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An omni-wheel robot platform prototype for batch soybean handling in a tempeh industry 4.0

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Abstract. In tempeh production, the availability of nutrition and bioactive compounds is significantly influenced by the production process, equipment, and sanitation standards. However, conventional methods face several challenges, including a high risk of product failure due to weather or process inconsistencies, unstable tempeh quality, the need for extensive experience, and uncertain hygiene standards. Additionally, batch soybean handling by human workers is prone to contamination and inconsistent processing times. This paper aims to develop a mobile robot platform optimized for soybean handling within a tempeh production facility. The prototype robot, designed with omni-directional movement capabilities using omni-wheels, can navigate constrained spaces efficiently. It is equipped with an RFID sensor and two Time-of-Flight distance sensors to accurately recognize production stations and position itself for precise soybean basket handling. The implementation of an omni-wheel robot for soybean handling is expected to stabilize tempeh quality and improve overall production efficiency.

Keywords: Omni-wheel robot, Tempeh industry 4.0, Soybean handling robot.

1. Introduction

1.1 Conventional and improved tempeh production

Tempeh is a healthy food originally from Indonesia, made from fermented soybeans. The health benefits of tempeh result from its nutritional content and bioactive compounds [1,2]. The availability of these substances greatly depends on the production process, equipment, and sanitation [3,4]. However, most tempeh production in Indonesia is still done conventionally, characterized by lengthy processing stages, and a high dependency on the worker's skill, experience, and weather conditions [5,6]. The stages of conventional tempeh production are depicted in Figure 1.

Additionally, other disadvantages of this manual process include: a) a high possibility of product failure due to weather or process inconsistencies, b) unstable tempeh quality, c) the need for extensive experience by the tempeh maker, and d) cleanliness and hygiene cannot be assured.

To improve this process, simplification of production stages and the utilization of automation with robots are being researched. The improved process includes the use of dry peeled soybeans

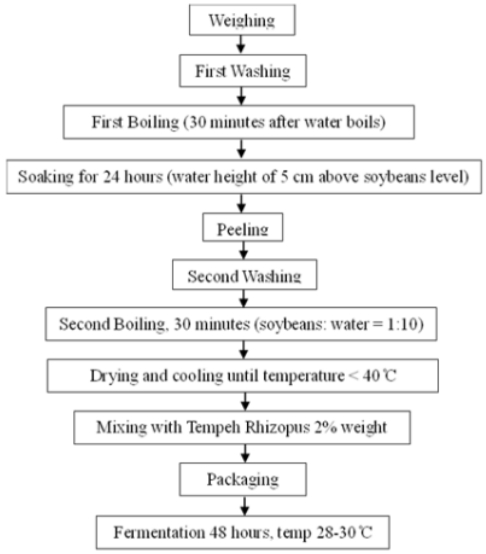

Figure 1. Stages of conventional tempeh production.

as input material, pressure boiling above atmospheric pressure, and soaking with citric acid. Dry peeled soybeans are produced by crushing the soybean shell and separating the shell from the bean, instead of the traditional method of soaking and trampling with human feet, which is unhygienic [7,8]. Meanwhile, boiling the soybeans for tempeh serves to eliminate competing microorganisms and release beneficial molecules for tempeh yeast growth [9]. Pressure boiling has been used in food products such as pressurized milkfish [10] but has not yet been applied to soybeans in tempeh production. Additionally, soaking soybeans, which typically takes 6 to 24 hours, is primarily done to increase acidity, which kills contaminating bacteria, and the addition of lactic acid bacteria can shorten the soaking time [11]. The improved production stages are shown in Figure 2.

