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The Auto Sprinkler Rover: An innovative fertiliser applicator for sustainable agriculture

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Abstract: Fertilisers are essential to agriculture since they provide crucial nutrients that stimulate crop growth, increase the yield and improve the yield quality. However, this practice requires the use of manual labour, which consumes energy and time as well as limits the effectiveness of fertilisation methods and is environmentally harmful. These factors have led to the development of an innovative product based on the Internet of Things (IoT) called the Auto Sprinkler Rover, which is a remote-controlled machine that operates automatically. It contains a 12 L water barrel that serves as a storage tank for a liquid fertiliser. This study designed a liquid sensor and light emitting diode to alert the user to the amount of liquid in the tank. The water pump facilitates the smooth spraying of liquid fertiliser from the pipe's nozzle. The Auto Sprinkler Rover differs from conventional methods because it integrates real-time monitoring via Wi-Fi, an automatic liquid level sensor as well as an automatic spraying system and an ergonomic design that is manually operated. The Auto Sprinkler Rover was designed to be a cutting-edge technology that benefits sustainable crop cultivation for households, communities and the global agriculture industry.

Keywords: conceptual design; ergonomic; Finite Element Analysis; IOT technology; SolidWorks software

Crops are confronted with various challenges, such as inadequate maturation, unstable growth periods and nature's elements. Fertilisers can play a role in overcoming this challenge by providing essential nutrients to crops, reducing the risk of disease and pests as well as enhancing the soil fertility (Laribi et al. 2024; van den Broek et al. 2024). The most widely used fertiliser in agricultural practices is the chemical fertiliser (Hao et al. 2024). Chemical fertilisers provide macronutrients, such as calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), and sulphur (S), as well as micronutrients such as iron (Fe), copper (Cu), zinc (Zn), manganese (Mn), cobalt (Co), molybdenum (Mo) and bismuth (B), which together help to fertilise the soil, optimise plant growth and assist the plant's physiological development processes (Dasgupta et al. 2024). The supply of critical micronutrients is often managed to meet specific fertilisation management objectives that are crucial for optimum crop growth. However, chemical fertilisers are composed of certain harmful substances that accumulate in the human body

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after they are deposited on plants and later absorbed by them (Hossain et al. 2022). The overuse of these chemical fertilisers could lead to several environmental issues, such as soil degradation, water pollution from fertiliser leaching and discharge, and air pollution from the use of a diesel motor during the fertiliser dispersion process. Therefore, it is imperative to prioritise sustainable fertilisation methods in order to enhance the agriculture productivity without risking human health or the environment (Kang et al. 2017; Kopittke et al. 2019).

Recent years have witnessed a divergence in researchers' interest in precision farming practices that have been revolutionised by the implementation of the Internet of Things (IoT). This method accomplishes precision implementation through the targeted and efficient application of fertilisers to the soil and crop. This technology, besides enhancing the soil fertility, also reduces the required labour, improves the ergonomic design during handling and conserves human energy, which are features that align with United Nations Sustainable Development Goals (SDGs) and the implementation of sustainable cultivation techniques (Ramadevi et al. 2022; Sharma and Shivandu 2024).

Self-sprinkler devices, agricultural drones, gardening buckets and knapsack sprayers are some of the methods currently available and can be beneficial to the fertilisation process (Laborde et al. 2020). The researchers identified an apparent gap in previous studies regarding the high labour cost, uneven fertiliser applications, as well as non-user friendly and operational challenges (Kopittke et al. 2019). The design of previous knapsack sprayers was found to vary in the pressurisation capacity due to different features found in various sprayer brands and models (Kang et al. 2017). This results in the inconsistent operation of knapsack sprayers, which, in turn, leads to a decrease in the fertilisation performance. The operational mechanism, such as the automatic pump in fertiliser machines, could solve this inconsistency (Abeya et al. 2025). According to Dharmalingam et al. (2023), the self-sprinkler machine's motor is diesel powered and can result in the absorption of diesel into the soil, as well as contributing to elevated noise and air pollution. Lin et al. (2021) asserted that sensors that measure the soil moisture, and the rainfall and temperature are available for optimising the watering in accordance with the present weather and soil conditions. Nonetheless, the inclusion of water level sensors as a novel feature when designing the Auto Sprinklers Rover has not been given adequate attention. It is imperative to enhance this aspect in order to optimise the operational effectiveness and user satisfaction.

In the context of drone applications, the majority of sprinkler drones are powered by electrical power due to their simplified systems, while others are powered by fuel or lithium-ion batteries (Paredes Aguilar et al. 2023). Batteries are a finite power source, while the electrical energy consumption rate is contingent upon the weight and flight distance (O'Hara and Toussaint 2021). The current primary obstacles in drone irrigation operations are battery-related. The financial implications include the price of batteries, which are costly due to their finite energy capacity, limited number of cycles and frequent replacement after 250 recharges. Moreover, batteries are fragile and should only be employed in specific circumstances (Prosekov and Ivanova 2018). Their acquisition is further complicated by the necessity for ships to deliver them, as they are classified as hazardous items by customs authorities. In comparison to conventional spraying equipment, agriculture spraying drones are more costly and require training and specific documentation prior to operation (Raju et al. 2021).

The majority of users continue to utilise the conventional method of manually distributing a fertiliser despite the advancements in fertilisation technologies. The user risks physical discomfort (back and upper body fatigue), which is elevated by an awkward body posture associated with substantial energy consumption. In addition, non-optimal fertilisation technologies can result in increased agriculture-related costs and energy consumption, as well as having an impact on human health and the environment. This puts sustainable agriculture at risk (Krasilnikov et al. 2022). Therefore, studies should look into creating fertiliser distribution equipment that is energy-efficient, ergonomic and ecologically friendly in order to meet the demand for increased crop yields.

