



DESIGN OF A LOW-COST MONKEY DETERRENT SYSTEM

Level 4 – HNC Electrical and Electronic Engineering

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1. Introduction

Protecting crops is essential for maintaining agricultural productivity, particularly in rural communities. The Chomzangari Women's Cooperative in Zimbabwe faces ongoing issues with monkeys damaging crops, which has a direct impact on income and food security. This problem is difficult to manage because monkeys are intelligent and quickly adapt to traditional deterrents.

To address this, an engineering-based approach using dynamics and control principles can provide a more reliable solution. A closed-loop control system is proposed so that the deterrent activates quickly and responds effectively when movement is detected.

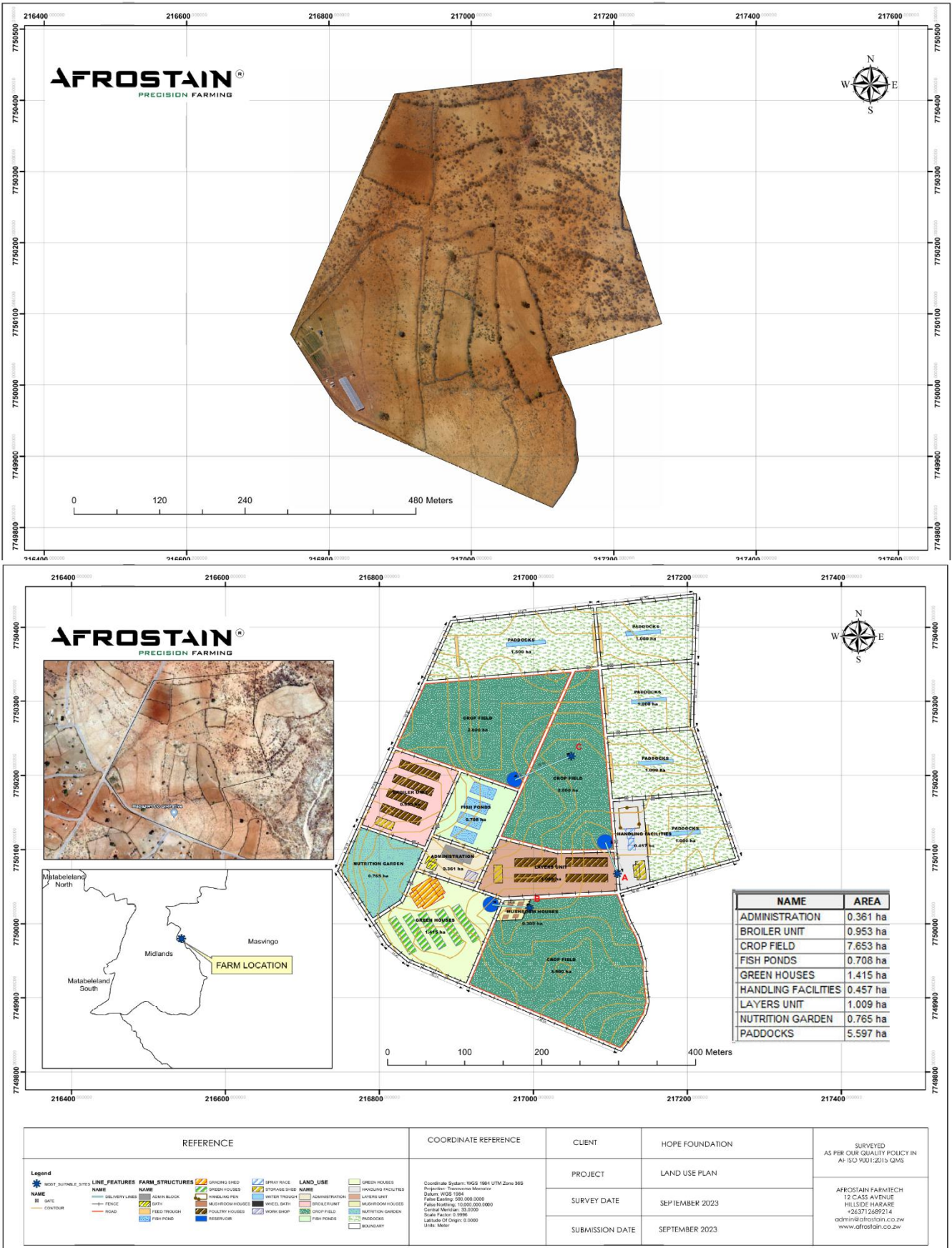
A PID (Proportional–Integral–Derivative) controller has been selected due to its simplicity, reliability, and common use in industry. It is also a suitable choice as it is a very low-cost system.

