Prototype Design of Palm Oil Fruit Collection Based on Automation Industrial Robotics using QFD Method

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Abstract : The manual collection of scattered palm oil fruits in plantation areas often causes worker fatigue and ergonomic risks. This study aims to analyze user requirements and design an automated robotic system for palm oil fruit collection using the Quality Function Deployment (QFD) approach. The proposed robot is designed to navigate autonomously between oil palm trees and detect fruit positions through sensors and intelligent camera integration. QFD is used to translate user needs into technical specifications for the robotic system. The analysis shows that several attributes are required, including high mobility on various terrains, a robotic arm for fruit collection and self-recovery when overturned, weather-resistant and easy-to-clean materials, an automated fruit collection mechanism, sufficient wireless power endurance, a solar-powered charging station, accurate fruit identification, a navigation system, and a fruit weight detection sensor. The highest improvement ratios are found in the navigation system, robotic arm, solar charging station, and weight detection sensor. These findings indicate that the proposed robotic system can meet user requirements and has the potential to improve collection efficiency, reduce worker workload, and support productivity in oil palm plantations.

Keywords: Prototype, Product Design, User Satisfaction, Quality Function Deployment.

Abstrak : *Pengumpulan brondolan kelapa sawit yang tersebar di area perkebunan masih banyak dilakukan secara manual, sehingga berpotensi menimbulkan kelelahan kerja dan risiko ergonomis bagi pekerja. Penelitian ini bertujuan menganalisis kebutuhan pengguna serta merancang sistem robotik otomatis untuk pengumpulan brondolan kelapa sawit dengan pendekatan Quality Function Deployment (QFD). Sistem robotik yang diusulkan dirancang untuk melakukan navigasi secara otonom di antara pohon kelapa sawit serta mendeteksi posisi brondolan melalui integrasi sensor dan kamera cerdas. Metode QFD digunakan untuk menerjemahkan kebutuhan pengguna ke dalam spesifikasi teknis sistem. Hasil analisis menunjukkan bahwa atribut utama yang diperlukan meliputi mobilitas tinggi pada berbagai kondisi medan, lengan robot untuk proses pengambilan dan pemulihan posisi saat terbalik, material tahan cuaca dan mudah dibersihkan, mekanisme pengumpulan otomatis, ketahanan daya yang memadai, stasiun pengisian daya berbasis surya, kemampuan identifikasi* *brondolan yang akurat, sistem navigasi, serta sensor pendeteksi berat. Rasio perbaikan tertinggi terdapat pada sistem navigasi, lengan robot, stasiun pengisian daya surya, dan sensor pendeteksi berat. Temuan ini menunjukkan bahwa rancangan sistem robotik yang diusulkan berpotensi memenuhi kebutuhan pengguna, meningkatkan efisiensi pengumpulan, mengurangi beban kerja, serta mendukung produktivitas perkebunan kelapa sawit.*

Kata Kunci: *Prototipe, Desain Produk, Kepuasan Pengguna, Quality Function Deployment.*

INTRODUCTION

The oil palm plantation sector is one of the leading contributors to economic growth in Indonesia. Plantation activities are distributed across 26 provinces and 200 regencies/cities, covering a total area of approximately 16.8 million hectares (Pebrianto et al., 2024). From this total area, national palm oil production is estimated to reach 50 million tons annually. A study conducted by M R Ramadhan & Gesmi I, (2026) indicates that palm oil can be utilized as both a supporting and primary raw material in various industrial sectors, including food, cosmetics, bioenergy, and chemicals. Another study by Punvichai et al., (2025) states that palm oil, derived from plant-based sources, has been proven to possess higher economic value compared to other vegetable oils such as soybean oil, sunflower seed oil, and canola oil. This advantage is further supported by its high productivity, particularly reflected in its shorter harvesting cycle compared to other oil-producing crops. Despite its significant contribution, the productivity of oil palm processing still faces various challenges, particularly at the harvesting stage (Azizi et al., 2026).

According to study W Fadhillah et al., (2023), harvesting is the most critical phase in determining production outcomes. However, an important aspect that is often overlooked is the collection of loose fruits (palm kernels) that detach from the bunches and scatter on the ground. Inefficient collection of these loose fruits can lead to yield losses, even though they have high economic value when properly collected and resold (Dalimunthe et al., 2026). Study Yuyoh et al., (2026) highlights that the collection of loose fruits is still frequently neglected and carried out manually by farmers, particularly in small-scale plantations. This activity requires workers to bend down and pick up palm fruits one by one from the ground, which, over time, can lead to physical fatigue (Susanti et al., 2026). Working conditions are further exacerbated by the heterogeneous characteristics of plantation land, such as muddy, rocky, and root-filled surfaces, as well as uneven terrain (Hassan et al., 2026). In addition, suboptimal harvesting conditions increase the potential for yield losses due to loose fruits that are not collected efficiently (Hakim et al., 2026). Limited labor availability, especially during peak harvesting seasons, also contributes to the inefficiency of the loose fruit collection process (A Saad et al., 2026). Various previous studies have identified technical and operational issues in the loose fruit collection process and have emphasized the importance of technological development to improve efficiency.

However, most researchers have primarily focused on technical or mechanical solutions and have not optimally integrated user needs, particularly those of farmers as the main end-users in the field. In fact, a user-centered approach is a critical factor to ensure that the developed technology can be used effectively, ergonomically, and in accordance with real field conditions. To address the needs of oil palm farmers, this study applies the Quality Function Deployment (QFD) methodology as an approach to designing a system or robotic solution that aligns with user requirements. This method is used to support the design process so that the system can function effectively as a tool to enhance productivity and improve harvest quality. Quality Function Deployment (QFD) is a systematic approach that can be used to translate user needs and expectations into technical product characteristics (Awad et al., 2026; Adzkiyak et al., 2026). QFD has been proven to improve product design quality by identifying the most relevant attributes for users and integrating them into the development process (SUN & ZHANG, 2026), (Chauhan et al., 2025).

