain seamless remote access. It assumes users have necessary permissions and security protocols in place to access remote machines. Also, adequate hardware resources on both the client and server sides are required.
- **Skill requirement:** Basic technical skills in setting up and configuring remote desktop connects. Familiarity with operating systems involved and basic understanding of network configurations. There is available documentation and communication support to help practitioners troubleshoot any issues.

Remote tool access

FarmBot

FarmBot is an open-source CNC (computer numerical control) farming machine and software platform that allows remote control and management for precision agriculture. FarmBot is run by Raspberry Pi computers and Farmduino micro-controllers providing millimeter accuracy using the FarmBot genesis model. FarmBot can specifically be used by AgrifoodTEF partners for testing remote control operations of planting, watering, and weeding. It has a web-based interface for real-time monitoring and control. FarmBot also provides integration with sensors for soil moisture, light and temperature and can be customized with new tools and software updates.

Tool Assessment:

- **Used by:** Off-the-shelf remotisation platform.
- **Link to the website:** https://farm.bot/
- **Tool effectiveness:** Effective for precision, agriculture tasks, offering precise control over planting, watering and weeding. Suitable tool for testing and optimizing farming practices.
- **Integration strategies:** FarmBot has a modular design to support integration with additional hardware and software components. It can be connected to other open-source tools, platforms and various sensors for enhanced agricultural functionality.
- **Cost analysis:** The platform is open source, but the initial setup costs can include purchasing hardware components (e.g., sensors, Raspberry pi). Ongoing costs are minimal, which mainly involve maintenance and potential upgrades.
- **Assumptions:** Access to stable internet connectivity for remote control and monitoring.
- **Skill requirement:** Basic technical skills and understanding of computer hardware, software, and web interfaces to set up and customize the system. There is documentation and support community available to assist practitioners.

OpenAG

OpenAG is an initiative to develop an open-source agriculture platform for controlled environment agriculture. It allows remote control and management of various agricultural processes. The platform uses a combination of hardware and software to create 'Food computers' that can monitor and control environmental conditions with high precision. The AgrifoodTEF partners can use OpenAG facilitated with a web-based interface for real-time monitoring and control, and it integrates with various sensors for environmental factors such as humidity, temperature, and CO2 levels.

Tool Assessment:

- **Used by:** Off-the-shelf remotisation platform
- **Link to the website:** https://www.media.mit.edu/groups/open-agriculture-openag/overview/
- **Tool effectiveness:** Useful for research and educational purposes, allowing users to conduct experiments and optimize growing conditions for various crops. OpenAG is mainly effective for controlled environment agriculture, enabling precise control over environmental variables.
- **Integration strategies:** OpenAG integrates with a variety of agricultural sensors and can be connected to other open-source tools and platforms. The platform design is modular which allows practitioners to add new components and software updates easily, enhancing its functionality and adaptability to different research needs.
- **Cost analysis:** OpenAG is an open-source platform, and the initial expenses will include the purchase of hardware components and sensors, but ongoing costs are primarily related to maintenance and potential upgrades.

- **Assumptions:** Access to a reliable internet connection for remote control and monitoring
- **Skill requirement:** Using OpenAg requires some technical skills, including familiarity with computer hardware, sensors, and web-based interfaces. However, extensive documentation and a supportive community are available to help users with various levels of expertise.

Summary

VNC is currently being used by EV ILVO to perform AI model training. The software's ability to facilitate collaboration and resource optimization makes it an asset as remotisation tool, especially in the field of AI research and development. Farmbot and OpenAG are tools used for remote control and management. Other than that, Josephinum research is planning to introduce remotisation pipeline for their new mobile sensor platform (Infrastructure WP1).

Discussion and future work

In this report we describe the status of the survey on available tools in AgrifoodTEF. Early results show a mix of tools and tool chains that is currently in use by the partners. We have in this report identified eight simulation- and three remotisation tools. This is still a work in progress and several tools may still be missing from this report. We see several avenues for expansion in the next yearly report. Besides extending the list of tools we see an opportunity to evaluate the performance, usability, and reliability of the tools, based on the feedback from the end-users and the technical partners, who have tested and validated the tools in different use cases and scenarios. This evaluation could involve the assessment of the technical, economic, and environmental impacts of the tools, as well as their compliance with ethical and legal standards.

Another topic of interest is the identification of the challenges, limitations, and future improvements of the tools, as well as the lessons learned from the implementation process. The report discusses the main difficulties and issues encountered during the development and testing of the tools, as well as the possible solutions and recommendations for enhancing their functionality, quality, and usability. The report can thus reflect on the best practices and methodologies adopted for the successful execution of the project from a tool utilization perspective.

Timeframes and next steps:

- ***In year 1***, our primary focus was to identify which tools are already in use by the AgrifoodTEF partners and to understand their effectiveness in agriculture-specific simulation and remotisation experiments. Based on the survey findings, our next step is to develop a series of seminars (that has already started) and workshops for AgrifoodTEF partners. These sessions will explore the practical applications of the different tools, discuss upcoming and possible AgrifoodTEF services, and map the tools to these services.
- ***In year 2***, we will continue the seminar series, which will serve as a platform for a more comprehensive evaluation of the available tools and an opportunity to identify new tools that meet agricultural requirements. This ongoing evaluation process will help us refine our approach and ensure we are utilizing the best possible tools for our needs.
- ***Between years 3 and 5,*** we will use the insights gained from these evaluations to set up a dedicated simulation and remotisation tool knowledge base specific to agricultural practices. This knowledge base will serve as a resource for all AgrifoodTEF partners, providing detailed information on the tools' capabilities, best practices for their use, and guidelines for integration into agricultural systems.

References

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