Previous studies have developed innovative methods to advance all aspects of the sector by focusing on the sustainability and utilisation of alternative energy sources. The IoT revolution endeavours to establish a more efficient manufacturing system that can integrate production processes and products into a sustainable and viable strategy (Schintler and McNeely 2022). Koh et al. (2019) utilised IoT tech-

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nology using Arduino Uno to develop the Arduino Uno Wi-Fi, which facilitates the establishment of a sustainable future by recognising and utilising all three dimensions of sustainability, namely social, economic and environmental dimensions. According to Shin and Choi (2022), the control range of lights, actuators and other outputs was determined by collecting input from a variety of switches or sensors. This permits Arduino Uno to either serve as an access point or grant access to the Wi-Fi network. Wireless data transmission and reception, as well as the execution of wireless received commands, are enabled by Wi-Fi modules. Raikwar (2017) also used Wi-Fi modules for inter-device communication in their Wi-Fi system design. Water levels and fluid leakages were detected by the water sensor brick. It is possible to monitor the presence, amount, volume or absence of water by connecting the water sensor to an Arduino unit, which is a useful instrument for identifying leaks and spills (Syrmos et al. 2023). Exposed traces that are connected to the ground are interlaced with detecting traces to enable this sensor to function. The sensor trace value is maintained at a high level by a 1 MΩ pull-up resistor until a water drop causes it to short circuit to the grounded wire. This concept detects water by utilising the Arduino's analogue or digital input/output (I/O) ports (Raikwar 2017). The process basically works by powering the servo using an external 5 V source, connecting the servo's control pin to any digital PWM-enabled pin on the Arduino board, and connecting the Arduino unit and servo grounds.

Closed-loop systems, including servo motors, are composed of a control circuit, servo motor, shaft, potentiometer, driving gears, amplifier and either an encoder or resolver. Servo motors are self-contained electrical devices that are capable of rotating machine elements with exceptional precision and efficiency. Its output shaft is capable of moving at a particular speed, location and angle that is not possible for a standard motor to do. In order to obtain positional feedback, the servo motor connects a conventional motor to a sensor.

There is a lack of automated fertiliser technology that combines ergonomic design and IoT-based real-time monitoring. Therefore, this study aimed to design, develop and evaluate the performance of a liquid fertiliser machine tool, namely the Auto Sprinkler Rover. This device was engineered with an automatic sprinkling system mechanism (through IoT technology) and ergonomic features aimed at reducing physical strain on farmers. This study first investigated a conceptual design framework and specific requirements from a market survey. The House of Quality and Pugh methods were then applied to select the best conceptual design among all the design options. The final approach to the prototype design selection was based on ranking the scores and screening the engineering characteristics to generate the design options. An analysis of the Auto Sprinkler Rover's performance was evaluated based on a Finite Element Analysis (FEA) on its mechanical properties and stability as well as testing the product design's efficiency by analysing the operational efficiency while focusing on parameters such as the spraying time taken to fertilise the crops and operational efficiency (water sensor features).

MATERIAL AND METHODS

This study used the design process development method for designing the Auto Sprinkler Rover. Data from previous studies were examined to define the research gap regarding the specification and benchmark design. Then a market survey, including customer requirements (CRs) followed by the application of the House of Quality (HOQ) method, was carried out based on respondents' data. The selected engineering characteristics (ECs) from the HOQ were then translated into each part of the design system before being further subjected to the Pugh method. The Pugh method is important for ranking the best design criteria among all the designs based on the screening and scoring method. Lastly, the best design prototype selected was simulated using a computer-aided-design program known as SolidWorks software version 2021 (Publisher: Dassault Systèmes). The selection of the best design was based on specific criteria determined by the CRs and ECs (Che Aziz et al. 2023). The methodological framework of the individual process used for designing the Auto Sprinkler Rover is summarised in Figure 1.

Defining the design parameters

Data collection. Two approaches were used to define the CRs related to agricultural practices, namely preparing a questionnaire for the interview session and surveying problems by using online Google Forms.

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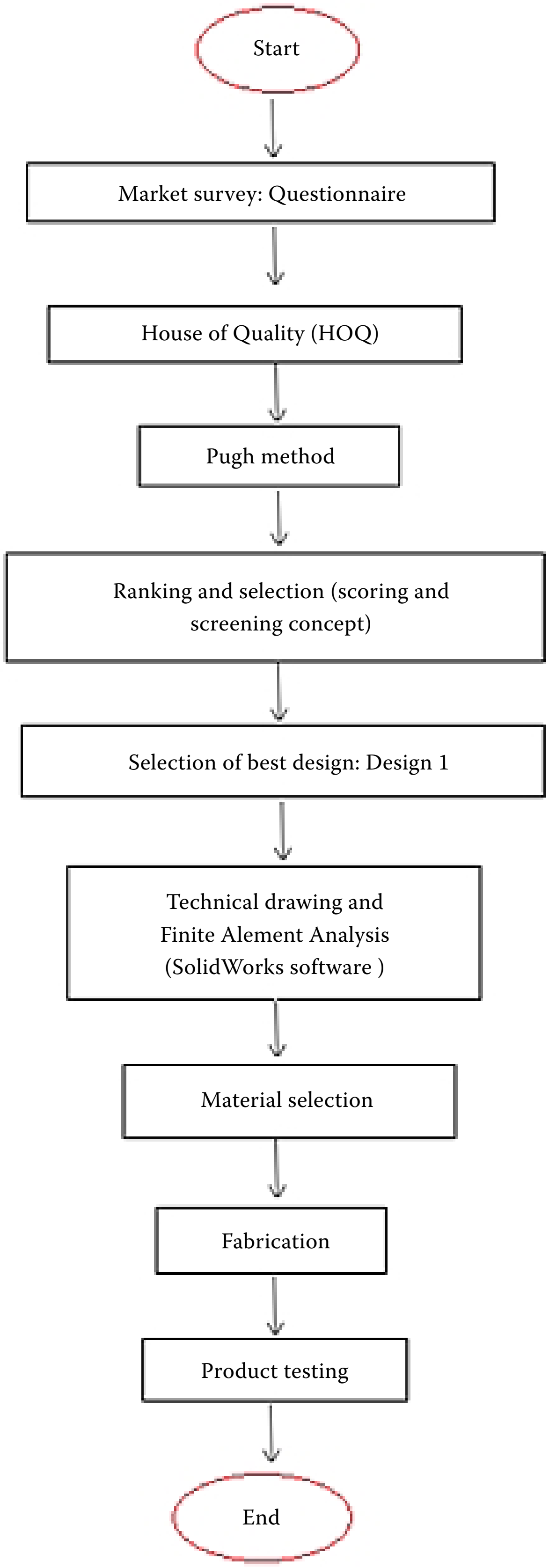