Furthermore, this approach positions users as a central element in the design process, ensuring that user needs and preferences serve as the foundation for product development through to implementation (Feri & Noormayasari, 2026). QFD not only functions to improve product quality but also ensures that the resulting product is capable of optimally meeting user requirements (Suhaeri & Jaqin, 2026; Nurselvi et al., 2026). Other studies have shown that the application of QFD can produce more ergonomic products that align with user characteristics (Andrejić & Pajić, 2025), and through the House of Quality (HOQ) approach combined with QFD attributes and anthropometric considerations, more comfortable designs can be achieved (Li et al., 2025). Moreover, the primary objective of QFD is to meet and even exceed user expectations in order to enhance product competitiveness Z Noor et al.,(2026), as well as to support process and system improvements in product development (Ren & Cha, 2025). Nevertheless, based on the existing literature review, several research gaps remain.

First, there is still a lack of studies that specifically address the development of oil palm loose fruit collection systems or robots based on user needs. Second, the application of the QFD method in the context of designing loose fruit collection technology remains limited. Third, there is a gap of a design approach that systematically integrates user requirements, field conditions, and ergonomic considerations into a comprehensive design framework. Based on these issues and identified research gaps, the objective of this study is to explicitly design a robotic-based system or device for collecting oil palm loose fruits using the Quality Function Deployment (QFD) method. This approach aims to translate user requirements into appropriate technical product specifications, thereby improving the efficiency of the collection process, reducing worker fatigue, and minimizing harvest losses.

METHODS

This study was conducted at an oil palm plantation owned by PT. Berau Coal, involving 33 respondents to identify user needs, preferences, and expectations regarding the product design. Data collection was carried out continuously from June 23 to June 28, 2025. The collected data were used as the basis for designing and developing a robotic system that aligns with operational requirements in the field. This study applies the Quality Function Deployment (QFD) method, which consists of several analytical stages in the product development process (Adzkiyak et al., 2026). The research stages used to support the design and development process of the robotic automation system are illustrated in Figure 1.

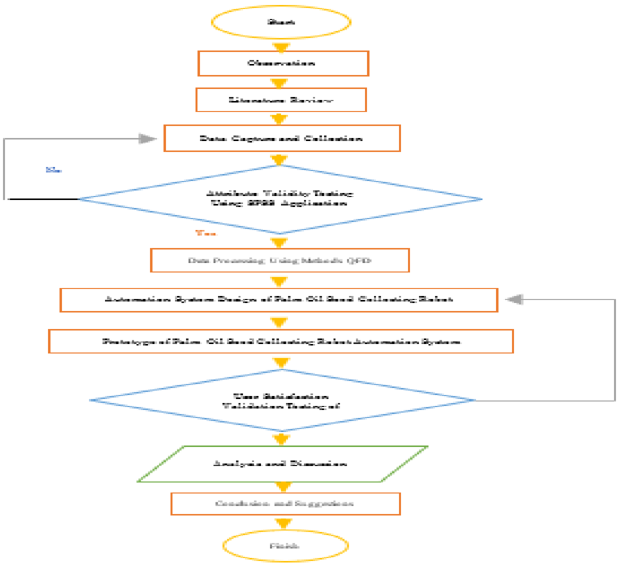

Figure 1. Research Workflow

The study began with field observations to obtain an overview of the operational conditions of oil palm plantations, followed by a literature review to strengthen the theoretical and methodological foundation. Data collection was carried out through interviews, attribute-based questionnaires, and documentation, with respondents selected using purposive sampling from workers involved in collecting oil palm fruits. The collected data were then tested for validity and reliability using SPSS Statistics to ensure data quality and consistency. If the data did not meet the required criteria, recollection was conducted. Data that met the criteria were subsequently processed using the Quality Function Deployment (QFD) method. The results of the QFD analysis were used as the basis for designing the system in accordance with user requirements, which was then realized in the form of a robotic prototype. Furthermore, an evaluation was conducted by collecting user satisfaction data to assess system performance and acceptance. The evaluation results were analyzed to identify potential issues and formulate design improvements. This sequence of stages forms a systematic workflow for the design and development of a QFD-based robotic system, as illustrated in Figure 2.

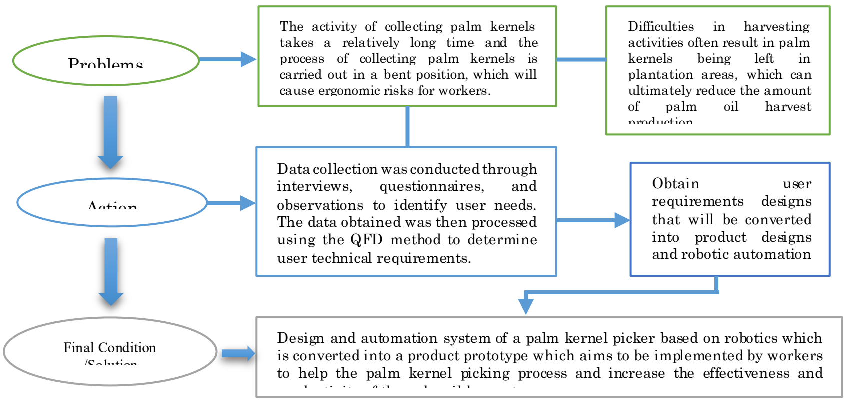

Figure 2. Research Framwork

The research framework encompasses problem identification, research actions, and the final condition as a solution. The primary issue is the difficulty faced by farmers in collecting scattered oil palm fruits during harvesting, which leads to physical fatigue and reduced work efficiency. Data were collected through interviews, questionnaires, and observations to be analyzed as the basis for research development. Data processing was carried out using the Quality Function Deployment (QFD) method, which is appropriate for designing a user-centered robotic system. This method translates user needs into technical specifications and design concepts for an automated, systematic oil palm fruit collection system. The result is a prototype expected to improve the effectiveness and productivity of the harvesting process.

