[F] PhD Extended Abstract Form

RESEARCH AND IMPLEMENTATION OF ROBOTIC, DIGITAL AND A.I. SOLUTIONS FOR THE MANAGEMENT OF AGRICULTURAL AND URBAN GREEN SPACES

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Extended Abstract

In the context of the digital and ecological transition promoted by European strategies, agriculture and green area management are increasingly required to adopt sustainable and technologically advanced approaches. Technologies such as robotics, digital imaging, and artificial intelligence (AI) can play a crucial role in optimizing maintenance operations, improving resource efficiency, and promoting biodiversity conservation.

1. Benchmarking agricultural robots

The field campaign of the ACRE Competition 2023 was designed to evaluate the performance of autonomous weeding robots through objective benchmarks. The test field designated for the campaign covered an area of 2.8 hectares and was divided into 35 distinct plots. These plots were sown with three crops: *Zea mays* L., *Phaseolus vulgaris* L., and *Beta vulgaris* L. The same number of crop plants in each row, with the same spacing between them, was chosen to ensure the same conditions for all participants. Manual weeding was carried out in each plot. Furthermore, 15,000 weed plants belonging to three species (wild mustard, ryegrass and chamomile) were manually transplanted. During the competition, a mobile rover was employed to perform the functionality BenchMarks and a large number of RGB-D images were collected. Then the work focused on the specific task of autonomous weeding, which requires expertise at the intersection of Computer Vision and agronomy. One key prerequisite to autonomous weeding is the capability to segment weeds and crops from robot-collected images. However, robust segmentation in Computer Vision relies on extensive and densely labelled datasets whose creation can be both expensive and time-intensive. Common detectors like YOLO perfectly exemplify this paradigm. By contrast, Few-Shot Learning (FSL) methods can learn from minimal annotated examples and drastically mitigate the costs and challenges associated with acquiring large datasets. We showed that HDMNet can already ensure 73 to 80% of the upper-bound performance of data-hungry YOLOv5 and YOLOv8 models for the detection of bean and corn crop regions. Due to the lack of reference data on annotation labour, we analysed the human effort required for labelling robot-collected crop and weed images. We also curated and contributed a comprehensive dataset for crop and weed segmentation, the 2023 ACRE Competition dataset, including an Early Dataset and a densely annotated Refined Dataset acquired under different environmental conditions. These novel contributions guide the development of weed-crop segmentation solutions that are both high-performance and cost effective.

The research then focused on sustainable turfgrass management. Autonomous mowers have emerged as an innovative solution, but the efficiency and quality of mowing operations depend on several factors. This analysis investigated the impact of mowing patterns and cutting heights on the performance of an autonomous mower through updated custom-built software. Three mowing patterns (vertical, diagonal and horizontal) and two cutting heights (3 and 6 cm) were tested. The vertical pattern emerged as the most effective, minimizing overlap and uncut areas. In contrast, the horizontal and diagonal patterns showed lower efficiency (0.71 and 0.76) and less coverage percentage (97.05% and 96.71%) compared to the vertical pattern (98.57%). Cutting height influenced performance, with higher heights sometimes requiring adjustments to prevent inefficiencies. The interaction between the mowing pattern and cutting height was critical for optimizing both operational efficiency and cutting quality. These results highlight the importance of selecting appropriate mowing patterns and cutting heights. A further analysis aimed to validate the measurement accuracy of a new function in custom-built software (v2.5.0.0) designed to analyse mower trajectories via RTK-GPS data, and to assess the influence of three mowing patterns (vertical, horizontal, diagonal) on overlapping and uncut areas. The software outputs were validated against two manual tracking methods: chalk powder and wire. The experiment was conducted on a mature Bermudagrass stand, and trajectory data were analysed using ANOVA. Results showed differences among measurement methods, while chalk powder and software produced comparable results. Significant differences were also observed in turn trajectory no-cut areas, especially with the diagonal mowing pattern, which generated the largest uncut zones (0.059 m^2).

2. Evaluation of the management of different agricultural systems with robots

In the framework of the ongoing digital and ecological transition in agriculture, an additional trial was designed to assess the real applicability of autonomous robotic systems for vineyard management. By comparing a traditional tractor-based approach with an autonomous robot for under row weed control, the study aimed to provide objective data on performance, environmental sustainability, operational efficiency and evaluate the feasibility of the autonomous approach through Business Process Model and Notation BPMN-CBA approach. The evaluation of both systems focused on several key performance indicators. Weed control efficacy was evaluated through biomass, coverage and floristic composition measurements. Soil compaction was analysed. The working width of the under-row portion managed by the robot and the crop damage rate, expressed as the percentage of injured plants per row, were also recorded. Operational efficiency was analysed by measuring the total working time, the energy consumption, and the weeding possibility zone. Environmental performance was quantified through CO_2 emissions (kg ha^{-1}) and comparative energy-use analysis between the robotic and tractor-based systems. Working capacity and the degree of automation were also evaluated considering operator supervision time. All the data collected were used to perform the BPMN-CBA analysis. Preliminary results show no difference in terms of weed control efficacy, compaction and in terms of weeding possibility zone. While the BPMN-CBA highlight a positive NPV for the adoption of autonomous solution on an area of 50 ha.

