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Smart Scarecrow Systems for Crop Protection: A Survey

Kartik Sanjaykumar Patil[1], Anis Ashpak Soundagar[2], Mahammadkaif Allabaksh Patel[3], Prathamesh Ganesh Jaganade[4], Julee Sudeep Kamble[5], Shital Mahadev Magdum[6]

[1234]*Student, Department of Mechanical Engineering, Ats. Sanjay Bhokare Group of Institute, Faculty of Polytechnic, Miraj, India,*
[5]*Lecturer, Department of Mechanical Engineering, Ats. Sanjay Bhokare Group of Institute, Faculty of Polytechnic, Miraj, India,*
[6]*Lecturer, Department of Mechanical Engineering, Ats. Sanjay Bhokare Group of Institute, Faculty of Polytechnic, Miraj, India.*

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I. Introduction

Birds and wild or stray animals remain a persistent cause of pre-harvest crop loss, and the cheapest defences against them lose force over time. Scarecrows, reflective tape, noise makers and fences are inexpensive, yet animals learn that a stimulus which never changes carries no threat. This habituation is the central weakness of passive deterrence and the reason researchers have turned to systems that sense an intruder and respond only when one is present [1]–[4].

Over the last decade, "smart scarecrow" designs have multiplied. They range from low-cost devices that pair a passive infrared (PIR) sensor with an Arduino-class microcontroller, a buzzer and a servo, to camera-based platforms that run deep-learning detectors on a Raspberry Pi or an embedded neural accelerator [5], [6]. Most reported work is spread across student theses, regional journals and conference papers, and the designs are rarely compared on common terms. Small farms, orchards and nurseries need a clear view of what is known, what is proven, and what is still guesswork before they invest in such a system.

This paper surveys the field with a mechanical-engineering emphasis, since many published prototypes pay little attention to the moving mechanism, structure and power budget. Its contributions are:

1. A taxonomy of crop-protection methods that separates passive, active and sensor-triggered deterrence.
2. A review of detection technologies (PIR, ultrasonic, vision, acoustic) and deterrent actuators (sound, light, airflow, mechanical motion), with their trade-offs.
3. A comparative table of representative smart scarecrow systems, from PIR-Arduino units to edge-AI platforms.
4. A worked case study of a low-cost PIR-Arduino prototype, including torque, energy and cost sizing.
5. A set of open research gaps and future directions.

The rest of the paper is organized as follows. Section II gives background on crop damage and habituation. Section III classifies deterrence methods. Sections IV to VI cover sensing, actuation, and control and power. Section VII compares reported systems, Section VIII presents the case study, and Sections IX to XI discuss challenges, future directions and conclusions.

II. Background: Crop Damage and Habituation

Bird and animal damage is large, uneven across crops, and worst when fruit or grain is ripening. Micaelo et al. summarise national and regional surveys that illustrate the scale [1]: Swedish complaints between 2000 and 2015 corresponded to roughly 34,500 tons of crop loss, mostly from cranes and geese; New York fruit surveys estimated damage of about 2.3% in apple, 3.6% in grape, 22% in blueberry and 26.8% in sweet cherry; and Polish questionnaires reported corn losses of 22% to 32% in some districts. These figures come from temperate-zone studies, so they show the order of magnitude and not the situation on an Indian smallholding. Local loss data remain scarce.

Damage stages. Loss concentrates at sowing (seeds), flowering and fruit set (tender shoots), and ripening (grain and fruit). Small birds such as sparrows, parrots, pigeons and crows take seed and grain. Larger animals such as monkeys, wild boar and stray cattle trample plants and strip produce. Farmers also bear indirect costs for guarding, fencing and replanting.

Habituation. Animals stop responding to stimuli that carry no consequence. The review in [1] reports that scarecrows are ineffective alone or only briefly effective, that relocating them every two to three days improves

results, and that moving scarecrows combined with other devices outperform static ones. It also cites a trial on waders in which birds had habituated to scarecrows, static or mobile, within about two hours. Rivadeneira reaches a similar conclusion for lights, lasers and noise makers, and warns that few independent studies have measured the efficacy of most deterrents [2]. Bioacoustic signals that vary in rhythm and number resist habituation better than fixed sounds [2].

Design implication. Because novelty and unpredictability delay habituation, an effective system should (i) act only when a threat is present, (ii) combine more than one sensory channel, and (iii) vary its output over time. These three principles guide the rest of this survey.