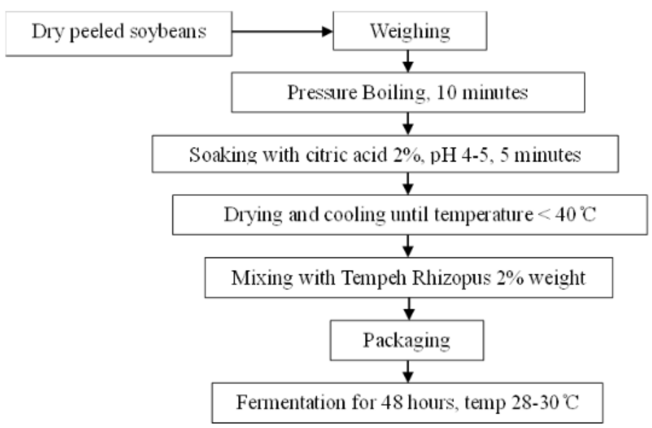

Figure 2. Stages of simplified tempeh production.

1.2 Robot in tempeh industry 4.0

The process improvements in simplified tempeh production primarily involve the preparation of soybeans before they are mixed with Rhizopus yeast. Currently, most soybean preparation processes are performed manually, in the form of batch handling. Human workers often struggle to maintain precise timing and are prone to contamination of materials. Additionally, the working hours for tempeh production do not align with standard office hours, as fermentation and soaking require more than 8 hours.

Thus, robots have potential for material handling tasks that demand energy, focus, and repetitive work. Handling failures in the food industry can lead to quality degradation of the food product [12]. Therefore, the aim of this research is to develop a mobile robot platform suitable for batch soybean handling in a tempeh production facility. The platform should be capable of moving in all directions within constrained spaces, recognizing each station on the production line, and adjusting its position precisely to pick up a basket of soybeans. The development of an actuator for picking the basket will be the next step after the platform has been completed.

2. Design of Omni-Wheel platform

In a tempeh factory, it is common for the stations to be arranged in line, with the process moving from one stage to the next until the final product is completed. Within the production facility, the material handling robot must have the ability to move in all directions with precision. An omni-directional mobile robot capable of holonomic motion can move in any direction without changing its orientation [13]. One type of wheel used by the omni robot for holonomic movement is the Universal Wheel, as shown in Figure 3. This wheel features passive rollers mounted at a 90-degree angle relative to the hub, allowing movement both in the hub direction and in the roller direction [13].

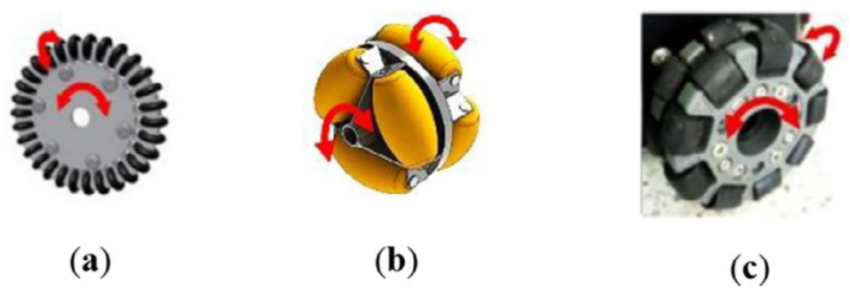

Figure 3. Some types of Universal Wheel [13].

Therefore, the Universal Wheel was designed with an outer diameter of 10 cm and contained 8 rollers on each wheel, with each roller covered in rubber to provide good friction with the floor. The wheels were arranged in a square configuration, with each wheel positioned at the middle of each side of the square, forming a cross pattern. The wheel is shown in Figure 4, and the designed platform with four Universal Wheels is shown in Figure 5. To move forward, the left and right wheels were driven forward while the front and rear wheels were stopped. To move backward, the left and right wheels were driven backward while the front and rear wheels were stopped. For movement to the left, the front and rear wheels moved left, while the left and right wheels were stopped. To adjust the angle or orientation, all of the wheels move in the same direction, either all clockwise or all counter-clockwise.

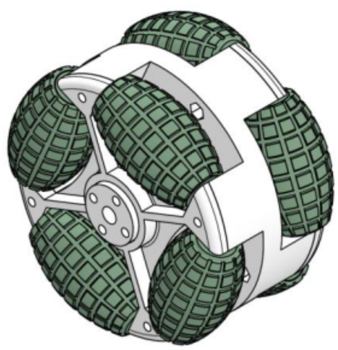

Figure 4. The Universal Wheel.