RESULTS AND DISCUSSIONS

User Requirements

The identification of user requirements represents the initial stage in the development of a robotic system for collecting oil palm fruits. This study involved 33 workers from the oil palm plantation of PT. Berau Coal, who are directly engaged in collection activities, enables them to provide relevant insights into operational needs in the field. Voice of Customer (VoC) data were collected through interviews to explore user needs, expectations, and constraints encountered during the collection process. The data were then analyzed to identify user requirement attributes, including equipment functionality, work efficiency, ease of use, and the ability to operate under plantation environmental conditions. These requirement attributes were subsequently structured systematically as the basis for analysis using the Quality Function Deployment (QFD) method. The results of the user requirement interpretation are presented in Table 1.

Table 1. Interpretation of User Requirements

No	*Voice of customers*	
	User Requirements	Interview

1	Having good mobility to operate across various terrain conditions	Open
2	Equipped with a robotic arm that functions to restore the robot's position when overturned and supports the collection of oil palm fruits	Open
3	Materials are easy to clean and resistant to train and heat conditions	Open
4	Having an automated collection system	Open
5	Having an automatic storage mechanism and collection station for oil palm fruits	Open
6	Having a wireless power system with long battery endurance	Open
7	The device is equipped with a solar-powered charging station	Open
8	Capable of identifying oil palm fruits effectively and efficiently	Open
9	Having a navigation system	Open
10	The device is equipped with sensors to detect the weight og oil palm fruits	Open

Table 1 presents the results of the Voice of Customer (VoC) identification from plantation workers as system users, representing the primary requirements in the development of an oil palm fruit collection robot. The analysis indicates that users emphasize key aspects such as robot mobility across various terrains, an automated collection system, and durability under plantation environmental conditions. In addition, users expect the integration of technologies such as navigation systems, detection sensors, and automated storage mechanisms. These findings demonstrate that user requirements extend beyond basic functionality to include efficiency, ease of use, and system reliability. All identified requirements were subsequently formulated into product attributes as the basis for design and were utilized in the Quality Function Deployment (QFD) analysis to be translated into the system's technical specifications.

Validity Test

The next stage is the validity test of user requirement attributes to ensure that each questionnaire item accurately represents the intended needs. The questionnaire items were developed based on interview results and compiled into a preliminary questionnaire, which was distributed to oil palm plantation workers directly involved in the collection process to confirm the initial findings. The questionnaire employed a five-point Likert scale to measure the importance level of each attribute, ranging from "not important" to "very important." The collected data were analyzed using SPSS through validity testing. An attribute is considered valid if it demonstrates a certain level of significance, indicated by an asterisk symbol in the SPSS output Z Noor et al., (2026), while non-significant attributes are eliminated. The analysis results show that all attributes meet the validity criteria without any elimination; therefore, all attributes were used in the subsequent stages of analysis within the Quality Function Deployment (QFD) method. The results of the validity test are presented in Table 2.

Table 2. Results of Validity Testing on Product Attributes Using SPSS Software

No	Product Attribute Validation			
	Voice of customers	calculated r-value	r-table s= 5% (N=33)	Meaning
1	Having good mobility to operate across various terrain conditions	0.704	0.344	Valid
2	Equipped with a robotic arm that functions to restore the robot's position when overturned and supports the collection of oil palm fruits	0.421	0.344	Valid
3	Materials are easy to clean and resistant to train and heat conditions	0.640	0.344	Valid
4	Having an automated collection system	0.413	0.344	Valid

No	Product Attribute Validation			
	Voice of customers	calculated r-value	r-table s= 5% (N=33)	Meaning
5	Having an automatic storage mechanism and collection station for oil palm fruits	0.678	0.344	Valid
6	Having a wireless power system with long battery endurance	0.477	0.344	Valid
7	The device is equipped with a solar-powered charging station	0.685	0.344	Valid
8	Capable of identifying oil palm fruits effectively and efficiently	0.770	0.344	Valid
9	Having a navigation system	0.384	0.344	Valid
10	The device is equipped with sensors to detect the weight og oil palm fruits	0.414	0.344	Valid

A variable is considered valid if the calculated r-value is greater than the r-table value. The validity testing in this study involved 33 oil palm plantation workers, resulting in a sample size of N = 33 at a significance level of 5%. Based on this criterion, the r-table value of 0.344 was used as the reference in the testing process. This r-table value was then used as the basis for comparison with the calculated r-values for each questionnaire attribute. The results show that all calculated r-values for the questionnaire attributes are greater than the r-table value. Therefore, it can be concluded that all questionnaire attributes are valid and suitable for use as research instruments.

Reliability Test

The attributes in a questionnaire can be considered reliable if respondents' answers to each item demonstrate a stable level of consistency over time. In other words, reliability reflects the extent to which a research instrument can produce consistent data when measurements are repeated under the same conditions. According to Z Noor et al., (2026), a questionnaire is considered reliable if it has a reliability coefficient (α) greater than 0.60. This value is also known as Cronbach's Alpha and serves as the minimum threshold for reliability. The results of the reliability test in this study show that the α value is 0.776, which is higher than the minimum Cronbach's Alpha value (0.776 > 0.60). These results indicate that the questionnaire instrument used has a good level of consistency. Therefore, the questionnaire is considered reliable and suitable for use as a data collection instrument in this study.

