Pilot Project for an Integrated Complex for clean soil-based production, harvest and delivery (logistic operations) of Iceberg lettuce

Ivan Gramatikov[1], Teodor Georgiev[2], Krasimir Kumchev[3], Kostadin Kostadinov[4], Marin Midilev[5]
Freelancer and Association Agrorobotika founder[1], Robco Smart[2], Chairman at the Association of Agrorobotika[3], Association Agrorobotika member, VSI Plovdiv[4], Representative of the Cluster for Electric Mobility[5]

***Abstract**: In order to address multiple UN Sustainable Development Goals, we aim to revolutionize iceberg lettuce harvesting with intelligent robots. Our team, comprised of agricultural producers and engineers, has utilized TRIZ methodology, brainstorming, and other techniques to develop an agricultural technology solution: an Integrated Complex that automates harvesting and loading of produce onto transportation vehicles. Our design leverages state-of-the-art deep computer vision – a form of AI that analyzes camera images – to precisely locate mature lettuce heads. The robot identifies optimal grasping points for harvesting and carefully places the heads in a designated transport area. With deep learning at its core, our robots will optimize yield, reduce waste and costs, ushering in a new era of intelligent agriculture.*
***KEYWORDS**: LETTUCE, HARVEST, ROBOT, COMPUTER VISION, LOGISTICS, INTEGRATED COMPLEX*

1. Introduction

The amount of food waste, the issues of lacking workforce in the field of agriculture (especially in countries like Bulgaria and in periods such as the COVID-19 pandemic), the number of starving people, etc. are among the food-related issues which the United Nations and the European Union and individual States are trying to resolve.

There are specific goals and strategies such as the Sustainable Development Goal 12.3, which aims to (halve per capita food waste at the retail and consumer level by 2030, and reduce food losses along the food production and supply chains) [1,2].

According to the Food and Agriculture Organization of the United Nations, (roughly one-third of food produced for human consumption is lost or wasted globally, which amounts to about 1.3 billion tons per year. This inevitably also means that huge amounts of the resources used in food production are used in vain, and that the greenhouse gas emissions caused by production of food that gets lost or wasted are also emissions in vain. Food is lost or wasted throughout the supply chain, from initial agricultural production down to final household consumption) [3].

The European Commission itself (has already carried out important steps to prevent food losses and waste, in line with the actions put forward under the first Circular Economy Action Plan, adopted in 2015) [4].

To these aims, the European Commission has suggested certain actions such as reforms aimed at increasing the awareness and usage of the food labels, the date of expiry, easing of the process of donating of foods to food banks and charity organizations, support of the initiatives for the increased usage of foods which have not been sold and other products which can be used as a resource in the production of animal feed [5].

During the COVID pandemic, a lot of the agricultural produce was left on the field, spoiled, due to the restrictions on the working conditions and the lack of workforce. The team, issuing this report, has witnessed first-hand the sheer number of rows of iceberg lettuce in Trilistnik, Plovdiv district, left unusable.

The resolution of such food related problems requires a complex cooperation of a country's administrative apparatus, producers, distributors, scientific institutes, associations, NGOs and consumers. Our team is mostly concentrated on the technological possibilities for solving these issues as it is our firm conviction that they can be addressed by the robotization of the agricultural lifecycle or at least, for the time being, the automation of the harvesting and delivery parts of the process. To this end, we suggest the development of an Integrated Complex of robots, which are based on a system of simple and existing building blocks.

2. Prerequisites and means for solving the problem

2.1 Necessary preconditions

The agricultural producers' role in the team are is vital, as they give the necessary data depending on the type or sort of plant, which will be worked on by the robot – sizes of the plant, physical characteristics of the ripe produce, the planting schematic data, the timetable of all necessary steps in the lifecycle of the plant's development.

For the whole process of research on iceberg lettuce robotic harvesting, the necessary data are being obtained from the rich repository of technical expertise of the agricultural producer Petar Kumchev, with the place of the production of lettuce being the village of Trilistnik, Plovdiv district.

Further requirements include the creation of an industrial park (type C), an agricultural robotics laboratory, equipped with a FabLab and a team of mechatronic engineers and software developers

2.2 Logistic considerations

2.2.1 Energy Expenditure

One can observe a very clear rise in the research and development of robots for the harvest of fruits and vegetables all over the planet. And there are multiple reasons for this.

A discussion on the energetic requirements of food production, including our future efforts, is in order, so as to prove the above point.

According to economist Manfred Max-Neef of the CEPAUR-Dag Hammarskjold Foundation:

(In Mexico, according to information provided by the Xochkalli Foundation, 19,000 kcal have to be used in order to put 2,200 kcal of food on the table. From another angle, the amount of energy consumed in transporting foodstuffs in Mexico is almost equal to the total energy required by the primary sector for food production. The fact that such situations are considered to be positive is, undoubtedly, a conceptual aberration) [6]

Other than the human energetic expenditure, it should also be noted that human workers normally spend all of this energy in an 8, 10 or even 12-hour workdays, however they can realistically be productive for about 6 of those 10 hours, as opposed to a robot, which can productively work for almost the entire day.