Figure 1. The methodological framework of the process used for designing the Auto Sprinkler Rover

The first approach used a questionnaire and structured interviews involving 10 respondents to collect precise information regarding the farmers' agriculture practices. The study location was a farming area in Setiu, Terengganu. The questionnaire posed three questions concerning the type of crops grown, fertilisation method used and spatial crop requirements. The first question aimed to establish the type of crops grown on the farm, and the farmers were required to name the crops they planted. This question helps to understand the crop diversity and provide relevant agriculture-related advice for each type of crop. The results indicated that the crops grown were kale, white radish and watermelon. The second question focused on the fertilisation frequency and methods used for the distinct crops. The respondents provided information on the fertilisation schedules adapted to the specific needs of each crop.

This study discovered that kale required a unique fertilisation regimen that included delivering harmful liquid fertilisers once a week in the morning at least two weeks before harvesting. This information is essential for developing crop-specific fertilisation regimes that promote growth and productivity. The third question aimed to determine the area required for planting various crops. The respondents submitted information on the optimum distances for planting each crop. The farmers estimated similar distances when planting kale and this avoided the need for precise spacing. Watermelons, on the other hand, require 203 cm width and 20 cm to 31 cm in height, while the white radish requires 15 cm between plants and 8 between rows. This information is critical for recommending appropriate planting practices in order to achieve the optimum growth conditions for each crop.

As for the second approach, this study distributed a Google Form-based questionnaire. Data were collected from 44 respondents, including students, housewives, self-employed individuals, government and private sector employees, farmers and commercial users. The questions were customised according to the state, crop growing practices, type of crops planted, problems associated with the conventional fertilisation method, and awareness of available tools and agricultural methods to help farmers. The customer requirements from the questionnaire survey were further subjected to the following questions:

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i) Question 1: Sustainable technology?
ii) Question 2: Easy maintenance?
iii) Question 3: Ergonomic features?
iv) Question 4: Compact size?
v) Question 5: Easy to store?
vi) Question 6: Durability?

Defining the design parameters. The materials used to design a new Auto Sprinkler Rover included an axial rod, a water sprinkler holder, inner and outer links for a chain, a DC motor, a rim, a tyre, a water tank, a sprocket and water sprinkler, an Arduino unit, an Arduino water sensor, WeMos D1 WiFi UNO R3 ESP8266, a 180-degree Servo MG90, a tooth motor, a battery and a timing chain. The list of design parameters used in this study and their function are summarised in Table 1.

The Arduino microcontroller was also employed in the system's development to determine the amount of liquid fertiliser in the storage tank. According to previous studies, a DC motor is the best type of motor to use because it is considered to be efficient and can easily be regulated at variable loads (Okoro and Enwerem 2019). Moreover, the machine can move more steadily when the tyre is the right size (Taghavifar et al. 2016). This design was chosen for enhancing a medium- and large-scale crop yield as its ultimate goal. It also aimed to simplify operations for users by reducing the human energy consumption and potentially saving time through the adoption of a battery as a power source and an automatic pumping mechanism based on this machine's concept. This machine's final product has the potential to accelerate crop growth and expand consumers' crop options according to their preferences and requirements (Shahrooz et al. 2020).

The WeMos D1 WiFi UNO R3 ESP8266 unit is a popular development board that includes an ESP8266 microcontroller with Wi-Fi connectivity. It offers a conducive environment for prototyping and implementing IoT solutions. The Node MCU ESP8266 feature is a powerful single-core processor with I/O pins for component interfacing, and provides support for programming environments. It allows the creation of connected devices and applications that can connect to wireless networks, communicate with other devices and perform various IoT tasks. The list of parameters and their function is displayed in Table 1.

Table 1. The list of the Auto Sprinkler Rover's parameters and their function

No.	Parameters	Function
1.	Axial rod	Support and align motion between the tyres.
2.	Water sprinkler holder	Spray the fertiliser on the crops.
3.	DC motor	Run the Auto Sprinkler Rover on direct current during the fertilisation process.
4.	Rim	Hold the tyres in place.
5.	Tyre	Facilitate the Auto Sprinkler Rover's movement on the pavement of the crops.
6.	Water tank	Stock tank for liquid fertiliser.
7.	Water pump	Pump the fertiliser solution into the water sprinkler.
8.	Sprocket	Move with motion and power via a chain.
9.	Water sprinkler	Responsible for dispersing the fertiliser solution onto the crops.
10	Arduino UNO	Create interactive features and control other systems, i.e. control the motor.
11.	Arduino water sensor	Sense the available water level in the water tank and provide an alert.
12.	Arduino WeMos D1 WiFi UNO R3 ESP8266	Connect the system using Wi-Fi capabilities when the water level in the water tank is empty, while providing component interfacing and support for programming environments. Acts as the onboard controller/receiver for remote operation.
13.	Motor Servo Arduino MG90 180°	Rotate machine parts with high precision and efficiency.