Stages of the Quality Function Deployment Method

After data collection and the completion of validity and reliability testing, the data were used as input for the Quality Function Deployment (QFD) analysis to translate user requirements into technical product characteristics. The initial stage of QFD involves competitive satisfaction analysis by calculating the average ratings of respondents for each requirement attribute. These values are used to compare the level of user need fulfillment with existing similar products. In this study, the comparison was made with an oil palm fruit collection device developed by previous researchers, which is still undergoing refinement. The visualization of this product is presented in Figure 3.

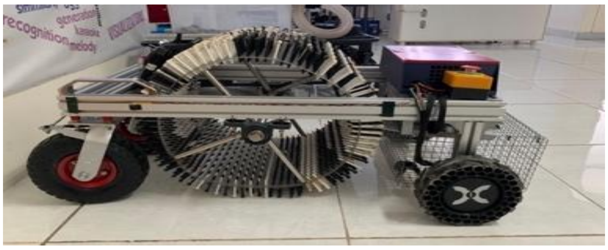

Figure 3. Competitive Products (Grondol)

The Grondol product was used as a competitive benchmark in this study to represent the level of user satisfaction with existing products in the field. The level of satisfaction was calculated based on the average ratings provided by respondents for each requirement attribute obtained from the questionnaire. These values were used to assess the extent to which user needs are fulfilled by the comparison product. The scoring was conducted using a weighted point system, where a score of 5 indicates "Very Good," 4 indicates "Good," 3 indicates "Neutral," 2 indicates "Poor," and 1 indicates "Very Poor." The detailed results of the satisfaction level calculation for the competitive product (Grondol) are presented in Table 3.

Table 3. Results of the Competitive Product Satisfaction Questionnaire (Grondol)

No	Results of the Competitive Product Satisfaction Questionnaire			
	Voice of customers	*Mean*	Rounded Value	Description
1	Having good mobility to operate across various terrain conditions	1.412210	1	Very Poor (the wheels used do not provide adequate mobility)
2	Equipped with a robotic arm that functions to restore the robot's position when overturned and supports the collection of oil palm fruits	1.012781	1	Very Poor (does not have a robotic arm)
3	Materials are easy to clean and resistant to train and heat conditions	1.005811	1	Very Poor (the materials used are difficult to clean and are not resistant to weather conditions, especially rain)
4	Having an automated collection system	3.000291	3	Neutral (the automation system has not been implemented and still uses remote control)
5	Having an automatic storage mechanism and collection station for oil palm fruits	1.331120	1	Very Poor (does not have an automated palm fruit collection station)
6	Having a wireless power system with long battery endurance	2.412211	2	Poor (has long battery endurance but does not have a wireless power system)
7	The device is equipped with a solar-powered charging station	1.043553	1	Very Poor (does not have a charging station; charging is done manually)
8	Capable of identifying oil palm fruits effectively and efficiently	2.000124	2	Poor (fruit identification is performed manually)
9	Having a navigation system	1.112391	1	Very Poor (does not have a navigation system)
10	The device is equipped with sensors to detect the weight og oil palm fruits	1.177515	1	Very Poor (does not have a weight detection sensor)

Based on Table 3, the level of user satisfaction with the competitive product shows variations across each requirement attribute. Most attributes received a score of 1 (very poor), such as mobility across various terrains, the robotic arm, weather-resistant materials, automatic storage systems, solar-powered charging stations, navigation systems, and weight detection sensors. This indicates that these attributes still fall significantly short of meeting user requirements. Several other attributes received a score of 2, such as the wireless power system and the ability to identify oil palm fruits, which are considered insufficient in meeting user needs. Meanwhile, the automated collection system received a score of 3 (neutral), indicating that it has not fully met user expectations. Overall, these results suggest that the competitive product still has limitations and therefore requires further design development that better aligns with field requirements. The next stage in the QFD method is the analysis of attribute importance (importance to the customer) to determine the priority of user needs. The assessment was conducted using a Likert scale ranging from 1 to 5, from “not important” to “very important.” The weighting results obtained from respondents were used to determine the priority of attributes in the development of the oil palm fruit collection robotic system, as presented in Table 4.

Table 4. Results of the User Importance Questionnaire for the Oil Palm Fruit Collection Robotic System

No	Results of the User Importance Questionnaire			
	Voice of customers	Mean	Rounded Value	Description
1	Having good mobility to operate across various terrain conditions	5.843211	5	Extremely Important
2	Equipped with a robotic arm that functions to restore the robot’s position when overturned and supports the collection of oil palm fruits	3.965210	4	Very Important
3	Materials are easy to clean and resistant to train and heat conditions	5.643110	5	Extremely Important
4	Having an automated collection system	5.544220	5	Extremely Important
5	Having an automatic storage mechanism and collection station for oil palm fruits	3.347832	3	Important
6	Having a wireless power system with long battery endurance	3.223528	3	Important
7	The device is equipped with a solar-powered charging station	4.329413	4	Very Important
8	Capable of identifying oil palm fruits effectively and efficiently	4.929424	5	Extremely Important
9	Having a navigation system	3.334879	3	Important
10	The device is equipped with sensors to detect the weight og oil palm fruits	3.451298	3	Important

Based on the questionnaire data in Table 4, the Voice of Customer (VoC) reflects the level of importance of each attribute in the oil palm fruit collection robotic system, calculated using mean values and categorized through score rounding. The analysis results indicate that several attributes are of the highest priority (category 5), namely high mobility across various terrains (mean 5.84), weather-resistant and easy-to-clean materials (mean 5.64), an automated collection system (mean 5.54), and the capability to identify oil palm fruits (mean 4.93). This indicates that users prioritize key performance aspects such as mobility, material durability, automation, and system accuracy. The next highest priority attributes fall under category 4 (very important), including the robotic arm to support the collection process (mean 3.97) and the solar-powered charging station (mean 4.33), indicating the need for supporting features that enhance efficiency and energy sustainability. Meanwhile, medium-priority attributes (category 3) include automatic storage (mean 3.35), long-lasting wireless power systems (mean 3.45), navigation (mean 3.33), and sensor systems for identifying and measuring the weight of oil palm fruits (mean 3.45), which function as complementary features to improve convenience and system optimization. The next stage in the QFD method is the evaluation of user satisfaction (customer satisfaction performance) to assess the extent to which the product meets user requirements. The assessment was conducted using a Likert scale from 1 to 5, ranging from "very dissatisfied" to "very satisfied," based on questionnaires distributed to respondents. The results of the user satisfaction analysis are presented in Table 5.