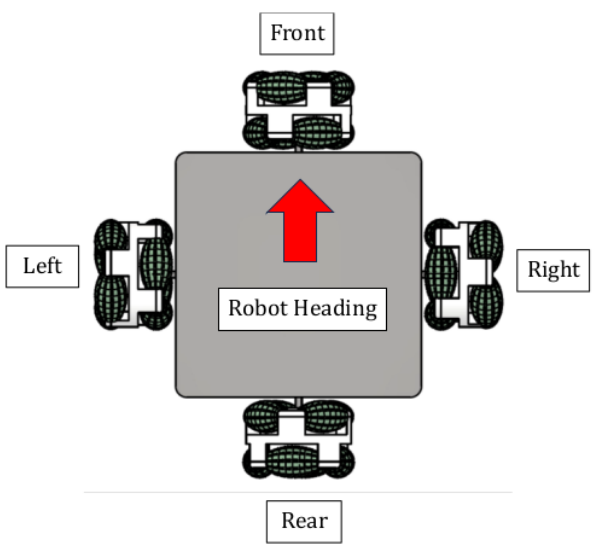

Figure 5. Design of the Omni-Wheel robot platform with four wheels.

3. Prototyping

The robot platform was equipped with an RFID MFRC522 for recognizing production stations. Chip less MIFARE S50 tags were placed in front of each station so the robot could read the name of the station. When the robot passed near a tag, it would read the name of the station [14]. Two ToF (Time-of-Flight) distance sensors, VL53L0X, were used to measure the distance between the robot and the stations, while a third distance sensor, installed in the front position, was used for obstacle avoidance. The prototype of the robot platform is depicted in Figure 6. A bar was installed in front of the stations for reference in sensor readings.

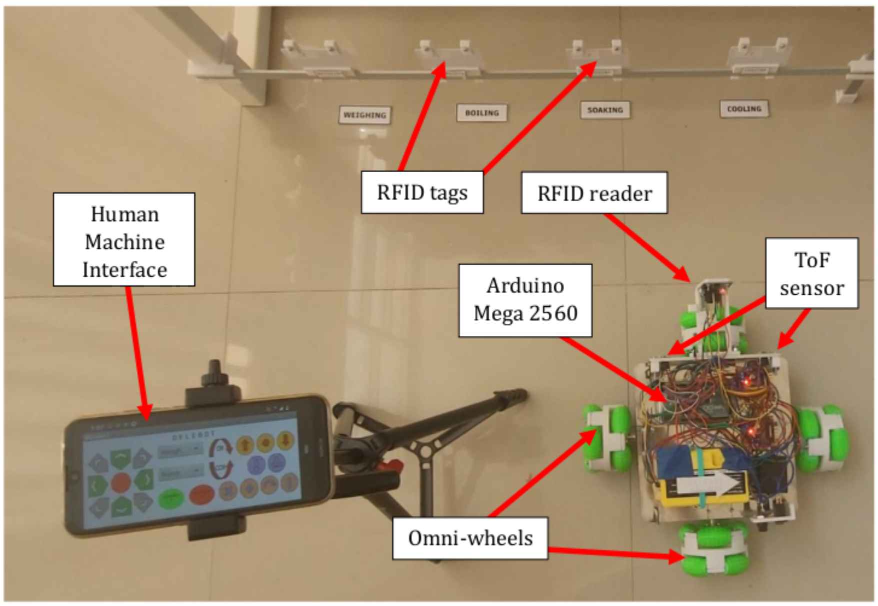

Figure 6. Prototype of the Omni-Wheel robot platform.

The robot moved along the five specified stations in a straight line, from the weighing station to the mixing station. Initially, the robot located the weighing station as the first station. Two ToF sensors on the left side of the robot measured the distances between the robot and a reference bar. If the two distances were not equal, the robot adjusted its position to align precisely with the bar. Afterward, the robot searched for the weighing station by reading the nearby RFID tag. It moved forward until it reached the designated station. From that station, the robot identified the position of the weighing station. If it was the boiling station, the robot needed to move to the left, and the next station was the weighing station. The sequence of the stations was stored in the robot's programming memory. With the correct distance and orientation between the robot and the station, the batch basket of soybeans could be picked up or placed down in the correct position, from the weighing station all the way to the mixing station. These navigation processes are depicted in Figure 7.

