IEEE

UNIVERSITÀ DI PISA

SCUOLA SUPERIORE SANT'ANNA PISA

2023 IEEE INTERNATIONAL WORKSHOP ON

METROLOGY FOR AGRICULTURE AND FORESTRY

NOVEMBER
6 - 8, 2023

PISA, ITALY

PROCEEDINGS

IEEE Catalogue Number: CFP23U22-USB
ISBN: 979-8-3503-1271-3

Field campaign and experimental design for robot performance evaluation (ACRE 2023)

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***Abstract*— Automating crop monitoring and management represents significant challenges for robotic solutions in agriculture. Autonomous navigation in open fields is crucial for evaluating robotics performance. The Agri-food Competition for Robot Evaluation (ACRE) aims to benchmark agricultural tasks and evaluate weeding robot performances. This paper presents the experimental design of the ACRE competition, focusing on the test field, navigation benchmark, organization management and challenges encountered. Accurate vehicle heading estimation and adaptive control techniques are key challenges for successful navigation. The ACRE competition promoted eco-friendly practices and sustainability by reducing chemical usage. The findings could contribute to the development of innovative solutions for precise crop monitoring, reducing environmental impact.**

Keywords— Crop monitoring, performance evaluation, robotics, smart agriculture, benchmarking

I. Introduction

Automating crop monitoring and management is one of the most challenging tasks for robotic solutions [1]. Autonomous navigation in open agricultural fields plays a critical role in evaluating the performance of robotics solutions. It requires high precision and adaptability to various unstructured environments, production systems, and target crops [2]. Navigation is one of the supporting tasks together with localization, obstacle avoidance, and object detection that robots must accomplish to successfully execute specialized agricultural operations such as structural characterization, physiology assessment, crop and weed detection [3]. Among these navigation tasks, precise vehicle heading estimation holds particular importance in the agricultural context. Developing and testing autonomous turning controls for robots that can reliably follow navigation paths and employ adaptive control techniques to account speed variations, terrain conditions, and field structures are key challenges [4]. Maneuvering lane changes and steering through narrow spaces within the same row present critical challenges for vehicle heading estimation to prevent heading drift and ensure accurate steering angle estimation [5], [6]. Robot navigation systems in open fields must demonstrate high accuracy and adaptability to different unstructured scenarios, weather conditions, crops and production systems [2]. The primary objective of agriculture robot navigation systems is to follow precise trajectories while maintaining a constant distance from near rows and avoiding obstacles [7]. Technologies like RTK GPS systems or tracking laser systems can be employed to verify field operations and efficiently design fields based on the type of plants and scheduled robot tasks [8].

In this context, the EU-funded METRICS project includes four robot benchmarking competitions, among them, the Agri-food Competition for Robot Evaluation (ACRE), aimed at assessing various agricultural tasks [8]. Previous field campaigns have been extensively described by [9] and were based on the concept of "benchmarking through competition" [10]. The ACRE competition is based on the ROSE Challenge, which focused on alternative intra-row weed control methods tominimize herbicide use [11]. Rigorous protocols and

objective metrics were employed to evaluate weeding robot performances. This correct evaluation cancontribute to the development of eco-friendly alternatives to the use of chemical products in agriculture, with all environmental and economic benefits connected.
The field campaign took place in a real agricultural setting and it was fundamental to simulate real environmental conditions, where different robotic platforms can execute the scheduled benchmarks (12):

- functionality BenchMark (FBM):
  - plant discrimination;
  - field navigation;
  - leaf area estimation;
  - weed destruction;
  - biomass estimation.
- Task BenchMark (TBM):
  - intra-row weeding;
  - crop mapping.

This paper aims to provide precise information about the ACRE competition experimental design, with a focus on the timeline and on all the necessary operations to arrange the test environment. The main attention is given to all the facilities and conceptual aspects required for both the initial set up and the subsequent execution of the navigation benchmark, where the robot had to navigate along specific trajectories with multiple rows (as in a real agricultural field). All these aspects are necessary to adopt a fitting metric method to evaluate all the other benchmarks execution. Additionally, a detailed description of different team organization management is provided, together with a focus on the major challenges encountered during the field preliminary phase.