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House of Quality (HOQ) and Pugh methods

The input from the market survey was used to determine the HOQ, which is of critical importance for satisfying the CRs (Shahin and Ebrahimi 2020). Each of the CR's criteria, such as the ergonomic design, ease of use, chemical hazard exposure, safety and stability, were then used to design a new product based on the market research and benchmark data. The Pugh Method was suggested by Che Aziz et al. (2023) and used to rank and rate the new design concept. The best design exhibited the highest rating and scoring value, which had the most significant effect on customer satisfaction.

Conceptual design of the Auto Sprinkler Rover

The Auto Sprinkler Rover conceptual design was created using the design parameters based on the market survey. These design parameter criteria were then combined to satisfy all the CRs. This study developed four conceptual designs, named as Design 1 through 4. Three primary issues were addressed, including ease of handling and maintenance, minimising the manual labour, user's body posture (ergonomic design) and the device's stability. All the designs were manually sketched by considering the design parameter criteria to meet the CRs, as stated below:

i) Determining the optimum weight of the liquid fertiliser on the design that was carried out during the fertilisation process.

ii) The design's safety features (the wiring system was installed neatly within the body design to facilitate the maintenance process).

iii) Effectiveness of the liquid fertiliser spraying system (position and function).

iv) Appropriate tyre size used (to ensure the stability of the design).

v) Use a holder if the machine's battery is running out (ease of handling).

vi) Ergonomic features (user's body posture).

The ranking and scoring values from the Pugh method were then used to select the best design to fulfil the CRs (Che Aziz et al. 2023).

Computer-aided engineering design development using the SolidWorks software

The technical drawing was generated using the SolidWorks software version 2021 (Publisher: Dassault Systèmes), and it provided a detailed description of the design, including its measurements, the selection of the materials and its cost. This software is crucial for ascertaining the dimensions of the Auto Sprinkler Rover design, together with the amount and size of the materials required for building the equipment. This is to ensure precision, a proper sensor system and material selection that combines various aspects of production and system installation. A 3D model can be transformed into 2D equivalents with more intricate details by adopting rendering and 3D drawing techniques created by the SolidWorks software.

A Finite Element Analysis, which focused on the force applied to the Auto Sprinkler Rover, was also conducted using the SolidWorks software. The Finite Element Analysis result focused on the shaft connecting the tire to the base of the body, since the latter accommodates the amount of liquid fertiliser. It is important to estimate the resistance created by the Auto Sprinkler Rover under pressure.

Fabrication process

The fabrication process was carried out in the workshop and it involved measuring, cutting, bending, joining, assembling and finishing. Shearers, benders and rivet manufacturing techniques were employed to create the various items. Cutting tools for sheet metal cutting and a shearing machine to make bends at 45° and 90° were used, while the rivet was used to join metal sheets and plastic together (McAuliffe and Gray 2002).

The retaining component at the Auto Sprinkler Rover's front machine was made by cutting a rectangular hollow square of mild steel using a metal cutting saw and a grinding machine. The drilling process began by making a 3 mm rivet hole on the plastic body so that a rivet can be attached to the plastic body, including both pieces of the connection for the riveting. A metal sheet was then bent according to the desired angle using a bending machine. The body cover device was made by bending metal sheets. All the metal components were cut according to the required size, as well as bent, drilled and riveted to join them to the plastic body.

Product testing

This study utilised the Auto Sprinkler Rover and its system to replace conventional techniques, which involves manual labour throughout the long-term fertiliser dispensing or spraying processes.

This design was chosen for enhancing the medium- and large-scale crop yield as its ultimate goal. It also aimed to simplify operations for users by re-

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ducing the human energy consumption and potentially saving time through the adoption of a battery as a power source and an automatic pumping mechanism, based on this machine's design concept. The final product would have the potential to accelerate crop growth and expand the consumers' crop options according to their preferences and requirements (Shahrooz et al. 2020).

The Auto Sprinkler Rover's performance in spraying crops with a liquid fertiliser was tested by measuring the time taken to fertilise the crops using a known volume of liquid fertiliser. This method was suggested by Alheidary (2023). The time taken to fertilise the crops (10, 20 and 30 crops) using different volumes of liquid fertiliser (4, 8 and 12 L) was recorded using a stopwatch. As a comparison, the same experiment was repeated on a sowing fertiliser (conventional method). The ergonomic height of the Auto Sprinkler Rover at 60–120 cm was verified according to ISO standards (Che Ani and Azid 2022). Lastly, the liquid or water sensor was tested to assess its ability to recognise whether the water reservoir was depleted, at which point the Light Emitting Diode (LED) lights would turn on and a buzzer rang.

RESULTS AND DISCUSSION

Conceptual design of the Auto Sprinkler Rover

The conceptual design of the Auto Sprinkler Rover was created after identifying the current problems and users' requirements before translating it into drawn sketches. This study proposed four conceptual Auto Sprinkler Rover designs, as shown in Figure 2. Design 1 had a compact size and a front-loaded water tank with a balanced weight distribution on four tyres. Design 2 had a water tank at the back of the machine with a handle that makes it easier to move. Design 3 had rotating wheels in the middle for easier movement on any ground surface and Design 4 had only two tyres and a lightweight body with a handle for easier movement on the crop bed. The proposed designs should have an ergonomic, user-friendly and easy-to-maintain product that satisfies all the user requirements derived from the problem analysis. The features, such as the weight of the liquid fertiliser, installation of a neat wiring system, a liquid spraying system, appropriate tyre size for machine stability and a battery compartment, were taken into consideration.