Larger fields of about 100-500 decares and more (100-500 000 square meters) that require crop care, harvesting and logistical post-processing and delivery operations would be a good example of cumbersome, repetitive and error-prone labor in the human worker case. Such a scale would be handled better by a fleet of robots, including drones/UAVs, as they would employ much bigger precision, starting from the process of precision agriculture, e.g. recording and evaluating the problematic areas on the field (such as in Fig. 1) [7], the predictive algorithms and AI architectures for the volumes of produce, which the farmer will obtain, etc. [8].

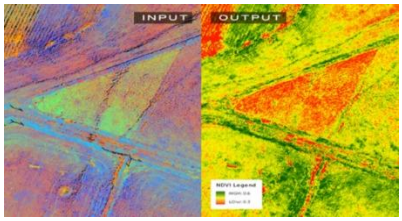

Fig. 1 *Remote Sensing spectral images by drone to evaluate problematic areas*[7]

Another useful feature would be evaluating the soluble solids (sugars) [9] and other contents present in the target plants for an overall picture, allowing estimation of the crop, the season and possible profits. Yet another one, which the team is planning, is a system for protection from hail.

2.2.2 Delivery and design considerations of the Integrated Complex

The logistics process after and other than the harvesting will now be discussed. Once a full crate has been filled by the harvesting robot, it is moved to a preset location, freeing up space for an empty crate. When there is a sufficient number of ready to deliver crates, they are loaded onto the transporting platform, which has already carried another set of empty crates ready to fill up. The transporting platform delivers the produce, which has been picked to an aggregating platform. The transporting platform carrying the produce is being unloaded and loaded with the necessary number of empty crates. The produce is carried then from the aggregating platform to the cooler by electric vehicles. On the way back, the said electric vehicles carry empty crates. Then the harvested produce is being processed (packaged) and is labeled with information for traceability of the quality, nutrients, pesticide content, etc.

On the basis of the information on the label and the overall aggregation of produce-related data, as discussed above, a subscription-based model for the delivery of specific products could be established, based on specific dietary, energy and health-related considerations (such as receiving fresh produce, which has been picked from the plant for up to 72 hours previously).

The aggregating platform provides the main energy for the 24-hour work cycles of the Integrated Complex by photovoltaics and air. It is situated outside of the crop area.

The electric vehicle is going to be supplemented with a robotic loading and unloading system and its task is to deliver empty storage crates to the robotic harvester mobile platform and carrying of the picked produce in the harvesting period. It may be used for carrying of materials during the rest of the production period.

An agrivoltaics system could be installed, which ensures the necessary electrical supply to the robotic harvester and the electric loading vehicle alike.

The delivery part of the logistics can be done to an end consumer, including shops, including fully automated ones, restaurants with or without robotic cooking systems (and robotic servers).

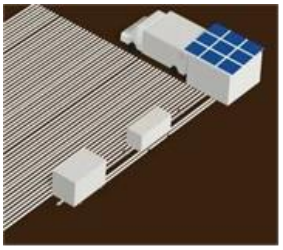

Fig 2 *A schematic representation of a part of the Integrated Complex*

3. Solution of the examined problem

3.1 Overall organization of the harvesting robot unit

The robots in the Integrated Complex, which will be used for plant care and harvesting will feature different (by function) types of attachable modules. Such modules could include: surface processing of the soil, soil sterilization, creation of plant beds and grooves, creation of a mulching and drip irrigation system, planting of seedling (growing of thinned out or pricked out seedling by means of robotic technology is being considered by our team as future work, as well).

There will also a system for grasping the lettuce and a system for removing the excess leaves prior to packaging so as to comply with the standards of the supermarket chains.

The changeable modules will have an application in the Integrated Complex system of machines for the lifecycle of the iceberg lettuce enterprise as a means to process said lettuce in outdoor conditions. It will also be able to perform in indoor conditions such as greenhouses, soilless (hydroponic and aeroponic) and vertical growing setups, some of which are situated in abandoned industrial buildings and rooftops (such as Gotham Greens, BrightFarms, Sky Vegetables and Brooklyn Grange in the US and the Lufa Farms in Canada). Naturally, due to the fact that the indoor growing methods rely on an artificial environment, the factors that influence the plant growth are less and the harvesting period for a robotic harvesting machine can be 24 hours a day, however the taste of an outdoor grown plant is better than an indoor grown one.

Figure 3 below presents an initial schematic 3D model for the prototype of the harvesting robot the team has created.

Fig. 3 *Basic schematic initial prototype of a robotic harvester.*

3.2 Sensors and perception

The harvesting robot module will feature the following main input or sensors: GPS, cameras for machine vision, an IMU, encoders and a laser scanner, etc., all of which will be gathering telemetry data for further processing.