II. EXPERIMENTAL DESIGN

The ACRE Field Campaign took place in May 2023 at "Azienda Agricola Ciro Menozzi – Cascina Baciocca – Cornaredo (MI)" (45° 30' 09'' N, 9° 01' 01'' E). It is an experimental farm of the Department of Agricultural and Environmental Sciences - Production, Landscape, Agroenergy of the University of Milano.
It occupies a total area of about 23 ha and it is characterized by a medium mixture soil with a high percentage of stones (Figure 1).

Figure 1 Aerial view of C.na Baciocca experimental field


Figure 2 Bean plots

The test field designated for the campaign covered an area of 2.8 hectares and it was divided into 35 distinct plots, each serving its specific purpose. These plots were sown with three different crops:18 rows of corn (*Zea Mays* L.), 16 rows of bean (*Phaseolus vulgaris* L.), and a larger plot of beet (*Beta vulgaris* L.).

The entire field was uniformly mowed before the competition, and field preparation activities were focused on the designated plots involved in the competition.
The evaluation plan included the use of a tractor equipped with an RTK-GPS system for:

- the soil ploughing at 25 cm of depth
- the passage of a rotary harrow at 20 cm of depth
- the passage of a stone burier at 15 cm of depth.

The dimensions of each test field were predetermined, with plots widths ranging from 3 to 15 meters and lengths varying from 50 to 100 meters. Moreover, the distance between sowing rows was established in advance, with a range of approximately 50 to 70 cm.
However, due to adverse weather conditions and the unavailability of the RTK-GPS equipped tractor, an emergency plan was adopted. As a result, soil ploughing was carried out using a Deutz-Fahr 105 farm tractor equipped with a plough, set to an average depth of 25 cm. Subsequently, a spring tine harrow with a working width of about 3 meters was employed. Additionally, a stone burier was utilized to prepare the plots before the actual plant sowing took place. The seeding of 8 rows of beans was conducted with an adapted seed drill at 40 cm of distance between the rows. *Z. mays* L. was sown with a row distance of 75 cm. Between each plant of mays, 14 cm were left.
During the competition, an unexpected challenge came out when pigeons and crows consumed the cotyledons of the majority of *P. vulgaris* L. plants two days before the event. To address this issue, an emergency order was promptly placed for 12,000 bean plants, which were manually transplanted at a consistent distance of 37.5 cm between rows. Between each plant of bean, 7 cm were left. Most of the rows within the test field were straight; however, two plots featured a "shift" indicating an intentional offset in the median axis of the row.

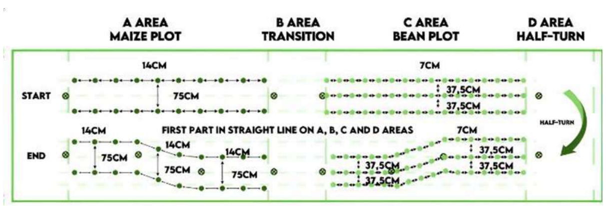

Figure 3 Design of shifting rows in bean and mays fields

Specifically, three shifting rows were in the bean plots, while two were observed in the mays plots. The same number of crop plants in each row, with the same space between each other, was chosen to ensure the same conditions for all participants. To facilitate manoeuvers and ensure clear demarcations between plots, designated corridors were intentionally left between them. Manual weeding efforts were carried out in each plot, except for the *B. Vulgaris* L. plots. It is worth noting that existing *Lolium perenne* L. plants were intentionally left untouched within the *P. vulgaris* L. plots. Furthermore, as part of the experimental design, 15,000 weed plants encompassing three different species (5,000 for each species) were manually transplanted. The selected species were wild mustard (*Sinapis arvensis* L.), ryegrass (*Lolium perenne* L.), and chamomile (*Matricaria chamomilla* L.).The weeds were selected to provide different patterns and shapes. The placement of weeds around the main crop followed a randomized method in terms of location, with controlled frequency within each row. Weeds were strategically placed in both the inter-row and intra-row spaces adjacent to the main crop. Moreover, a fixed distance of 10 m was deliberately maintained at the beginning andend of each row.

