Quality Festival 2025
ISBN 978-86-6335-121-9

Ivan Macuzic [1]
Aleksandar Djordjevic
Miladin Stefanovic
Marko Djapan
Marija Savkovic
Djordje Milojevic

Research paper
DOI – 10.24874/QF.25.109

INDUSTRY 4.0 – INNOVATIVE ROBOTIC STATION FOR FRUIT & VEGETABLE PROCESSING

Abstract: *This paper aim is to present idea and results of work on research, development and construction of innovative robotic station which should help in automation of fruit and vegetable primary processing tasks. Basic idea is related to introduction of Industry 4.0 tools and methods in order to achieve increasing efficiency, productivity, quality and flexibility for small and medium-sized producers in food industry.*

Keywords: *industrial robot, machine vision, AI, Industry 4.0*

1. Introduction

In today's dynamic and rapidly evolving food supply chains, one of the challenges, that the fruit and vegetable industry faces, is the need for enhanced efficiency, quality, and sustainability throughout the products primary processing stages. The traditional methods of manual labor and/or semi-automated processing often result in inconsistencies in product quality, increased labor costs, and higher levels of waste. These challenges are additionally increased by the rising of global demands for processed fruits and vegetables, which requires processes that can meet expectations of modern markets.

One of possible solutions, offered by Industry 4.0, to address these challenges, is oriented on innovative, multifunctional robot stations for the primary processing of fruits and vegetables (Xiao et al., 2024). This station seeks to introduce advanced robotic and machine vision, in affordable and easy to use way, so small and mid-sized companies could use benefits from cutting-edge robotics and automation technologies.

Such solutions could have implication not only for the fruit and vegetable processing industry but also for complete food supply chain from plantation to final consumers. Farmers, processors, distributors, and consumers are all affected by the current inefficiencies in primary food processing.

Farmers struggle with managing crop quality during harvesting, processors are facing with labor intensive jobs on sorting, washing, cutting, drying/freezing preparation and packaging tasks. Distributors have various problems connected with maintaining of product quality and freshness, and ultimately, consumers may receive products that vary in quality and nutritional content (Kondo, 2010).

Bearing in mind all the above, use of innovative technologies represents a necessity in the future, both for large systems and for numerous of small and medium-sized processors who are fighting for their place in a specific and demanding market. The use of technologies that include robotics, machine vision and artificial intelligence undoubtedly has great potential (Soltani Firouz & Sardari, 2022).

1 Corresponding author: Ivan Macuzic
Email: ivanm@kg.ac.rs

2. Proposed innovative solution

Inspiration for new and innovative solution was derived from previous collaborations with small to mid-sized companies operating within the fruit and vegetables processing sector. Through close interaction and collaboration, first-hand insights was gained into the difficulties and challenges these companies faced, including labor shortages, inconsistent product quality, and the struggle to meet the demands of consumers.

It is obvious that lack of skilled workforce, for permanent and seasonal jobs in this sector, become increasing problem globally. On the other side, demands for quality and productivity improvement in fruit and vegetables primary processing, represent key factor for achieving long term sustainability on market. Both factors highlighted the pressing need for introduction of innovative solutions that can enhance both, the efficiency and quality of primary processing and also substitution of human work in monotonous and repetitive jobs .

The goal is to try to offer solution for some of challenges faced by the fruit and vegetable processing industry by creating a flexible and adaptable robotized platform that could be easily introduce to various jobs and products. This platform will enable to users streamlining of process, minimizing waste, reducing labor costs, and delivering of consistent, high-quality products to the customers.

Primary efforts were focused on strawberries processing and initial tests of developed prototype provides a solid foundation for the upcoming phases and represent important milestone, showcasing the feasibility and efficacy of applied concept and technologies.

Existing solutions, that address challenges in the fruit and vegetable processing industry, mainly rely on traditional automated machines, while the application of robotic systems is still quite limited (Xiao et al., 2024).