For the machine vision, a picture dataset will be created, featuring all necessary aspects – photos of iceberg lettuce will be made in different conditions – lighting, occlusion, deformation, different scales, viewpoints, similarly-looking objects and one of the most

essential ones – background noise and clutter (which is most definitely going to be present in an outdoor setting with leaves of lettuce involved, weeds, etc.). Different additional techniques will be used to dramatically boost the accuracy of the machine vision model, such as data augmentation, transfer learning, etc. Annotation of the gathered and augmented dataset will be done and with the help of frameworks such as Detectron2, one can further improve the process of labeling by crafting (or reusing existing) semi-automatic annotation features [10].

Convolutional Neural Networks such as the Mask R-CNN [11] architecture will be used for multiple object detection (instance segmentation) and size measurement/evaluation in order to determine if the iceberg lettuce is ready for harvesting or not. This readiness will be a trigger for different operations, mostly the harvesting sequence if ready – including localization in space, grasping, cutting, lifting, placing in the respective container for transportation as discussed, etc.

An important fact to point out is that the research phase of such a robot clearly presents the opportunity to reuse certain concepts, technologies and implementations for other (especially similar) plants This achieves speeding up the time for research, development and production of robots for other plant cultures as well as reduces their cost.

As noted above, the telemetry data gathered from the sensors, calculated, etc. can be analyzed and used for improvement and data pipelines can be utilized for that end, as well as for the deep computer vision model MLOPS lifecycle [12] (from dataset gathering to retraining for continuous model improvement).

While the annotation, experiment handling, deep computer vision model training, etc. can be done on a cloud platform (such as GCP, AWS, Azure, FloydHub, Paperspace, etc.), the model will have to fit on an embedded processing platform with AI acceleration capabilities such as the NVIDIA Jetson Xavier AGX, Orin, etc., where one could start with a prototype device at the experimental phases and then move on to professional carrier boards for real world model deployment on an embedded system (in this case, an agricultural robot).

4. Results and discussion

The integrated complex for the growing/care, harvesting and delivery to an end consumer gives a practical solution to the requirement of the amount of realized production being the basis of subsidies for the EU-based agricultural producers.

The harvesting robot is in its very infancy – a lot of work is yet to be done on it for the fruition of the first robot in a fleet that will automatically and optimally take care of the lifecycle of multiple types of plant produce due to its planned reusability and multifunctionality.

5. Conclusion:

The presented report attempts to lay out the principle of the Integrated Complex system, its most notable characteristics and uses.

6. References:

[1]https://food.ec.europa.eu/safety/food-waste/eu-actions-against-food-waste_en

[2]https://sdgs.un.org/goals/goal12#targets_and_indicators

[3]https://www.fao.org/4/mb060e/mb060e00.pdf

[4]https://food.ec.europa.eu/safety/food-waste/eu-actions-against-food-waste/eu-platform-food-losses-and-food-waste_en

[5]https://wwwx.mzh.government.bg/media/filer_public/2021/10/15/natsionalna_programa_za_predotvratiavane_i_namaliavane_na_zagubata_na_khrani.docx

[6] King, Alexander, and Bertrand Schneider. The First Global Revolution. New York: Pantheon Books, 1991, 40p.

[7] Meivel, S., Maheswari, S. Remote Sensing Analysis of Agricultural Drone. J Indian Soc Remote Sens 49, 689–701 (2021). https://doi.org/10.1007/s12524-020-01244-y

[8] Rehash, Rushmi & Pavitra, A.Rehash Rushmi & Vadhani, Madhu. (2022). A SURVEY ON HARVEST PREDICTION USING MACHINE LEARNING AND INTERNET OF THINGS. 10. 85-87. 10.33144/23478578/IJCST-V10I3P16.

[9]https://www.sciencedirect.com/science/article/abs/pii/S1350449523000993

[10] Guillermo, Marielet & Billones, Robert Kerwin & Bandala, Argel & Vicerra, Ryan & Sybingco, Edwin & Dadios, Elmer & Fillone, Alexis. (2020). Implementation of Automated Annotation through Mask RCNN Object Detection model in CVAT using AWS EC2 Instance. 708-713. 10.1109/TENCON50793.2020.9293906.

[11] Sumaiya Islam, Md Nasim Reza, Milon Chowdhury, Shahriar Ahmed, Kyu-Ho Lee, Mohammod Ali, Yeon Jin Cho, Dong Hee Noh, Sun-OK Chung, Detection and segmentation of lettuce seedlings from seedling-growing tray imagery using an improved mask R-CNN method, Smart Agricultural Technology, Volume 8, 2024, 100455, ISSN 2772-3755 https://doi.org/10.1016/j.atech.2024.100455.

[12] https://easyflow.tech/mlops-for-computer-vision/