The distances and number of rows were predetermined based on the characteristics of the robots and the experience gained from previous field campaigns. Regarding weed location, low and medium weed planting frequencies wereadopted for the first and last meters of the rows, 10 meters respectively, while high frequency was adopted in the central 5 meters. In the *Z. mays* L. plots, only *S. arvensis* L. and *M. chamomilla* L. were purposely planted,whereas *L. perenne* L. was additionally present in the *P. vulgaris* L. plots.

To ensure standardized test field conditions, the age and size of transplanted weeds were the same across all plots. After the location of both weeds and beans, the plots were subjected to a irrigation volume consisting of two rounds of daily watering using a spraying bar. This process involved the distribution of 2.5 litres of water persquare meter, conducted twice a day for two days.

As for the plots with *B. vulgaris*, the entire plot design was executed by the team, which conduct tests on this species.

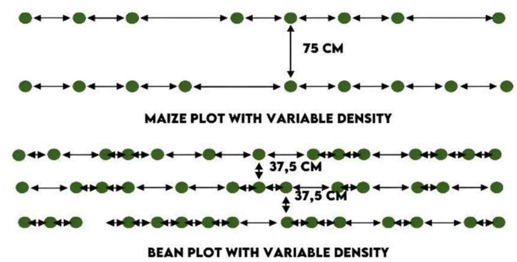

Figure 4 Design of mays and bean plots

III. Participants

The entire experimental design, along with the selection of benchmarks (functionality and tasks benchmarks) was thought to incorporate different feedback from stakeholders, sponsors and effective competition participants. Each team focused on specific tasks and different types of robots were employed in the field, ranging from prototypes to machines already used in the agricultural domain.

Three robotics platforms were custom-designed by two private companies and they are currently employed in the agricultural sector: Moondino and FarmDroid by Arvatec (Rescaldina, Italy) (Figure 5) and different robot mowers by a Barbieri s.r.l. (Sossano, Italy), one of them 100% electric, the X ROT EPOWER 70 EVO.

Moondino is an autonomous agricultural robot for mechanical weeding able to work on dry or submerged soil which was first designed for rice paddy. It is equipped with two photovoltaic panels to store solar energy in the robot batteries. It is able to mechanically control weed in a rice paddy up to 10 hectares. It is equipped with two GNSS RTK receivers which allow it to work without ever stopping for about 1.5-2 months at a speed of 1 km/h from the date of the sowing of the rice.

Figure 5 Moondino on the beet field

FarmDroid (FD20) is a robot that autonomously carries out sowing and mechanical weeding of crops. It could be equipped with 6 or 8 seeds containers on rows and different seeding discs to have different configurations during sowing and mechanical weeding depending on the main crop selected. FD20 integrates GPS RTK technology for high precision seeding and subsequent precision weeding. Through the GPS RTK technology the robot knows the position of each seed planted and mechanical remove all the plants not recognized as main crop also not yet emerged from the ground. It could be equipped with tools for both inter and intra-row weeding.

The X ROT EPOWER 70 EVO is a mulching mower equipped with 100% electric motor at 3000 RPM. It is equipped with two floating edge blades capable to cut a maximum grass height of 40 cm on dry soil inclined up to 25 degrees and it has got a cutting width of 70 cm. It could cover an area of 3000 m^2 and it has got a battery run time of 3 hours.

Three other prototypes took part in the competition: one from the University of Milan Bicocca (Unimib), one was designed by the private company AGROVAI (Salerno, Italy) and the last one was AgroBot from the University of British Columbia. The IRALab team (Unimib) robotic platform was adapted from a Volksbot RT3, that is differential drive platform, with a castor wheel. The castor wheel support structure was modified in order to use a larger diameter one and substituted the driving wheel tires suitable for agricultural fields. The main sensors used for the challenge are the Piksi RTK-GPS receiver and the Azure Kinect RGBD camera. All computations are handled onboard by an Intel NUC. The software solution is based on the ROS framework, which provides drivers, ready-to-use software components, and interfaces to ease robotic platform development. The navigation was handled using the Navigation Stack provided by ROS. Moreover, the Azure Kinect camera was employed to scan the surrounding environment, and to detect the plants to avoid, using the SLAM framework RTAB-Map.