MATLAB (Mathworks 2024) is used to model and simulate the system before physical implementation. The aim of this project is to design and evaluate a low-cost, solar-powered monkey deterrent system that is practical for use in remote rural environments.

The key objectives are:

- To develop a mathematical model of the actuator system
- To design a suitable PID-controlled closed-loop system
- To simulate and analyse system performance using MATLAB
- To evaluate performance metrics such as rise time, settling time, overshoot, and steady-state error
- To design a simple solar power supply for off-grid operation

1.1 Map of Terrain



2. Literature Review

2.1 Dynamic System Modelling

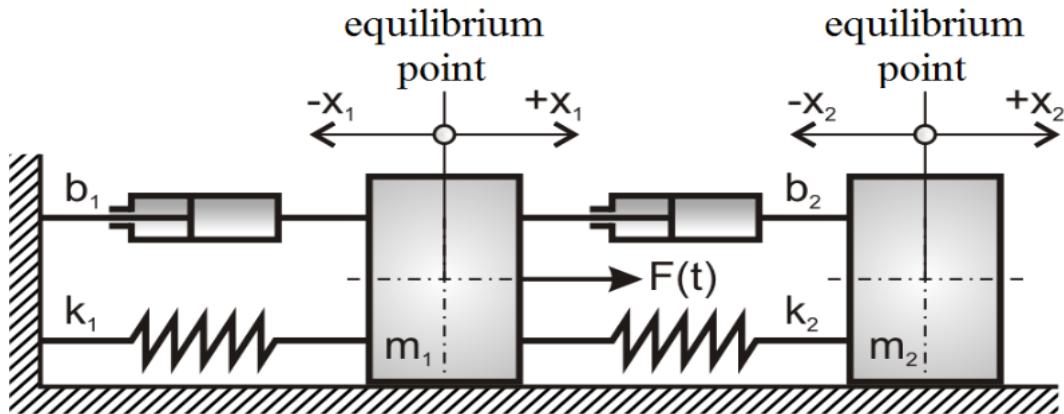
Dynamic modelling is a core part of control engineering, allowing system behaviour to be predicted before building physical hardware. Mechanical systems are often represented using second-order differential equations based on Newton's Second Law (Ogata, 2010).

A common model is the mass–spring–damper system, it is one of the most widely used due to its ability to capture inertia, damping and stiffness, fundamental characteristics of mechanical dynamics. The general form of a second order system is:

$$m\ddot{x}(t) + b\dot{x}(t) + kx(t)$$

where:

- m is the mass (or inertia)
- b is the damping coefficient
- k is the stiffness
- $x(t)$ is displacement



This model reflects the key physical behaviour of many electromechanical systems, including motors, actuators, and rotating mechanisms. In this project, the deterrent actuator (such as a rotating arm or vibration device) can be realistically represented using a second-order system.

In practice, engineers often use tools like MATLAB and Simulink to test and simulate these systems before building any hardware (MathWorks, 2024). This helps identify potential issues early on, making the system more reliable while also reducing development time and cost.

2.2 Control Systems and PID Controllers

Control systems can either be open loop or closed loop. Closed loop systems use feedback to compare the output with a desired value and adjust it accordingly, which improves stability and performance (Åström & Murray, 2012).

The proportional-integral-derivative (PID) controller is widely used in industrial settings. Its simplicity, low computational requirements, ease of tuning and efficient performance across a variety of systems are the main reason for its popularity (Dort & Bishop, 2017).

The general PID transfer function is:

$$C(s) = K_p + \frac{K_i}{s} + \frac{K_d s}{1 + \frac{s}{N}}$$

Where:

- K_p = Proportional Gain
- K_i = Integral Gain
- K_d = Derivative Gain
- N = Derivative filter coefficient

Each term contributes differently to system behaviour:

Proportional Control (P):

Increases system responsiveness. A higher proportional gain reduces rise time but may increase overshoot.