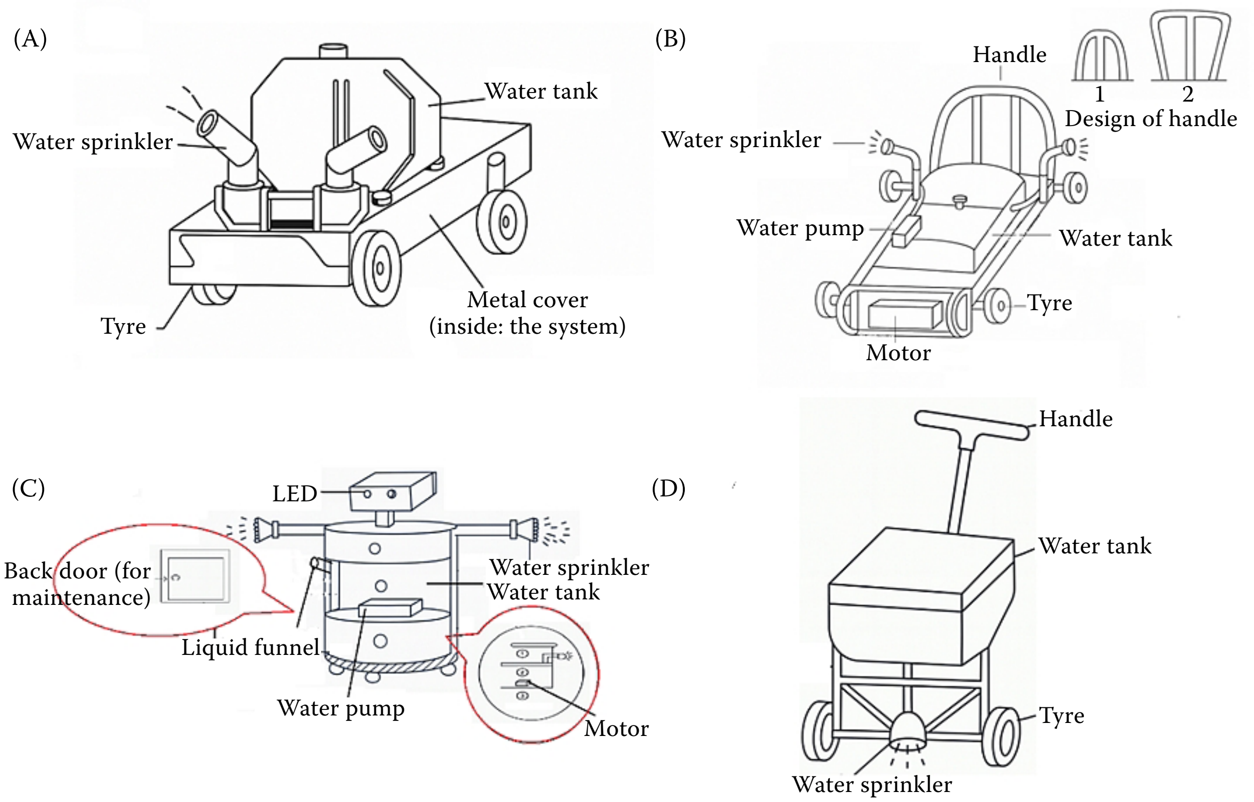

Figure 2. The conceptual design of the Auto Sprinkler Rover
(A) Design 1; (B) Design 2; (C) Design 3 and (D) Design 4

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Pugh method

The screening and scoring concept was applied for scoring each design based on the Pugh method. The best two (Designs 1 and 2) out of the four suggested designs in the screening concept were chosen based on the scoring process for further analysis. Results of the screening and scoring concepts are shown in Tables 2 and 3, respectively, and based on the results, Design 1 was finalised, accepted and sketched for designing the Auto Sprinkler Rover. The SolidWorks software was used to illustrate a 3D model of the Auto Sprinkler Rover, as shown in Figure 3A.

The technical drawing of the Auto Sprinkler Rover using the SolidWorks software is shown in Figure 3. The material's dimensions, quantity and size were determined from this drawing. The materials used in the Auto Sprinkler Rover's design included a liquid tank, a sprinkler water tool, a sprinkle holder, a sprocket, a motor housing, a timing chain, an axial rod, a rim, a tyre and a sprocket (illustrated in Figure 3). The estimated cost of the project was Malaysian Ringgits (RM) 400. This approach proves to be more cost-effective compared to battery-powered crop fertilisation devices, like drones (Moreira et al. 2019). Figure 3A illustrates the assembled part of the Auto Sprinkler Rover. Details of the materials used, their quantity and their connections are shown in an exploded view (Figure 3B).

Fabrication and assembly processes

The Auto Sprinkler Rover underwent several manufacturing fabrication processes, including shearing, bending and riveting, before the final assembly of all the parts began. At this stage, some of the riveted joint components were moved to the installation stage. The main cover, door cover and machine head were all assembled by using sheet metal. The liquid barrel was then positioned on top of the device together with the nozzle holder and water nozzle. This position offers an ergonomic design that prevents the user from bending his body when handling the liquid fertiliser. The 12 V battery

Table 2. Screening concept for designing the Auto Sprinkle Rover

Selection criteria	Design 1	Design 2	Design 3	Design 4
Ergonomic	+	0	–	–
Ease of use	+	+	+	+
Chemical hazard exposure	+	+	0	–
Safety	+	+	+	+
Stable for various type of surfaces	+	+	0	0
Sum (+)	5	4	2	2
Sum (0)	0	1	2	1
Sum (–)	0	0	1	2
Net score ranks	5 1	4 2	3 3	0 4
Decision	yes	yes	no	no

Table 3. Scoring concept for designing the Auto Sprinkle Rover

Selection criteria	Weight (%)	Design 1		Design 2	
		rating	weight	rating	weight
Ergonomic	18.87	5	0.94	5	0.94
Ease of use	28.30	5	1.42	4	1.13
Chemical hazard exposure	15.09	4	0.60	5	0.75
Safety	18.87	5	0.94	3	0.57
Stable for various type of surfaces	18.87	5	0.94	5	0.94
Total score	100.00	4.84		4.33	
Rank		1		2	
Decision		yes		no	