On the other hand, in ornamental, sports, and landscape contexts robotic solutions and technological advances for turfgrass management demonstrated high performance in terms of turf quality and energy/time efficiency. Two battery powered autonomous mowers with random patterns were evaluated according to different trampling levels (control, low, medium, high) on a typical warm season turfgrass at University of Pisa, Italy. Operational data were collected through RTK devices and processed using custom-built software (1.8.0.0). The main quality parameters of the turfgrass were also analysed. Soil penetration resistance was measured through a digital penetrometer. The efficiency significantly decreased as the trampling level increased (from 0.29 to 0.11). The trampling activity caused a reduction in turf height. The energy consumption was low and varied from 0.0047 to 0.048 kWh per cutting session. Results from this trial demonstrated suitable quality for a residential turf of the Mediterranean area, despite the over-trampling activity. Soil penetration data were low due to the reduced weight of the machines, but slightly higher for the 4WD model (at 5 cm of depth, about 802 kPa vs. 670 kPa. Attention was also focused on navigation patterns affecting turfgrass quality. The trial aimed to evaluate the impact of three different autonomous mower navigation patterns (random, vertical, and chessboard) on operational performance and the effect of trampling activity on turfgrass. Each pattern was evaluated in terms of passages, travelled distance, intersections and mowed area using remote sensing data. Green coverage percentage was assessed weekly using image analysis to evaluate the turfgrass quality. The green coverage percentage, together with the number of passages, are analysed and correlated. The random pattern generated the highest number of passages and intersections, leading to lower average green coverage (64%) compared with the chessboard (80%) and vertical (81%) patterns. The effective number of passages to reach 60% green cover was 56, 87, and 155 for random, vertical, and chessboard, respectively. Future studies should extend this approach to other species and environmental conditions, integrating the effective dose (in terms of passages) method into decision-support systems for smart mowing management

3. Robotic agricultural management: effects on biodiversity

The last part of the PhD project focused on the effect of robotic systems on biodiversity, both in sport facilities and ornamental areas. The first study examined the effect of two different cutting systems, a traditional ride-on mower and an autonomous mower, on the quality and functional parameters of a municipal football field. The analysis included visual assessments, measurements of grass height, and evaluations of surface hardness, comparing the performance of the two cutting systems. Additionally, studies of turfgrass composition and machine learning techniques, particularly with YOLOv8s and YOLOv8n, are conducted to test the capability of assessing weed and turfgrass species distribution. The results indicate significant differences in grass colour based on the position (5.36 in the corners and 3.69 in the central area) and surface hardness between areas managed with a traditional ride-on mower (15.25 Gmax) and an autonomous mower (10.15 Gmax) in the central region. Higher height values are recorded in the area managed with the ride-on mower (2.94 cm) than with the autonomous mower (2.61 cm). Weed presence varies significantly between the two cutting systems, with the autonomous mower demonstrating higher weed coverage in the corners (17.5%). Higher overall performance metrics were obtained through YOLOv8s.

The planning and management of green spaces play a key role in biodiversity conservation in urban environments. Residential and public lawns are important habitats for pollinators. However, lawn management practices, especially

intensive mowing, can negatively affect plants diversity and abundance disrupting pollinators activity. Since the numerous limitations associated with the use of traditional machines autonomous mowers are becoming increasingly widespread. However, little is known about their influence on biodiversity and pollinators. In this perspective the use of *Phyla nodiflora*, obtained positive results when managed with an autonomous mower. In this study, *P. nodiflora* plants are transplanted in spots within a turf mainly composed of bermudagrass with the aim of promoting greater floral diversity and the conservation of pollinators. The research aim is to evaluate two different autonomous mowers navigation systems (random vs systematic) and two different cutting height (2 cm vs 6 cm) in terms of the effect on *P. nodiflora*. *P. nodiflora* flowers height, number of *P. nodiflora* flowers, *P. nodiflora* coverage per plot and turfgrass height were assessed. A script for automatic flower counting was developed and its reliability was assessed. Data on monitoring of pollinators were used to calculate the family richness, the Shannon diversity index and the Evenness. The treatment, the survey data and their interaction had a significant effect ($p<0.001$) on flower height, number of flowers and coverage percentage. Highest values of flower height were recorded in treatment with systematic pattern, the highest one in treatment 2 (6.08). The same trend was recorded for others parameters with highest value in treatment with systematic pattern. Regarding the automatic flower counting YOLOv8s and YOLOv11s exhibited better performance compared with nano models, but, overall YOLOv8s represent a preferable choice. The family richness exhibited the highest value in treatment 2, the evenness in the treatment 4.

Final remarks concerning benchmarks and strength points of the the Pellizzi Prize 2026

The thesis stands out for its high level of originality in the field of Automation and Electronics applied to agriculture, integrating robotics, artificial intelligence, and digital technologies to enable more sustainable and efficient systems. It presents innovative methods for data-efficient weed–crop segmentation alongside robust benchmarking frameworks for evaluating and optimizing autonomous platforms. A major strength is its validation in diverse real-world settings, demonstrating reliability and scalability for practical use. The research delivers valuable tools, datasets, and decision-support strategies, fostering strong potential for technology transfer and adoption. The results offer clear improvements in operational efficiency, environmental impact, and biodiversity conservation. Overall, the thesis fully aligns the Prize criteria by combining automation innovation with tangible agricultural benefits for farmers.

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