III. Taxonomy of Crop-Protection Methods

Micaelo et al. group bird deterrents into visual, auditory, chemical, exclusion, habitat modification and removal methods [1]. This survey keeps that grouping and adds a second axis, the trigger: passive devices run all the time, timed devices run on a schedule, and sensor-triggered (smart) devices run only on detection. Table I compares the families.

Table I. Families of crop-protection methods (evidence as reported in [1], [2])

Family	Examples	Habituation risk	Practical limits
Visual	Scarecrows, reflective tape, kites, lights, lasers	High when static; lower when moving or combined	Scarecrows work best moved every 2 to 3 days; lasers pose safety risk to people
Auditory	Gas cannons, AV-alarms, distress calls, ultrasound	High for fixed sounds; lower for varied bioacoustic calls	Noise nuisance; ultrasound showed 5% or less reduction in bird numbers
Chemical	Methyl anthranilate, tactile gels, behavioural baits	Low	Dosing, cost, species range and environmental concerns
Exclusion	Overhead netting, bird balls	None reported	Cost and difficulty on large areas; netting hinders harvest
Habitat modification	Tall grass, water or food removal	Low	Site-specific; may attract other species
Family	Examples	Habituation risk	Practical limits
Removal	Trapping, falconry, shooting	Low to moderate	Skilled labour, permits, short-term effect
Smart (sensor-triggered)	PIR, ultrasonic or camera detection with sound, light and motion	Reduced by acting only on detection and varying output	Sensor range, power supply, weather exposure, false triggers

Two observations follow. First, almost every family improves when combined with another, which supports multi-modal designs [1]. Second, sensor-triggered devices are not a separate physics of deterrence. They reuse visual and auditory stimuli, and add value by timing them, which matters because habituation depends on how often a stimulus is experienced without consequence.

IV. Detection and Sensing Technologies

Detection decides how often the system acts and how many false alarms it raises. Three sensor classes dominate the literature.

PIR motion sensors. A PIR module senses changes in infrared radiation from a warm body moving across its field of view. Hobby modules such as the HC-SR501 typically offer an adjustable range of about 3 to 7 m and a cone of roughly 110° to 120°, with a 30 to 60 s warm-up after power-on. They are cheap and draw little power, so they dominate student and small-farm prototypes, including rice-field scarecrows that move a servo and sound a speaker on detection [7]. Their weakness is that they respond to any warm moving object, so they cannot tell a sparrow from a farmer or wind-blown foliage warmed by the sun.

Ultrasonic and laser ranging. Distance sensors confirm that something has entered a defined zone. They are usually paired with a camera, as in a Raspberry Pi 4 prototype from Bhutan that adds an ultrasonic sensor to a night-vision camera [6], or with a laser tripwire as in the edge-AI system of Reddy et al. [5].

Camera and deep learning. Convolutional detectors classify the intruder before any response. Reported laboratory accuracies include 95.7% for a YOLOv8-based system [6], 96.7% for the lightweight EvoNet model on edge hardware [5], and 92.54% for a CNN that identifies stray dogs in livestock areas [9]. Other work pairs a deep CNN with species-specific ultrasound emission [10] or uses video-based SlowFast features [11]. Classification enables species-specific deterrence and alerts to the farmer, but raises cost, computing load and power demand, and most results come from laboratory or limited field data [6].

Table II. Detection options

Sensor	Discriminates species	Typical role	Main drawback
PIR	No	Low-cost trigger	False triggers; short range
Ultrasonic or laser	No	Zone confirmation	Narrow beam; needs alignment
Camera with CNN	Yes	Classification and alerts	Cost, power, training data

Radar and thermal imaging are also used in larger installations, but they fall outside the small-farm scope of this survey.

V. Deterrent Actuation and Mechanism Design

Smart scarecrows reuse four stimulus channels. Each has a different physics, power cost and habituation profile.

Sound. Buzzers and speakers are the cheapest option. Fixed synthetic tones are the most prone to habituation, whereas recorded distress or alarm calls and synthesized bird vocalizations that vary rhythm and number hold attention longer [2], [12]. A Latvian fishpond deterrent, for example, synthesizes bird-like calls digitally so that the output can be reprogrammed and varied [12].

Light. LEDs and flashing lamps add a visual cue. Evidence on lights is mixed: some trials show increased attention without flight, and results improve when light is combined with movement [1]. Light is therefore best treated as a supporting channel.

Air flow. A small fan moves lightweight fabric or streamers and adds irregular motion. Air-dancer style devices are reported to work in the short term but require power and relocation to avoid habituation [13].