The platform AGROV is designed for tunnel greenhouse environments with the aim of reducing the workload and exposure to high temperatures for agricultural operators. It consists of a lightweight rover on 4WD/4WS wheels equipped with a navigation camera, a weed detection camera, and a gripper on an XYZ table dedicated to mechanical weed removal and placement in a specific bin for weed collection. The system uses a CAN open bus for easy migration to ISObus if needed. It is highly flexible and easily customizable thanks to the APIs it exposes for seamless integration with third parties. The central control system of the rover is based on the open ROS2 platform. The weed recognition system is based on OpenCV and Tensorflow.

Figure 6 The Agrovai prototype on the bean field during the navigation task

No information and data have been provided by AgroBot yet.

The Artificial Intelligence and Robotics Lab of Politecnico of Milan employed a mobile rover developed by Agilex (Bareggio, Italy). It is a skid-steering robot on wheels, which is equipped with batteries and wheel control electronics inside the base. A CANBus system or a remote control allow to interface with the wheel control electronics. The robot is driven by a Shuttle PC with an x86 processor with Ubuntu and ROS 1 on board.

The robot wheels are suitable for muddy and earthy terrain During the ACRE competition the mobile rover was equipped with an Intel RealSense 435 RGBD camera and it was driven. The sensor data were saved in a rosbag, and later extracted the frames once in the lab.

Figure 7 The mobile rover developed by Agilex on the mays field during the navigation task

IV. RESULTS AND CRITICAL ISSUE

No numerical results regarding the collected data have been already processed and presented in this paper. However, the current section aims to provide a qualitative summary and description of the platform's performance as well as the technical challenges encountered.

The Table 1 summarize the FBM actually performed by each team.

Table 1 Participants activities

Participants	Scheduled BM	Execution
AGROVAI s.r.l.	Plant Discrimination; Field Navigation	not actually performed
Barbieri s.r.l.	Field Navigation	performed
Arvatec	Weed Destruction	performed
AgroBot	Weed Destruction; Plant discrimination	not actually performed
IraLab	Field Navigation	not actually performed

The AGROVAI team had some problems due to a recent and significant system upgrades not yet tested for the lack of time and underestimation of the effort required. The main issues were observed in the User Interface, which had been migrated from a dedicated remote control to a mobile app environment just a few days before. Additional problems arose with the on board CANbus damage during the transport. The problems were solved at the end of the competition and simple basic system tests gave a positive outcome.

A preliminary test conducted by IraLab revealed critical issue due to a loose screw got stuck in the left transmission, between a pinion and the chain. It caused mechanical and motor failures. Only RTK-GPS + RGBD datasets were collected in the fields, which will be used to further improve mapping and plant detection pipeline.

V. CONCLUSIONS

The entire preparatory process of the competition field highlighted some possible technical challenges. Factors as the unavailability of selected machinery for the soil preparation, adverse weather conditions, and plants destruction by birds are some elements which could significantly impact the main crop and weed growth, consequently affecting competitiveness. These factors should be taken into account for the evaluation of robots performances in a real agricultural scenario.

In addition, the design process revealed several essential tasks required by an efficient agricultural robotic platform:

- autonomous exploration of a multi-row cultivated plot
- creation of a precise field mapping
- recognition of individual plants giving thema precise target
- provision of precise plants position

A precise experimental design has been demonstrated to be crucial to ensure objectivity, repeatability and reproducibility for agriculture robot performance benchmarking.
The ACRE Field Campaign could represent a significant step toward the advancement of sustainable agricultural practices. These practices could support the development of innovative solutions useful to promote agricultural sustainability by reducing the use of chemical products and minimizing environmental impact.

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