In comparison to existing solutions, innovative Fruit & Vegetables Robot Station offers number of advantages that could represent a transformative shift in how fruit and vegetable processing challenges are addressed. .

1) **High flexibility and adaptability**: Unlike traditional systems that are often designed for specific processing tasks, our robot station stands out for its exceptional flexibility. Its modular design allows fast reconfiguration, making it adaptable to a wide range of processing needs throughout the year. This flexibility eliminates the need for separate systems for each task, resulting in cost savings and enhanced operational efficiency.

2) **Improved efficiency and productivity:** Traditional manual processes often result in production bottlenecks, inconsistencies and resource wastage. Our solution leverages robotics and automation to optimize production flows, reduce human error, and maintain high levels of efficiency and productivity.

3) **Reduced manual work:** Existing solutions may rely heavily on manual labor, which is often costly and challenging to manage, especially during peak processing periods. Our robot station significantly reduces the need for labor-intensive tasks, resulting in lower operational costs and decreased manual labor dependency while maintaining consistent output.

4) **Improved quality:** Proposed solution incorporates advanced robotic technologies, supported by machine vision and AI that ensure consistent and precise processing. This results in improved product quality, reduced waste and enhanced consumer satisfaction.

5. **Specially designed for SME's:** Many existing solutions are focused to larger-scale operations and are financially and operationally impractical for small and medium-sized producers. Our solution is designed based on unique needs of SME's, offering them an affordable, efficient, and

scalable tool that could follow their growth and company development.

3. Robotic station prototype development

Result of work is materialized in the form of a specific robotic station prototype designed for primary processing of fruits and vegetables.

This robotic station represents a highly automated, adaptable, and flexible solution that integrates robotics and machine vision into a functional unit. The core platform of robotic station can be customized to perform various tasks and adapt to different types of fruit or vegetables processing.

Initial prototype was developed to address the primary processing of strawberries (removal of stems) as a first step in their preparation for drying or deep freezing. The choice of strawberry processing was intentional, as it presents a highly complex task. Strawberries vary in size and shape, depending on the variety, making them particularly challenging to handle.

Additionally, the sensitivity of strawberries and the unique nature of their stems (which cannot be removed by simple straight-line cutting) posed intricate technological demands. Proposed solution, originally developed for strawberries, can be adapted for other fruits and vegetables through using of different tools and software modifications. (Figure 1).

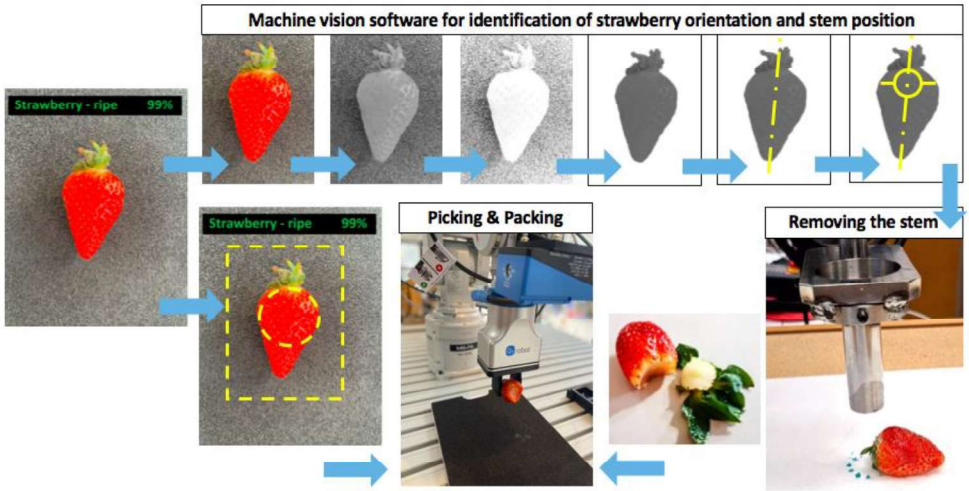

Figure 1. Strawberry machine vision identification and robotic stem removal

The fundamental elements of the robotic station for strawberry processing include:

1) **Machine Vision System:** This system features an industrial-grade color camera with appropriate characteristics that continuously monitors the conveyor belt and the moving fruits. In real-time, the system determines the characteristic dimensions of each fruit and defines the "Point of Action" (PoA). The PoA is a critical point on the object (the fruit or vegetable) that determines the precise coordinates for activating the tool on the robotic arm. The PoA is determined by the software processing the video feed from the camera. Operators of robotic station can additionaly adjust the PoA, during processing, to align it with technological requirements and the specific characteristics of each batch of fruit.

2) **Industrial Robot:** The system incorporates an industrial robot equipped with a specialized tool responsible for the operation on each individual fruit. For the prototype, we utilized a SCARA robot with

cell mounting. This type of robot demonstrated excellent characteristics, but future development should involve also testing of a delta-type industrial robot. An in-depth analysis of results will determine which of these two robot types better suits the specific processing requirements.

The tool used for stem removal is a cylindrical blade adapted for attachment to the robotic arm. The blade includes an outlet for vacuum pump, which efficiently removes the cut stems from the processing zone.

The software algorithm for determining the PoA is a combination of mathematical functions and AI, specifically machine learning. The application of mathematical functions significantly accelerates the entire process, while machine learning ensures adaptability to variations.

The industrial cameras we used in machine vision system are housed within specialized robust enclosures, offering a high degree of protection against water and mechanical influences, which is a critical aspect considering the conditions in fruit and vegetable processing facilities.

4. Conclusion

Conducted research and development acctivities showed significant potential for innovative solutions that will introduce robotics and automation in primary processing of fruit and vegetables.

Acknowledgment: Project "*Green Goody - Innovative Osmotic Fruit Dehydration System*" financed by Innovation Fund of the Republic of Serbia.

References:

Kondo, N. (2010). Automation on fruit and vegetable grading system and food traceability. *Trends in Food Science & Technology*, *21*(3), 145-152. https://doi.org/10.1016/j.tifs.2009.09.002.

Soltani Firouz, M., & Sardari, H. (2022). Defect detection in fruit and vegetables by using machine vision systems and image processing. *Food Engineering Reviews*, *14*(3), 353-379. https://doi.org/10.1007/s12393-022-09307-1

Xiao, X., Wang, Y., & Jiang, Y. (2024). Review of research advances in fruit and vegetable harvesting robots. *Journal of Electrical Engineering & Technology*, *19*(1), 773-789. https://doi.org/10.1007/s42835-023-01596-8

Ivan Macuzic
University of Kragujevac,
Faculty of Engineering,
Kragujevac,
Serbia
ivanm@kg.ac.rs
ORCID 0000-0001-6153-6456

Aleksandar Djordjevic
University of Kragujevac,
Faculty of Engineering,
Kragujevac,
Serbia
adjordjevic@kg.ac.rs
ORCID 0000-0003-2856-6578

Miladin Stefanovic
University of Kragujevac,
Faculty of Engineering,
Kragujevac,
Serbia
miladin@kg.ac.rs
ORCID 0000-0002-2681-0875

Marko Djapan
University of Kragujevac,
Faculty of Engineering,
Kragujevac,
Serbia
djapan@kg.ac.rs
ORCID 0000-0002-8016-8422

Marija Savkovic
University of Kragujevac,
Faculty of Engineering,
Kragujevac,
Serbia
marija.savkovic@kg.ac.rs
ORCID 0000-0002-3620-7762

Djordje Milojevic
University of Kragujevac,
Faculty of Engineering,
Kragujevac,
Serbia
djordjevmilojevic@gmail.com
ORCID 0009-0003-6816-7296