Mechanical motion. Moving arms add the strongest visual signal, since realistic form and movement raise scarecrow effectiveness [1]. Motion is also the part where mechanical design matters most. A DC geared motor can drive a crank-rocker or gear-and-crank linkage that converts continuous rotation into flapping of two arms, which avoids the extra servo hardware and keeps motor current low.

Sizing the arm drive. For an arm of mass m held horizontal with its centre of gravity r from the pivot, the static torque is:

$$T = m\,g\,r$$

With m = 0.2 kg and r = 0.15 m per arm, one arm needs about 0.29 N·m and two arms about 0.59 N·m. A factor of safety of 2 gives about 1.2 N·m, or roughly 12 kg·cm, so a 12 V geared motor of 30 to 60 rpm with at least 15 kg·cm is a reasonable first choice. These values are preliminary and should be checked against datasheets and tests.

Structure and protection. A human-shaped frame of mild-steel square tube on a base plate, with the controller in a weatherproof head box, keeps the centre of mass low and protects electronics. Moving arms and the fan should be guarded for the safety of people working in the field.

VI. Control, Power and Connectivity

Controllers. Three tiers appear in the literature. Arduino-class 8-bit boards handle simple trigger logic: read the sensor, switch outputs, hold them for a fixed time, then return to standby [7]. ESP32-class boards add Wi-Fi and a camera, as in a 2026 rice-field design that combines a PIR sensor, ESP32-CAM, servo actuators, a solar panel and the Blynk IoT platform [20]. Single-board computers such as the Raspberry Pi run deep-learning detectors [6], while TinyML work shows lightweight models can run on low-end edge hardware [5].

Power. The controller is rarely the limiting factor. Motors, fans and speakers dominate consumption, and standby draw dominates energy because the device is idle most of the day. Table III gives a worked budget for the case-study design in Section VIII, using assumed loads that must be verified by measurement.

Table III. Illustrative daily energy budget (assumed values)

Item	Value
Active load (motor 6 W, fan 1.8 W, buzzer and LEDs 0.8 W, controller and PIR 0.5 W)	9.1 W
Standby load	0.5 W
Active time per day	2 h
Energy per day (9.1 × 2 + 0.5 × 22)	29.2 Wh
12 V, 7 Ah battery at 50% depth of discharge	42 Wh usable

Autonomy without charging (42 / 29.2)	about 1.4 days
Solar panel (29.2 / (5 sun-hours × 0.7))	about 8.3 W, so a 10 to 20 W panel

The budget shows why solar assistance is attractive: autonomy of about a day and a half is too short for unattended operation, while a modest panel closes the gap. Reported rice-field designs also add small solar modules and lithium cells for this reason [20].

Connectivity. Wi-Fi, GSM and mobile applications give the farmer alerts and remote status. A Bhutanese system falls back to SMS and voice calls when the data link is down [6], an important feature where coverage is patchy. Connectivity adds cost, power draw and a failure mode, so it is best optional in small-farm units.

VII. Comparative Review of Reported Systems

Table IV lists representative systems, newest first. Entries marked "not stated" were not described in the abstract or page consulted, and all accuracies are laboratory or prototype figures unless noted.

Table IV. Representative smart scarecrow and intrusion-deterrent systems

Ref.	Year	Detection	Deterrent	Platform and extras	Reported result
[20]	2026	PIR	Servo-driven repellers	ESP32-CAM, solar panel, Blynk IoT	Functional tests in rice-field conditions
Ref.	Year	Detection	Deterrent	Platform and extras	Reported result
[6]	2025	Night camera, ultrasonic sensor, YOLOv8	Alerts to farmer	Raspberry Pi 4, app, SMS and voice fallback	95.7% detection accuracy in lab; field validation pending
[7]	2024	PIR	Servo movement, speaker	Arduino, rice fields	Sensor reading, servo and speaker tested
[9]	2024	Camera, CNN	Deterrent sounds, user alerts	IoT, mobile app, livestock dogs	92.54% classification accuracy
[5]	2024	Laser detection, AI-CAM, EvoNet	Deterrence with IoT rover	TinyML edge AI	96.7% classification accuracy
[18]	2023	Automated detection	Warning mechanisms	IoT	Not stated
[11]	2023	Video, SlowFast features	Alert to owner	IoT sensor network	Not stated
[10]	2022	Deep CNN	Species-specific ultrasound	Edge computing	Not stated
[17]	2022	Smart detection	Automatic deterrent	Not stated	Reduced need for monitoring
Ref.	Year	Detection	Deterrent	Platform and extras	Reported result
[14]	2021	AI and IoT bird detection	Automatic repellent	AIoT	Not stated
[12]	2021	Not applicable	Synthesized bird calls	Direct digital synthesis, reprogrammable	Prototype tested
Proposed	2026	PIR	Sound, light, fan airflow, crank-driven arms	Arduino Uno, 12 V battery, optional solar	To be measured