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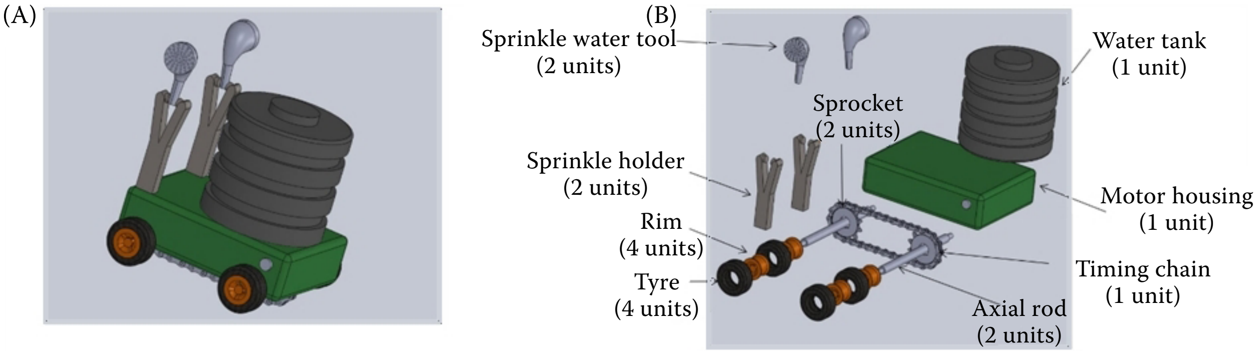

Figure 3. View of (A) assembled parts and (B) exploded view of the Auto Sprinkler Rover using SolidWorks software

and converter were then installed on the machine's body, and the water pump was installed in the liquid tank as it used an automatic pumping mechanism. This newly designed system and product replaced the conventional techniques, such as knapsack sprayers or garden buckets, which usually force farmers to expend a lot of energy throughout the long-term fertilisation process. The assembly of the Automatic Sprinkler Rover's parts is shown in Figure 4.

The Arduino Wemos WiFi board was used to regulate the Auto Sprinkler Rover, execute the predetermined sequences of operations and acquire the necessary components. The Auto Sprinkler Rover's automated system was designed to reduce the air pollution based on its fuel-free operation, increase the plant productivity by applying targeted fertiliser techniques, as well as decrease the time and energy consumption. This device was also fitted with an automatic sprinkling system and ergonomic features to reduce the physical strain on farmers. Moreover, the machine's maximum permissible load in the form of a liquid fertiliser tank was also computed. Its suitability for daily use in agriculture or residential gardens was also assessed.

Performance analysis

Finite Element Analysis. The Finite Element Analysis (FEA) is related to the applied force on the shaft that joins the tyre and the Automatic Sprinkler Rover body's base. The body's base accommodates the amount of liquid carried by the machine. The Finite Element Analysis (FEA) of the Auto Sprinkler Rover body's base is shown in Figure 5. When 100 N of pressure was applied, the body's base experienced a minimum pressure of $6.767e^{-2}$ and a maximum of $7.519e^{-2}$ MPa. The body's base, shown in yellow, is not wide, and the effect is minimal, which means that this body's base design can be safely used.

As for the frame cover product, the FEA analysis indicated that the Auto Sprinkler Rover's frame

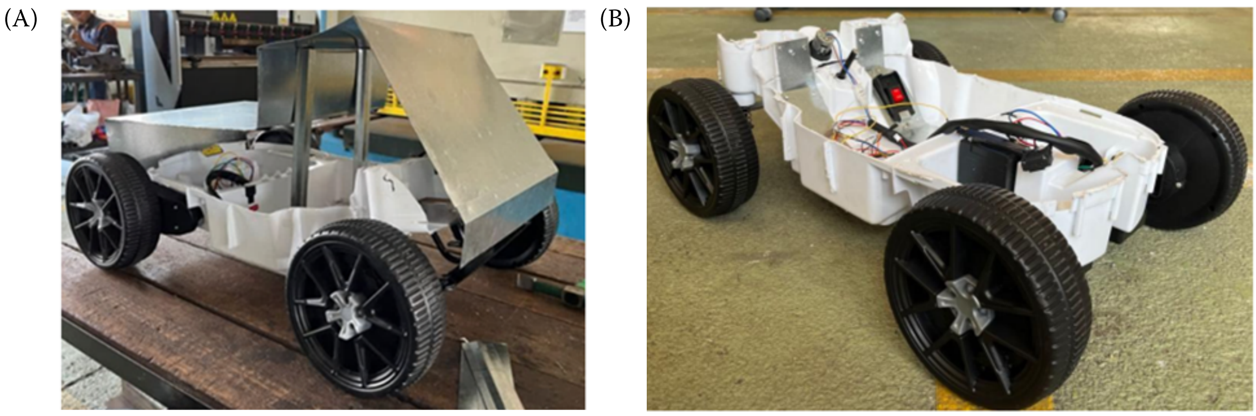

Figure 4. (A) The Auto Sprinkler Rover's assembly of metal sheets and plastic body parts and (B) the components of the IoT system inside the Auto Sprinkler Rover

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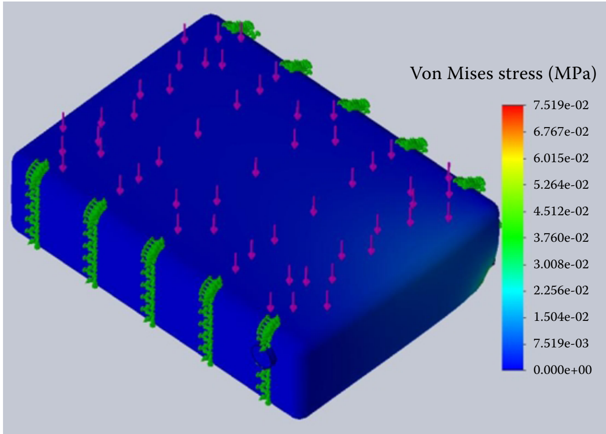

Figure 5. FEA of the Automatic Sprinkler Rover's base body

cover had a slight bend on the front edge of the Auto Sprinkler Rover when subjected to a pressure of 120 N, as shown in Figure 6A. A small, crimson-coloured scale underwent significant bending on that particular side. No bend on the front side was observed when a pressure of below 120 N was applied, as shown in Figure 6B. This indicates that the maximum force that can be applied to this product is 120 N.