Table 5. Results of the User Satisfaction Questionnaire for the Oil Palm Fruit Collection Robotic System

No	Results of the User Satisfaction Questionnaire			
	Voice of customers	Mean	Rounded Value	Description
1	Having good mobility to operate across various terrain conditions	4.987765	5	Extremely Satisfied
2	Equipped with a robotic arm that functions to restore the robot's position when overturned and supports the collection of oil palm fruits	4.321114	4	Very Satisfied
3	Materials are easy to clean and resistant to train and heat conditions	5.122190	5	Extremely Satisfied
4	Having an automated collection system	5.001224	5	Extremely Satisfied
5	Having an automatic storage mechanism and collection station for oil palm fruits	3.885113	4	Very Satisfied
6	Having a wireless power system with long battery endurance	4.789610	5	Extremely Satisfied
7	The device is equipped with a solar-powered charging station	4.187624	4	Very Satisfied
8	Capable of identifying oil palm fruits effectively and efficiently	5.523313	5	Extremely Satisfied
9	Having a navigation system	3.234370	3	Satisfied
10	The device is equipped with sensors to detect the weight og oil palm fruits	4.478643	4	Extremely Satisfied

Based on Table 5, the level of user satisfaction with the attributes of the oil palm fruit collection robotic system was analyzed using mean values, which were then categorized through score rounding from "very dissatisfied" to "extremely satisfied." The results show that several attributes fall into the "extremely satisfied" category (score 5), including robot mobility across various terrains (mean 4.99), weather-resistant and easy-to-clean materials (mean 5.12), the automated collection system (mean 5.00), long-lasting wireless power systems (mean 4.79), and the capability to identify oil palm fruits (mean 5.52). This indicates a very high level of satisfaction with the system's core performance, particularly in terms of operational capability, efficiency, and device durability.Other attributes fall into the "very satisfied" category (score 4), such as the robotic arm (mean 4.32), automatic storage (mean 3.89), solar-powered charging station (mean 4.19), and weight detection sensor (mean 4.48), indicating good satisfaction levels but with room for improvement in performance and usability. Meanwhile, the navigation system falls into the "satisfied" category (mean 3.23), making it the attribute with the lowest satisfaction level and therefore requiring further enhancement.

The next stage in the QFD method is the determination of target fulfillment (goal), which involves setting the expected level of satisfaction for each attribute based on the product design capability. The target assessment uses a Likert scale from 1 to 5, ranging from “very dissatisfied” to “extremely satisfied,” as a reference for development. The results of the target fulfillment determination are presented in Table 6.

Table 6. Results of the Target Fulfillment Questionnaire for the Oil Palm Fruit Collection Robotic Automation System

No	Results of the Target Fulfillment Questionnaire		
	Voice of customers	Mean of Target	Description
1	Having good mobility to operate across various terrain conditions	5	Extremely Satisfied
2	Equipped with a robotic arm that functions to restore the robot’s position when overturned and supports the collection of oil palm fruits	5	Extremely Satisfied
3	Materials are easy to clean and resistant to train and heat conditions	5	Extremely Satisfied
4	Having an automated collection system	5	Extremely Satisfied
5	Having an automatic storage mechanism and collection station for oil palm fruits	4	Very Satisfied
6	Having a wireless power system with long battery endurance	5	Extremely Satisfied
7	The device is equipped with a solar-powered charging station	5	Extremely Satisfied
8	Capable of identifying oil palm fruits effectively and efficiently	5	Extremely Satisfied
9	Having a navigation system	4	Very Satisfied
10	The device is equipped with sensors to detect the weight og oil palm fruits	5	Extremely Satisfied

The data in Table 6 indicate the target level of user satisfaction for each attribute of the oil palm fruit collection robotic system, expressed as mean values and classified as achievement standards. The analysis results show that most attributes are targeted to reach the “extremely satisfied” category, indicating that the system is expected to optimally meet user requirements. The next stage in the QFD method is the determination of the improvement ratio, which aims to identify the level of enhancement required for each attribute. This assessment is conducted by comparing the actual satisfaction values with the target values. Attributes that have met or exceeded the target do not require improvement, whereas those below the target need to be enhanced during the development process. The improvement ratio is calculated using a specific formula as presented in Equation (1). The results of the improvement ratio calculation for each user requirement attribute are presented in detail in Table 7.

$$\text{Improvement Ratio} = \frac{\text{Target Fullfillment}}{\text{Customer Satisfaction Performance}} \dots\dots\dots\dots\dots\dots\dots\dots\dots..(1)$$

Table 7. Results of the Improvement Ratio for the Oil Palm Fruit Collection Robotic Automation System

No	Result of The Improvement Ratio		
	Voice of customers	Improvement Ratio	Description
1	Having good mobility to operate across various terrain conditions	1.0	No improvement required