Integral Control (I):

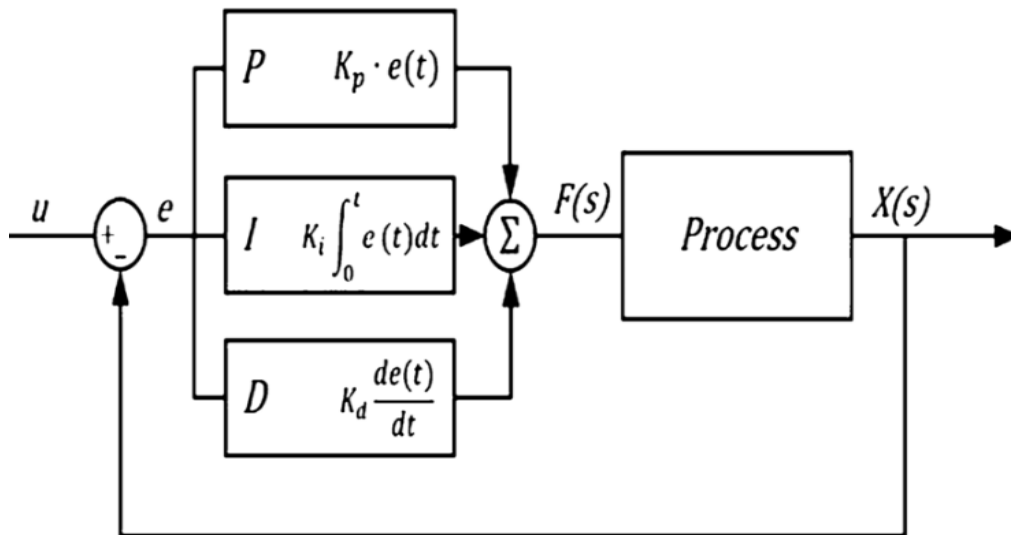
Eliminates steady state error by accumulating past errors. This ensures full activation of the deterrent mechanism when monkey detection occurs.

Derivative Control (D):

Improves damping and anticipates system behaviour by reacting to the rate of change of error. This reduces oscillation and improves stability.

Derivative Filtering:

The derivative term is sensitive to high frequency noise, which is common in outdoor environments due to sensor disturbances from wind, vegetation movement and temperature fluctuations. The derivative filter coefficient 'N' helps mitigate these effects, improving stability.



Alternative control strategies such as fuzzy logic, sliding-mode control, and adaptive control have been explored in wildlife deterrent research (Anthony 2021). However, these methods typically require more computational power and complex tuning. Given the project's constraints, low cost, low power, and rural deployment, the PID controller remains the most appropriate choice.

2.3 Sensory Actuator Feedback Systems

Effective deterrent systems rely on accurate sensing, reliable decision making and timely actuation. This forms a feedback loop consisting of:

- **Sensors** to detect monkey presence
- **Controller** to process the signal
- **Actuator** to generate the deterrent response
- **Feedback** to maintain performance

PIR (Passive Infrared) sensors are widely used in low power motion detection systems due to their low cost, low energy consumption, and ability to detect warm blooded animals. PIR sensors are particularly effective in outdoor environments when combined with thresholding and filtering to reduce false triggers.

However, monkeys are intelligent and capable of learning behavioural patterns. Research on wildlife deterrence (Anthony 2021) emphasises the importance of unpredictability and multi-modal stimuli to prevent habituation. This supports the inclusion of variable sound frequencies, intermittent lighting, and randomised actuator motion in the system design.

The integration of sensors and actuators through a closed-loop control system ensures that the deterrent responds dynamically to real-time conditions, maintaining effectiveness even as monkeys adapt.

2.4 Solar Powered Systems

Many rural areas do not have access to reliable electricity, so solar power is an ideal solution. Solar panels convert sunlight into electrical energy and Zimbabwe's climate makes this particularly effective. (Radley & Lehmann-Grube 2022)

Embedded systems consume very little power, especially when idle. The actuator only requires short bursts of energy, making solar power a practical option.

Advantages include:

- Low running costs
- Minimal maintenance
- Environmental benefits
- Reliable operation in remote areas

3. System Analysis and Modelling

3.1 Mathematical Modelling of the Deterrent Actuator

The mechanical component of the proposed monkey deterrent system consists of an actuator, which is in the form of a rotating arm, designed to produce rapid motion or vibration when monkey activity is detected. To predict its behaviour, the actuator model is a second order dynamic system using the mass-spring-damper.