Three patterns emerge. First, camera-based systems report high classification accuracy but few field trials, and most state no cost or power figures [5], [6]. Second, PIR-based units are cheap and simple, yet report functional checks and not measured effectiveness against birds [7], [20]. Third, the mechanical subsystem is usually a servo that swings a limb. Few studies size motors, linkages or structure, or report arm-motion measurements, which is the gap the case study addresses.

VIII. Case Study: A Low-Cost PIR-Arduino Smart Scarecrow

The design below was proposed by the authors' project group at a polytechnic mechanical engineering department as a small-scale prototype for farms, orchards, nurseries and greenhouses. It is a design proposal. No field results exist yet, and every figure is an assumed or planned value.

Architecture. A human-shaped mild-steel frame, about 820 mm tall on a 600 mm × 300 mm wooden base, carries two sections. The sensing and control section holds the PIR sensor, Arduino Uno, motor driver, battery, switch and wiring in a weatherproof head box. The deterrent section holds a buzzer, LED lights, a 12 V DC fan, and a DC geared motor that drives a gear-and-crank mechanism to flap two arms.

Operating sequence.

1. The PIR sensor monitors the surroundings.
2. On detecting motion, it sends a signal to the Arduino.

3. The Arduino switches on the buzzer, LEDs, fan and motor for a set time of 10 to 15 s.
4. The motor drives the crank mechanism and the arms flap.
5. If motion persists, the cycle repeats. Otherwise all outputs switch off and the unit returns to standby.

Table V. Proposed Arduino Uno pin allocation

Device	Pin	Note
PIR output	D2	Digital input, powered from 5 V
Buzzer	D8	Through a transistor if needed
LED lights	D9	Through a 220 Ω resistor
Motor driver ENA, IN1, IN2	D3, D5, D6	DC geared motor for the arms
Motor driver ENB, IN3, IN4	D10, D11, D12	12 V DC fan
Power	Vin, GND	12 V battery through a switch, common ground

Table VI. Indicative cost (Indian rupees, to be confirmed by quotations)

Item	Min	Max
Arduino Uno	500	700
PIR sensor	100	150
12 V geared DC motor	300	500
Motor driver module	150	250
Buzzer and LEDs	50	50
12 V DC fan	150	250
12 V rechargeable battery	700	900
Switch and wiring	150	250
Item	Min	Max
Frame material and sheet	800	1,200
Wooden base plate	200	300
Fasteners, paint, miscellaneous	300	500
Total	**3,400**	**5,050**

Design critique. Two points from the survey apply to this design. First, the outline firmware holds identical outputs for a fixed 10 s and reads the sensor only afterwards, so the stimulus is predictable and invites habituation. Randomizing duration, sound pattern and arm speed, and using non-blocking timing, would address this [1], [2]. Second, a PIR sensor cannot separate target animals from people or moving vegetation, so the guard on the arms and fan, and a field trial that logs false triggers, are essential.

Planned evaluation. The group plans to measure detection range and angle, response time, noise level, motor current, power consumption, battery backup time, and reliability over repeated cycles, followed by field observation of bird or animal reactions where possible.

IX. Open Challenges and Research Gaps

The Smart Scarecrow for Crop Protection system offers an automated approach to reducing crop damage caused by birds and animals. However, several technical challenges must be addressed to improve its performance, reliability, and suitability for agricultural applications.

9.1 Open Challenges

1. Limited Detection Range: The proposed system uses a PIR sensor to detect movement. Its detection range is limited, and it may not cover large agricultural fields effectively.
2. False Detection: The sensor may respond to unwanted movement or environmental conditions, causing unnecessary activation of the buzzer, LED lights, fan, and motor.
3. Adaptation of Birds and Animals: Birds and animals may gradually become accustomed to repeated sounds, lights, and mechanical movements, reducing the long-term effectiveness of the system.
4. Power Supply and Energy Consumption: Continuous monitoring and the operation of multiple electrical components require a reliable power source. Battery charging and replacement may increase

maintenance requirements.

5. Weather Resistance: Rain, dust, humidity, and high temperatures may affect electronic components and mechanical parts. Proper protection is necessary for outdoor operation.