No	Result of The Improvement Ratio		
	Voice of customers	Improvement Ratio	Description
2	Equipped with a robotic arm that functions to restore the robot's position when overturned and supports the collection of oil palm fruits	1.25	No improvement required
3	Materials are easy to clean and resistant to train and heat conditions	1.0	No improvement required
4	Having an automated collection system	1.0	No improvement required
5	Having an automatic storage mechanism and collection station for oil palm fruits	1.0	No improvement required
6	Having a wireless power system with long battery endurance	1.0	No improvement required
7	The device is equipped with a solar-powered charging station	1.25	No improvement required
8	Capable of identifying oil palm fruits effectively and efficiently	1.0	No improvement required
9	Having a navigation system	1.33	No improvement required
10	The device is equipped with sensors to detect the weight og oil palm fruits	1.25	No improvement required

Based on the calculation results, all attributes have an improvement ratio greater than 1 (>1), indicating that the level of user satisfaction has met the target and, in general, does not require improvement. However, several attributes with relatively higher ratios still require attention, namely the navigation system, robotic arm, solar-powered charging system, and oil palm fruit weight sensor, as they have the potential to enhance product performance and competitiveness. The next stage in the QFD method is the evaluation of sales points to measure product attractiveness based on the fulfillment of requirement attributes. The assessment is conducted using weighted values of 1.5 (high), 1.2 (moderate), and 1 (low/not significant) to identify attributes that contribute most to the product's market value. The results of the sales point evaluation for each attribute are presented in Table 8.

Table 8. Results of the Sales Level Questionnaire for the Oil Palm Fruit Collection Robotic Automation System

No	Results of the Sales Level Questionnaire		
	Voice of customers	Mean Sales Level	Description
1	Having good mobility to operate across various terrain conditions	1.5	High sales potential
2	Equipped with a robotic arm that functions to restore the robot's position when overturned and supports the collection of oil palm fruits	1.5	High sales potential
3	Materials are easy to clean and resistant to train and heat conditions	1.5	High sales potential
4	Having an automated collection system	1.5	High sales potential
5	Having an automatic storage mechanism and collection station for oil palm fruits	1.5	High sales potential
6	Having a wireless power system with long battery endurance	1.5	High sales potential

No	Results of the Sales Level Questionnaire		
	Voice of customers	Mean Sales Level	Description
7	The device is equipped with a solar-powered charging station	1.5	High sales potential
8	Capable of identifying oil palm fruits effectively and efficiently	1.5	High sales potential
9	Having a navigation system	1.2	Moderate sales potential
10	The device is equipped with sensors to detect the weight og oil palm fruits	1.5	High sales potential

Based on Table 8, most attributes obtained a sales point weight of 1.5, indicating high sales potential, including robot mobility, automated collection system, material durability, energy system, as well as identification and sensor capabilities. This indicates that the main attributes have strong market prospects. Meanwhile, the navigation system received a weight of 1.2 (moderate), suggesting that it still requires further development to enhance product attractiveness and competitiveness. The next stage in the QFD method is the calculation of raw weight, which is used to determine attribute priorities based on the level of importance, improvement ratio, and sales potential. This value is obtained by multiplying these three factors, thereby identifying the attributes that should be prioritized in the development process. The calculation formula is presented in Equation (2), and the results are shown in Table 9.

$$\text{Raw Weight} = (\text{User Importance})X(\text{Improvement Ratio})X(\text{Sales Level}) \dots\dots\dots\dots (2)$$

Table 9. Results of the Raw Weight Calculation for the Oil Palm Fruit Collection Robotic Automation System

No	Results of the Raw Weight Calculation	
	Voice of customers	Raw Weight
1	Having good mobility to operate across various terrain conditions	7.50
2	Equipped with a robotic arm that functions to restore the robot's position when overturned and supports the collection of oil palm fruits	7.50
3	Materials are easy to clean and resistant to train and heat conditions	7.50
4	Having an automated collection system	7.50
5	Having an automatic storage mechanism and collection station for oil palm fruits	4.50
6	Having a wireless power system with long battery endurance	4.50
7	The device is equipped with a solar-powered charging station	7.50
8	Capable of identifying oil palm fruits effectively and efficiently	7.50
9	Having a navigation system	4.79
10	The device is equipped with sensors to detect the weight og oil palm fruits	5.62

The results of the raw weight calculation in Table 9 indicate that user preferences are primarily concentrated on aspects such as mobility, the robotic arm, material durability, the automated collection system, solar energy, and identification capability, all of which obtained the highest weight of 7.50. These attributes represent critical priorities in product implementation. Meanwhile, navigation components, power systems, storage mechanisms, and weight sensors fall into the medium priority category, which still require further development.

The next stage in the QFD method is the determination of the normalized raw weight. This value represents the level of urgency of each user requirement, where a higher score indicates a more critical need for the user. The calculation of this weight is based on Equation (3), with the results presented in detail in Table 10.

$$\text{Normalized Weight} = \frac{\text{Raw Weight}}{\Sigma\text{Raw Weight}} \dots\dots\dots\dots\dots\dots\dots\dots (3)$$

Table 10. Results of the Normalized Calculation for the Oil Palm Fruit Collection Robotic Automation System

No	Results of the Normalized Calculation	
	Voice of customers	Normalized Weight
1	Having good mobility to operate across various terrain conditions	1.17
2	Equipped with a robotic arm that functions to restore the robot's position when overturned and supports the collection of oil palm fruits	1.17
3	Materials are easy to clean and resistant to train and heat conditions	1.17
4	Having an automated collection system	1.17
5	Having an automatic storage mechanism and collection station for oil palm fruits	0.70
6	Having a wireless power system with long battery endurance	0.70
7	The device is equipped with a solar-powered charging station	1.17
8	Capable of identifying oil palm fruits effectively and efficiently	1.17
9	Having a navigation system	0.74
10	The device is equipped with sensors to detect the weight og oil palm fruits	0.88

The normalized values indicate that attributes such as mobility, the robotic arm, material durability, the automated collection system, solar energy, and identification capability have the highest scores (1.17), making them the top priorities in the design process. Meanwhile, attributes such as storage, power systems, navigation, and weight sensors fall into the medium priority category and still require further optimization. The next stage in QFD is the determination of technical requirements, which involves translating user needs into technical specifications as the basis for product design. This stage helps formulate a design that aligns with user requirements, the results of which are presented in Table 11.