3.2 PID Controller Design

To improve the systems performance and ensure a rapid and stable activation, a PID controller is implemented. It follows the combined PID configuration therefore achieves:

- Fast rise time
- Least steady state error
- In controlled overshoot
- Improved damping
- Robustness to sensor noise

These characteristics are particularly crucial in a solar powered system, where efficiency and longevity must be considered.

3.3 State Space Representation

While transfer functions are useful, state-space modelling provides a more complete description of system behaviour.

In MATLAB, both the plant and controller are converted into state-space form and combined into a closed-loop system. This allows:

- More accurate simulation
- Analysis of internal system behaviour
- Easier implementation in digital systems

3.4 Integrated System Architecture

The complete system architecture combines sensing, decision making, control and actuation into a unified closed-loop structure. The PIR sensor provides the primary detection input, which is processed through thresholding and delay logic to ensure reliable activation. The PID controller regulates the mechanical actuator, while the Night/Day logic and AND gate manage auxiliary deterrent outputs such as the buzzer and strobe light.

This integrated approach ensures that the system responds rapidly to genuine monkey activity while conserving energy and reducing unnecessary wear. The architecture directly reflects the Simulink model and supports the practical implementation of the design in a rural agricultural environment.

4. Instrumentation and Control Methodology

4.1 Detection Logic and Triggering

A threshold-based detection method was used to ensure the system only activates during genuine monkey activity. The PIR sensor output is compared to a set threshold of 0.95, with detection triggered only when this level is exceeded.

To reduce false alarms from short disturbances like wind or birds, a 5-second delay is included, so only sustained motion activates the system. This improves reliability and reduces unnecessary wear on components, supporting a low-maintenance design.

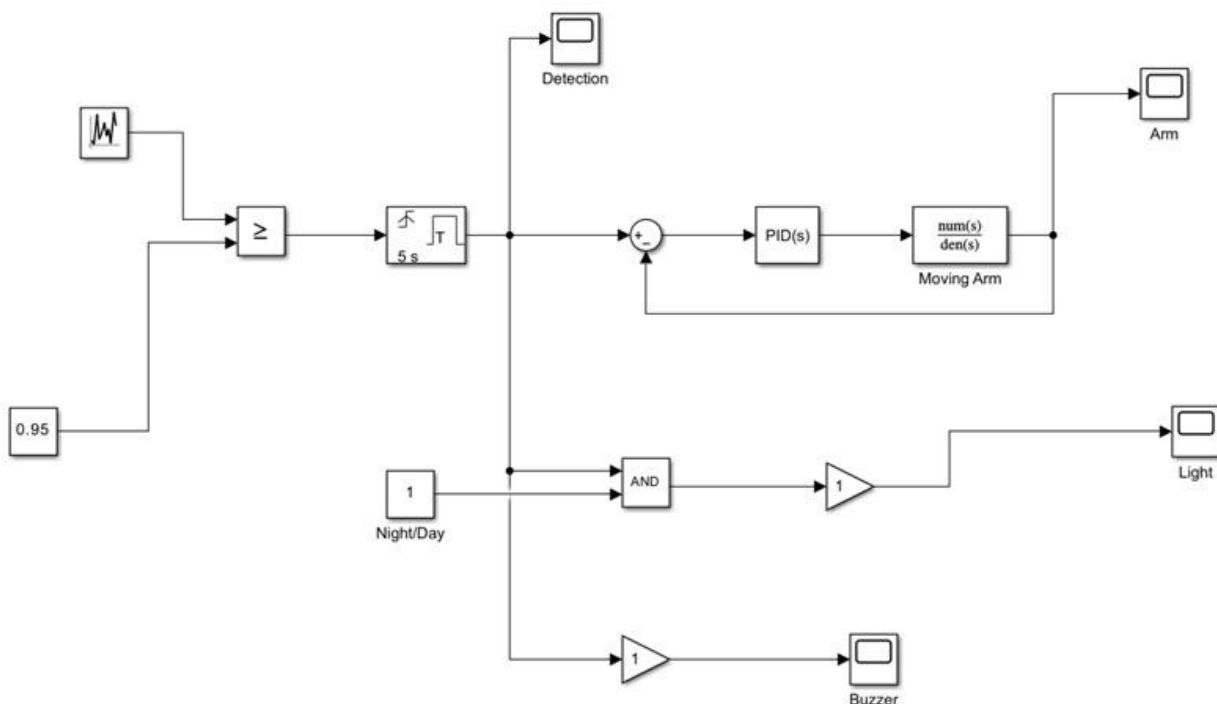
This detection stage acts as the first part of the closed-loop system, ensuring the PID-controlled actuator only operates when needed.