6. Mechanical Reliability: Repeated movement of the arms and operation of the gear-and-crank mechanism may cause wear, vibration, or loosening of mechanical connections.

7. Large-Field Coverage: A single unit may not protect a large agricultural area. Multiple units or an improved detection system may be required.

9.2 Research Gaps

The literature review in the synopsis indicates a need for a crop-protection system that is affordable, simple, energy-efficient, and easy to maintain. The proposed research addresses this need through the integration of a PIR sensor, Arduino Uno, buzzer, LED lights, DC fan, and a motor-driven mechanical arm mechanism.

The main research gaps are:

- Development of a low-cost system suitable for small-scale farmers.
- Integration of multiple deterrent methods into one automatic system.
- Improvement of detection accuracy and reduction of false triggering.
- Evaluation of actual scaring effectiveness under field conditions.
- Measurement of power consumption, battery backup, response time, and system reliability.
- Development of a design that is easy to fabricate, maintain, and upgrade.

These gaps should be investigated through prototype testing and comparison with conventional crop-protection methods. The actual effectiveness of the proposed system must be established experimentally rather than assumed.

X. Future Directions

Future developments in smart scarecrow technology can improve detection accuracy, energy efficiency, automation, and crop-protection performance. The proposed system provides a foundation for integrating mechanical mechanisms with advanced sensing and control technologies.

10.1 Integration of Artificial Intelligence

Artificial Intelligence (AI) and computer vision can be used to identify different types of birds and animals. A camera-based system could distinguish actual intruders from unwanted movement and activate an appropriate deterrent. Previous research has explored AI-based moving-bird detection and machine-learning-based animal classification.

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10.2 Internet of Things (IoT) Connectivity

IoT technology can connect the scarecrow to a mobile application or cloud platform. Farmers could receive alerts about detected movement, monitor the system remotely, and check its operating status. IoT-based agricultural scarecrow designs have also explored mobile monitoring and control.

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10.3 Solar-Powered Operation

A solar panel with a charge controller and rechargeable battery can provide a more sustainable power supply. This approach may reduce dependence on grid electricity and make the system suitable for remote agricultural fields. Solar-panel sizing and battery capacity should be determined from measured energy consumption.

10.4 Improved Deterrent Mechanisms

Future systems can use variable sound patterns, changing light sequences, ultrasonic devices, and improved mechanical movement. Combining different deterrents and changing their activation patterns may help reduce habituation in birds and animals. Their effectiveness should be verified through field experiments.

10.5 Improved Mechanical Design

The frame, arm mechanism, and gear-and-crank assembly can be optimized to reduce vibration, mechanical wear, and power consumption. Lightweight materials, improved bearings, weather-resistant enclosures, and corrosion-resistant components may increase durability and service life.

10.6 Multi-Unit Crop Protection

Multiple smart scarecrow units can be installed at different locations in large fields. Wireless communication between units could support coordinated operation and improve coverage. Future research should evaluate detection overlap, communication reliability, installation cost, and overall energy requirements.

10.7 Performance Testing and Validation

Future studies should conduct field trials under different weather conditions and with different crops and bird or animal species. Important parameters include detection range, response time, false-trigger rate, power consumption, battery backup, durability, and observed reduction in crop damage.

Overall, future improvements should focus on developing a reliable, affordable, energy-efficient, and easy-to-maintain smart scarecrow suitable for practical agricultural use.

XI. Conclusion

This survey paper examines smart scarecrow technologies for crop protection, with particular emphasis on automatic movement detection, microcontroller-based control, mechanical deterrent mechanisms, and emerging smart-farming technologies.

Traditional scarecrows and manual guarding have limitations, including continuous labour requirements and reduced effectiveness when birds and animals become accustomed to static deterrents. The proposed Smart Scarecrow for Crop Protection addresses these limitations through a PIR sensor, Arduino Uno, buzzer, LED lights, DC fan, and a DC motor-driven gear-and-crank mechanism.

The system is designed to detect movement and activate sound, light, air disturbance, and arm movement automatically. Its proposed advantages include reduced manual monitoring, simple construction, and suitability for small farms, orchards, nurseries, and greenhouses.

However, practical performance depends on sensor coverage, environmental conditions, power availability, mechanical reliability, and the behavioural response of birds and animals. Therefore, experimental testing is necessary before drawing conclusions about crop-loss reduction or long-term effectiveness.

Future integration of AI, IoT, solar power, and coordinated multi-unit operation may further improve the system. In conclusion, smart scarecrow technology represents a promising approach to automated crop protection, provided that its performance, affordability, and reliability are validated through systematic field studies.

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