Table 11. Technical Requirements Derived from the Voice of Customer

No	Technical Requirements Derived	
	Voice of customers	Technical Requirements
1	Having good mobility to operate across various terrain conditions	The drive system utilizes wheels with a fumble and roller mechanism, mechanically designed to generate high torque at low rotational speeds, thereby producing greater traction across various terrain conditions.
2	Equipped with a robotic arm that functions to restore the robot's position when overturned and supports the collection of oil palm fruits	The robotic arm is designed to perform object manipulation functions, such as grasping, moving, lifting, and precisely positioning objects during the oil palm fruit collection process.

No	Technical Requirements Derived	
	Voice of customers	Technical Requirements
3	Materials are easy to clean and resistant to train and heat conditions	The device structure uses lightweight steel, stainless steel, and fiber-reinforced materials selected based on structural strength, corrosion resistance, relatively low weight, and durability in working environments.
4	Having an automated collection system	The collection mechanism is designed using a flexible and selective roller system capable of adapting to ground surface conditions and improving accuracy in object retrieval.
5	Having an automatic storage mechanism and collection station for oil palm fruits	The storage container is designed with a hydraulic mechanism integrated with an automatic control system, enabling stable and efficient loading and unloading processes.
6	Having a wireless power system with long battery endurance	The power supply system uses a 12 V battery with a capacity of 20,000 mAh, capable of supporting device operation for approximately 6–8 hours, and is equipped with wireless charging technology.
7	The device is equipped with a solar-powered charging station	The charging system utilizes solar panels integrated with electromagnetic induction technology through transmitter and receiver modules, enabling energy transfer without direct cable connections.
8	Capable of identifying oil palm fruits effectively and efficiently	The identification system uses a camera with a specific field of view to optimally monitor the operational area and accurately detect objects.
9	Having a navigation system	The navigation system employs Global Positioning System (GPS) technology to support autonomous navigation and robot position correction. This system is also integrated with Internet of Things (IoT) technology for real-time device monitoring.
10	The device is equipped with sensors to detect the weight og oil palm fruits	A load cell sensor is used to accurately measure the weight of collected oil palm fruits in the storage container and to control load capacity before transfer to the collection point.

After conducting data collection and analysis, it can be concluded that oil palm farmers require the proposed product, namely a robotic automation system for collecting oil palm fruits. Therefore, a recapitulation of evaluation criteria for product design will be carried out, structured based on user priority needs to facilitate the design process, as presented in Table 12.

Table 12. Recapitulation of Values as a Basis for Designing the Oil Palm Fruit Collection Robotic Automation System

No	Recapitulation of Values as a Basis for Designing				
	Voice of customers	Improvement Ratio	Sales Level	Raw weight	Normalized Values, Technical Response, and Correlation
1	Having good mobility to operate across various terrain conditions	1.0	1.5	7.50	1.17

No	Recapitulation of Values as a Basis for Designing				
	Voice of customers	Improvement Ratio	Sales Level	Raw weight	Normalized Values, Technical Response, and Correlation
2	Equipped with a robotic arm that functions to restore the robot's position when overturned and supports the collection of oil palm fruits	1.25	1.5	7.50	1.17
3	Materials are easy to clean and resistant to train and heat conditions	1.0	1.5	7.50	1.17
4	Having an automated collection system	1.0	1.5	7.50	1.17
5	Having an automatic storage mechanism and collection station for oil palm fruits	1.0	1.5	4.50	0.70
6	Having a wireless power system with long battery endurance	1.0	1.5	4.50	0.70
7	The device is equipped with a solar-powered charging station	1.25	1.5	7.50	1.17
8	Capable of identifying oil palm fruits effectively and efficiently	1.0	1.5	7.50	1.17
9	Having a navigation system	1.33	1.2	4.79	0.74
10	The device is equipped with sensors to detect the weight og oil palm fruits	1.25	1.5	5.62	0.88

Based on Table 12, priority attributes are identified from the lowest improvement ratio values, including robot mobility across various terrains, weather-resistant and easy-to-clean materials, an automated collection system, automatic storage, long-lasting wireless power, and oil palm fruit identification capability. These attributes constitute the primary focus, as they have a significant impact on overall system performance. The sales point analysis indicates that most attributes exhibit high market potential, with only one attribute classified in the moderate category (1.2), suggesting that the majority of features are attractive to users. Furthermore, the normalized values of technical responses and correlations reflect the relative importance of each attribute, where the highest values represent the key priorities in the system design process.

Design Planning

The next stage is the design development based on the results of the user requirements analysis, which is modeled using Fusion 360 (CAD/CAM/CAE). The visualization of the design results is presented in Figure 4.

Figure 4. Front View of the Design of the Oil Palm Fruit Collection Robotic Automation System

The primary material used is stainless steel, with a frame and reinforcement based on fiber composites in accordance with user preferences. These materials are selected due to their strength, ease of cleaning, and corrosion resistance. The front section is equipped with a flexible and selective roller-based collection mechanism. The drive system combines wide tracks, internal traction fins, and rollers to maintain rotational stability, generating high torque and traction force, enabling operation on extreme and uneven terrains. The side view visualization is presented in Figure 5.