Product testing. An improved sprinkler holder contributed to the stability and strength required for holding the pipe and sprinkler, thus ensuring that there are no leaks at any pipe fittings or connections. The improvement also increased the longevity and securely retained the liquid in the sprinkler while spraying. This rover was also designed to determine the lower body's ability to support a loaded liquid fertiliser tank to exhibit the features of an ergonomic design. The height of the liquid barrel in this study was 110 cm, hence, fulfilling the ergonomic features of an Automatic Sprinkler Rover and adhering to the International Organisation for Standardisation (ISO) standards. The final prototype of the Auto Sprinkler Rover is shown in Figure 7, and the specifications are listed in Table 4.

The Auto Sprinkler Rover's performance is supplemented by a 6 V motor and battery. The maximum speed of the Auto Sprinkler Rover was around 3–8 km.h^{-1}, and it was controlled using a remote-controlled motor handle. The Auto Sprinkler Rover's low speed is crucial for the uniform spray-

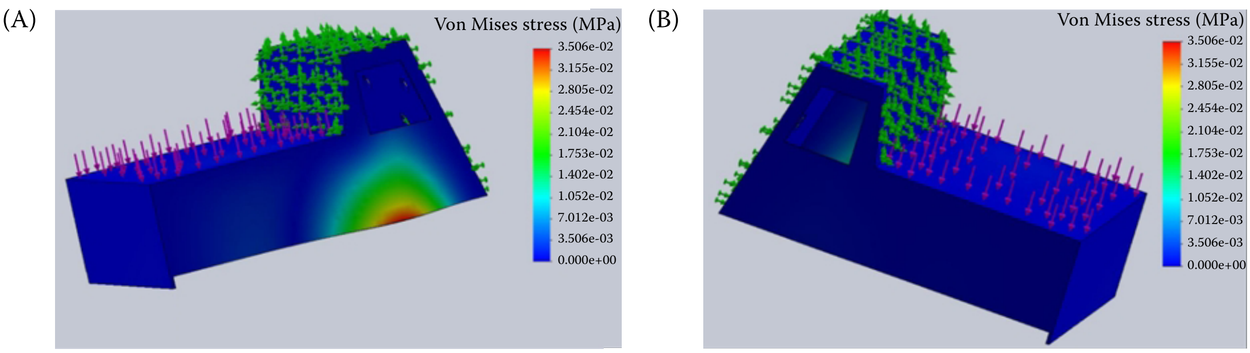

Figure 6. FEA of the Auto Sprinkler Rover's frame cover (A) before and (B) after improvement

Figure 7. (A) Top view; (B) front view and (C) side view of the final version of the Auto Sprinkler Rover prototype

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Table 4. Final features of the Auto Sprinkler Rover

Criteria	Specification
Dimension (cm)	110 × 70 × 68
Maximum weight (kg)	15
Pumping mechanism	automatic
Maximum crops per plant row	8/1
Maximum water (L)	12
Speed (km.h^{-1})	3–8

ing of fertiliser (Chen et al. 2020). This speed range represents the maximum unloaded travelling speed of the Auto Sprinkler Rover. During fertilisation operations, the rover operates under a controlled intermittent-motion mode, which includes navigation, positioning, fertiliser dispensing, and stopping periods (Liu et al. 2021). However, in larger farming areas, the rover's 6 V battery would be insufficient for spraying liquid fertiliser over crops for an extended period. Therefore, a higher voltage battery would be needed for this task. The battery's voltage was increased to 12 V and connected to the water pump. This single level of spray was directly regulated by a 12 V converter.

The Auto Sprinkler Rover's efficiency in applying fertiliser. The number or area of crops fertilised using a specific volume of liquid fertiliser and the time taken to complete the fertilisation were recorded (see Table 5). Table 5 reports the number of crops successfully fertilised within the specified operating periods. These values do not represent the total distance travelled by the rover during operation. Initially, the experiment used 4 L of liquid fertiliser. Ten crops were effectively fertilised in only 10 min, owing to the Auto Sprinkler Rover's automatic spraying technique. Twenty crops were successfully fertilised in 20 min by using 8 L of liquid fertiliser, while 30 crops were fertilised in 30 min by using 12 L of liquid fertiliser. The results indicate that by increasing the volume of the liquid fertiliser, the time taken to fertilise the crops also increases.

In the Table 5, the fertilisation performance was compared between the conventional method and the Auto Sprinkler Rover based on the number of crops successfully fertilised within the specified operating periods. Using 4 L of liquid fertiliser, the conventional method fertilised 8 crops within 15 min, whereas the Auto Sprinkler Rover fertilised 10 crops within 10 minutes. When the fertiliser volume was increased to 8 L, the conventional method fertilised 16 crops within 30 min, while the Auto Sprinkler Rover fertilised 20 crops within 20 minutes. Similarly, with 12 L of liquid fertiliser, the conventional method fertilised 24 crops within 60 min, whereas the Auto Sprinkler Rover fertilised 30 crops within 30 minutes. This finding demonstrates that the conventional fertilising method requires a significant amount of time to cover each plant border. It also indicates that by using the Auto Sprinkler Rover, the time taken to fertilise the crops is reduced, while fertilising a greater crop area. The use of conventional methods frequently results in overspray or uneven distribution, inevitably leading to the wastage of time and financial resources.