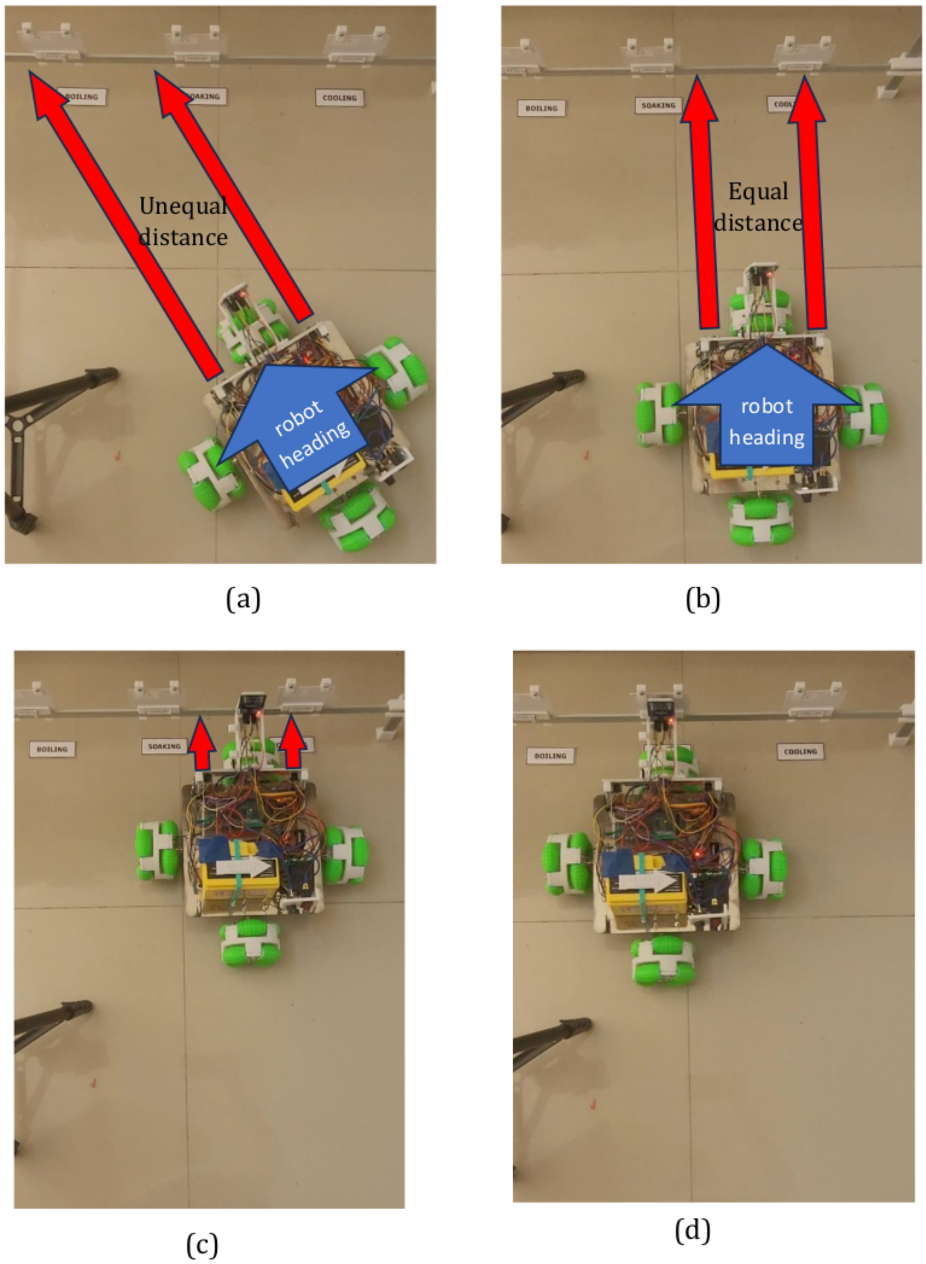

Figure 7. Robot navigation and localization. (a) The robot sensed the difference in distance readings to the reference bar. (b) The robot adjusted its orientation against the reference bar until it obtained the same reading from the two ToF sensors. (c) The robot moved until it achieved the correct distance between the robot and the reference bar. (d) The robot moved to the left until it found tags and read the name of the station.