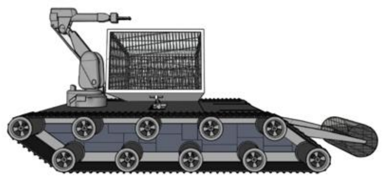

Figure 5. Side View of the Design of the Oil Palm Fruit Collection Robotic Automation System

The robotic arm in this system functions to automate several tasks, including restoring the robot's position when overturned, assisting in the collection process, and supporting the performance of the collection rollers by depositing the collected fruits into the storage unit. The storage unit is designed with a hydraulic mechanism to enable automatic loading and unloading operations. The rear view configuration of the system components is illustrated in Figure 6.

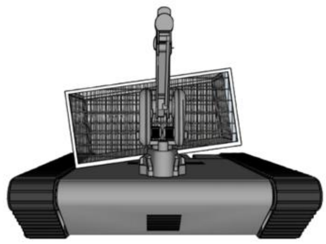

Figure 6. Rear View of the Design of the Oil Palm Fruit Collection Robotic Automation System

At the rear of the product design, there is a wireless charging system based on electromagnetic technology, utilizing a receiver module on the robot and a transmitter module at the solar-powered charging station. Meanwhile, Figure 7 presents the attribute specifications of the oil palm fruit collection robotic automation system based on user requirements.

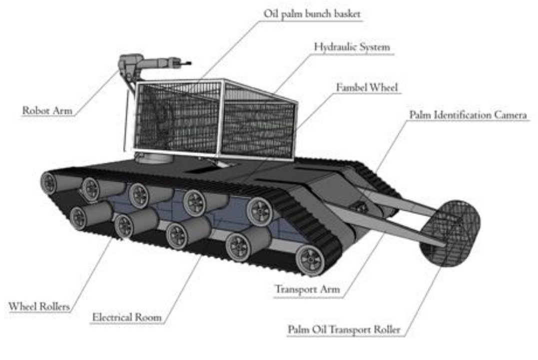

Figure 7. Attribute Specifications in the Design of the Oil Palm Fruit Collection Robotic Automation System

Product Prototype

The prototype was developed to evaluate its suitability with user requirements. The system design was realized in the form of a prototype, which was subsequently tested and validated. Figure 8 presents the implementation of the designed prototype. Furthermore, re-evaluation was conducted with users to assess system performance and product suitability, in order to ensure optimal fulfillment of user needs. The evaluation results are presented in Table 13.

Figure 8. Prototype of the Oil Palm Fruit Collection Robotic Automation System

To test and validate the prototype, a weighted scoring system was established, where a score of 5 indicates "Very Good," 4 indicates "Good," 3 indicates "Neutral," 2 indicates "Poor," and 1 indicates "Very Poor."

Table 13. Questionnaire Result of Prototype Product Satisfaction

No	Questionnaire Result of Prototype Product Satisfaction			
	Voice of customers	Mean	Rounded Value	Description
1	Having good mobility to operate across various terrain conditions	5.526634	5	Very Good
2	Equipped with a robotic arm that functions to restore the robot's position when overturned and supports the collection of oil palm fruits	5.773524	5	Very Good
3	Materials are easy to clean and resistant to train and heat conditions	3.977564	4	Good
4	Having an automated collection system	4.877210	5	Very Good
5	Having an automatic storage mechanism and collection station for oil palm fruits	5.311121	5	Very Good
6	Having a wireless power system with long battery endurance	5.764531	5	Very Good
7	The device is equipped with a solar-powered charging station	4.574310	4	Good
8	Capable of identifying oil palm fruits effectively and efficiently	5.671221	5	Very Good
9	Having a navigation system	3.966722	4	Good
10	The device is equipped with sensors to detect the weight og oil palm fruits	5.567834	5	Very Good

Based on the questionnaire results in Table 13, the prototype generally achieved a very high level of user satisfaction, with most attributes receiving a score of 5. Of the ten attributes evaluated, seven fall into the "very good" category, namely robot mobility, the robotic arm, the automated collection system, storage, power system, identification capability, and weight sensor, indicating performance aligned with operational requirements. Meanwhile, the remaining attributes solar-powered charging and the navigation system fall into the "good" category, suggesting that they still require further development. Overall, the prototype is considered feasible and capable of meeting user needs, particularly in its core functions.

CONCLUSION

This study aims to design a robotic automation system for collecting oil palm loose fruits (grondol) using the Quality Function Deployment (QFD) approach, which is employed to translate user requirements (voice of customer) into technical product specifications. The results of the user needs analysis indicate that the main expected attributes include the robot's mobility across various terrain conditions, the presence of a robotic arm to support the collection process and restore the robot's position when overturned, the use of weather-resistant, easy-to-clean materials, and an automated system for collecting and storing oil palm fruits. In addition, users emphasize the importance of a wireless power system with sufficient energy endurance, the availability of a solar-powered charging station, effective fruit identification capability, an adaptive navigation system, and sensors to detect the weight of collected fruits. Overall, the developed prototype has been able to meet most of the user requirements identified through the QFD approach and demonstrates potential effectiveness in supporting the collection of scattered oil palm fruits in plantation areas.

The implementation of this system has the potential to provide significant benefits, including improved work efficiency, reduced labor workload, and minimized harvest losses. However, to enhance performance and readiness for field implementation, further development and research are required, particularly in improving robot mobility to better adapt to various terrain conditions, enhancing the accuracy of navigation and object identification systems through the integration of artificial intelligence algorithms, and optimizing the energy system to achieve greater efficiency and sustainability. Furthermore, the development of a more precise and robust robotic arm mechanism, improved material durability under plantation environmental conditions, and large-scale field testing are also necessary to ensure the overall reliability of the system.

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