This result demonstrates that the Auto Sprinkler Rover's automatic pumping mechanism enables the efficient movement between crops, and hence, eliminates the idle handling time and enables the machine to cover more crops in less time. The Auto Sprinkler Rover moves at a regular pace while maintaining an optimal spraying pattern, unlike the inconsistent conventional method of using a manual sprayer technique. The Auto Sprinkler Rover's automated pumping mechanism minimises the human effort and errors, thus, ensuring uniform crop spraying. The use of a sprinkler to disperse the liquid fertiliser can potentially transport nutrients, such as nitrogen (N), phosphorous (P), and potassium (K), directly and uniformly onto the crops and soil. This dispersing mechanism provides crucial nutrients to the crop (Ahmed et al. 2024). It also ensures a sufficient and consistent supply of fertil-

Table 5. Comparison between the conventional method and the Auto Sprinkler Rover used for fertilising crops

Conventional method			Auto Sprinkler Rover		
Volume of liquid fertiliser (L)	number of crops	time (min)	Volume of liquid fertiliser (L)	number of crops	time (min)
4	8	15	4	10	10
8	16	30	8	20	20
12	24	60	12	30	30

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iser to each crop, resulting in a balanced distribution of nutrients and improved soil fertility by reducing the nutrient runoff and waste (Nathbuva 2023).

Therefore, the Auto Sprinkler Rover can assist and simplify the fertilisation process for farmers growing crops on a small or large scale by ensuring it is carried out more efficiently, promptly, effectively and safely by preventing exposure to any hazardous chemicals contained in the liquid fertiliser. In addition, it has the potential to minimise the manual labour, reduce exposure to hazardous chemicals found in fertilisers and enhance the efficiency of liquid fertiliser spraying (Reinecke and Prinsloo 2017).

The Auto Sprinkler Rover also tested the liquid sensor, which is capable of recognising a depleted liquid reservoir. After the liquid fertiliser ran empty, the LED lights turned on, and a buzzer rang. This indicates the design concept's success in alerting users when the tank is empty. The LED, in conjunction with the buzzer, serves as a real-time alarm system that notifies users when the liquid fertiliser tank is empty.

When the liquid is low, the LED lights illuminate and the buzzer sounds, thus, providing visible and audible cues. This dual-alert mechanism improves user convenience and operational efficiency by eliminating tank refill delays and allows the Auto Sprinkler Rover to run continuously. This study verified the design concept's success that ensures prompt intervention, reduces the downtime and prevents the rover from running empty, which could limit its performance or harm its components. Furthermore, this feature indicates a meticulous design, especially in an agricultural context, where timely reactions are crucial for maintaining continuous fertiliser delivery as well as ensuring optimal crop and soil health.

The integration of IoT elements into the alert system improves the Auto Sprinkler Rover's functionality and usefulness. When the liquid fertiliser tank is empty, the LED lights turn on and a buzzer rings, thus providing rapid visual and audio feedback. The IoT sensors can detect an empty tank and provide real-time messages to a connected device, such as a smartphone or computer, via Wi-Fi or Bluetooth. This IoT-enabled feature enables farmers to remotely monitor the fertiliser level, and this allows for timely refills without the need to physically inspect the tank. This solution not only validates the design concept's ability to warn consumers, but it also increases operational efficiency by automating the monitoring process and minimising the downtime. This integration of IoT features is especially useful in agricultural operations, where remote management can boost output and ensure continuous nutrient treatment to keep the soil and crops healthy.

LIMITATION AND FUTURE IMPROVEMENTS

The Auto Sprinkler Rover has some restrictions that must be addressed even if its benefits outweigh others. Its battery life is the main drawback since it determines how long it can function before needing a recharge. The existing model still depends on human control as it lacks autonomous navigation, which can lower the user convenience and efficiency. The high initial investment cost could create financial difficulties for small-scale farmers wishing to adopt this technology. Many improvements can be made in the next Auto Sprinkler Rover versions to overcome these constraints. The integration of Artificial Intelligence-driven path planning is one major development since it would allow the rover to negotiate independently and maximise the movement throughout the farm, therefore lowering the demand for human involvement. Creating a smartphone app for remote monitoring and control could help improve user accessibility and convenience. Integrating solar panel charging technologies could greatly increase the rover's energy efficiency and enable a longer operational time and lower the reliance on external power sources to solve the energy constraints.

CONCLUSION

The Auto Sprinkler Rover is an innovative and practical solution for overcoming modern agricultural challenges that combines automation, IoT technology and ergonomic design. The Auto Sprinkler Rover uses IoT elements, such as Arduino units, Wi-Fi modules and water sensors, to provide remote monitoring and control over fertilisation activities. Farmers can now receive real-time notifications regarding liquid fertiliser levels and manage operations efficiently by using an automatic sprinkler spraying system, which saves them a substantial amount of time and energy. This fo-

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cused delivery of consistent liquid fertiliser to the soil decreases the environmental pollution through the use of a battery, resulting in better soil management and improved plant growth via a consistent and effective fertilisation method. The Auto Sprinkler Rover's ergonomic and user-friendly design is suitable for small and large-scale farmers as it reduces the physical strain and increasing the use. It also reduces any environmental and health concerns related to traditional fertilising methods. The rover harnesses IoT technology to establish a standard for sustainable, efficient and intelligent agriculture practices by overcoming limitations inherent in conventional techniques. This discovery is a crucial step towards better farming solutions that ensures global food sustainability.

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