The algorithm concept for the robot navigation and localization can be seen in the flowchart in Figure 8. At the beginning of the operation, the robot always searches for the weighing station after adjusting its position relative to the reference bar with the correct angle and distance. After that, it moves from one station to the next until it reaches the mixing station. For the movement from the packaging station to the fermentation station, another material handling robot with a different working algorithm needs to be employed.

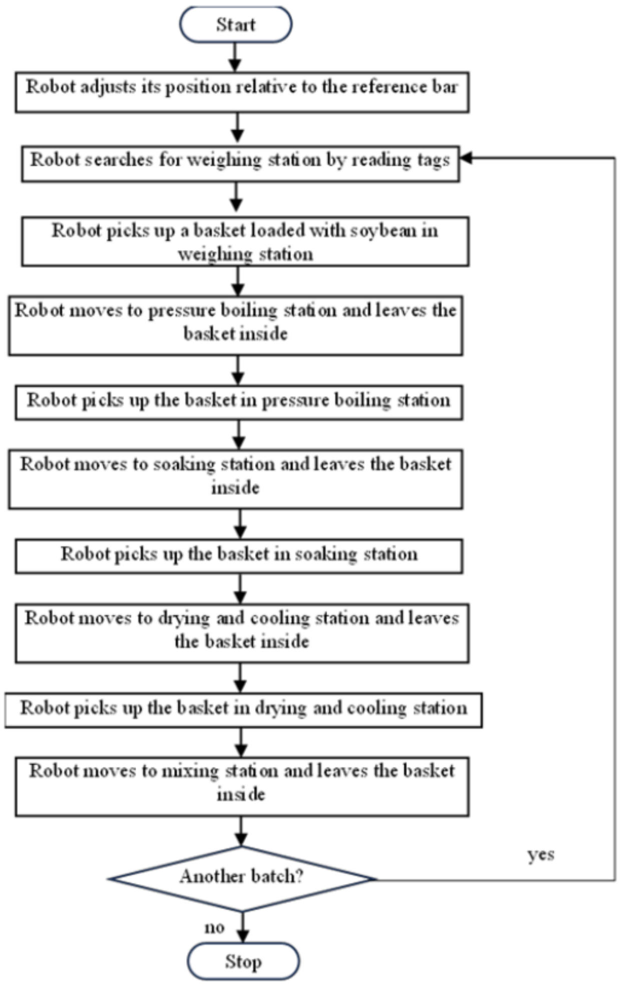

Figure 8. Flowchart of the robot navigation and localization algorithm.

The robot was controlled by an Arduino Mega 2560, which was connected to a smartphone serving as a user interface via Bluetooth for convenience. In a small factory, a Bluetooth connection is viable [15]. The user could choose between autonomous and manual control modes, facilitating troubleshooting during operation.

4. Conclusion

In this paper, a prototype of an omni-wheel robot platform was developed for batch soybean handling in a tempeh industry. The robot was capable of holonomic motion, meaning it could change direction without altering its heading. It moved from one station to another with the front side of the robot leading before the front side of the stations, using a continuous reference bar mounted at the front of the stations. Two distance sensors guided the robot along the bar, helping to maintain the correct distance and orientation. The robot recognized the name of each station by reading an RFID tag mounted on top of the reference bar. Thus, the robot was able to move from one station to another, handling a soybean basket processed at each station. An actuator for picking up and putting down the soybean basket will be installed on the robot platform. With this soybean handling robot platform, the quality of the tempeh produced is expected to be stable, and contamination during handling can be minimized.

5. Acknowledge

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