4.2 Multi-modal Deterrent Output

To increase deterrent effectiveness and reduce the likelihood of monkey habituation, the system incorporates multi-modal outputs. As well as the rotating arm, a high-frequency buzzer and an LED strobe light are used. These outputs are activated simultaneously when the detection logic confirms monkey presence during daytime.

In the Simulink model, both outputs are driven by digital activation signals, producing rapid on/off pulses. This pulsed behaviour is intentional, as intermittent sound and light patterns are more effective at startling animals than continuous signals. The buzzer and light are controlled independently of the mechanical actuator, ensuring that even if the motor is temporarily inactive, the system still provides an immediate deterrent response.

This design choice supports the project requirement to consider monkey intelligence and adaptability by introducing variability and unpredictability into the deterrent stimuli.



4.3 Environmental Logic

In rural agricultural settings, it is unnecessary for the lighting part of the deterrent system to operate continuously throughout the night. To address this, a Night/Day logic input was added to the Simulink model. This input acts as an enable signal, allowing the actuator and buzzer systems to operate only during daylight hours.

The detection signal and the Night/Day signal are combined using an AND gate, ensuring that the light deterrent activates only when both conditions are met:

- Monkey activity detected
- Nighttime operation enabled

5. MATLAB Code

```
clc;  
clear;  
close all;
```

```
%% MONKEY DETERRENT SYSTEM
```

```
%% 1. PARAMETERS
```

```
m = 2;  
b = 5;  
k = 20;
```

```
G = tf(1, [m b k]);
```

```
%% 2. PID WITH DERIVATIVE FILTER
```

```
Kp = 60;  
Ki = 40;  
Kd = 10;  
N = 50;
```

```
C = pid(Kp, Ki, Kd, N);
```

```
%% 3. Convert to State Space
```

```
Gss = ss(G);  
Css = ss(C);
```

```
%% 4. Build Closed Loop Manually
```

```
% States: [controller_states ; plant_states]
```

```
Acl = [ ...  
    Css.A,      -Css.B*Gss.C;  
    Gss.B*Css.C,  Gss.A - Gss.B*Css.D*Gss.C ];  
Bcl = [Css.B; Gss.B*Css.D];
```

```

C_y = [zeros(size(Gss.C,1), size(Css.A,1)) Gss.C];
C_u = [Css.C zeros(size(Css.C,1), size(Gss.A,1))];

D_y = 0;
D_u = Css.D;

sys_y = ss(Acl, Bcl, C_y, D_y); % output
sys_u = ss(Acl, Bcl, C_u, D_u); % control effort

%% 5. SIMULATION
t = 0:0.01:10;
r = ones(size(t)); % monkey detection step

y = lsim(sys_y, r, t);
u = lsim(sys_u, r, t);

%% 6. ERROR
e = r - y;

%% 7. PERFORMANCE
info = stepinfo(sys_y);

fprintf('\nSYSTEM PERFORMANCE:\n');
fprintf('Rise Time: %.2f s\n', info.RiseTime);
fprintf('Settling Time: %.2f s\n', info.SettlingTime);
fprintf('Overshoot: %.2f %%\n', info.Overshoot);

%% 8. PLOTS

figure;

subplot(3,1,1)
plot(t,r,'--','LineWidth',1.5)
hold on
plot(t,y,'LineWidth',2)
grid on
title('System Output (Monkey Deterrent Activation)')
legend('Monkey Detected',' System Response')

subplot(3,1,2)
plot(t,e,'LineWidth',2)
grid on
title('Error Signal')

subplot(3,1,3)
plot(t,u,'LineWidth',2)
grid on
title('Control Effort (Motor/Speaker Power)')
xlabel('Time (s)')

```

6. Simulation and Results

The Simulink model was used to simulate the closed-loop behaviour of the deterrent actuator under a step input representing monkey detection. The simulation outputs include the actuator displacement response, the control error signal and the control effort applied by the PID controller.

6.1 System Output

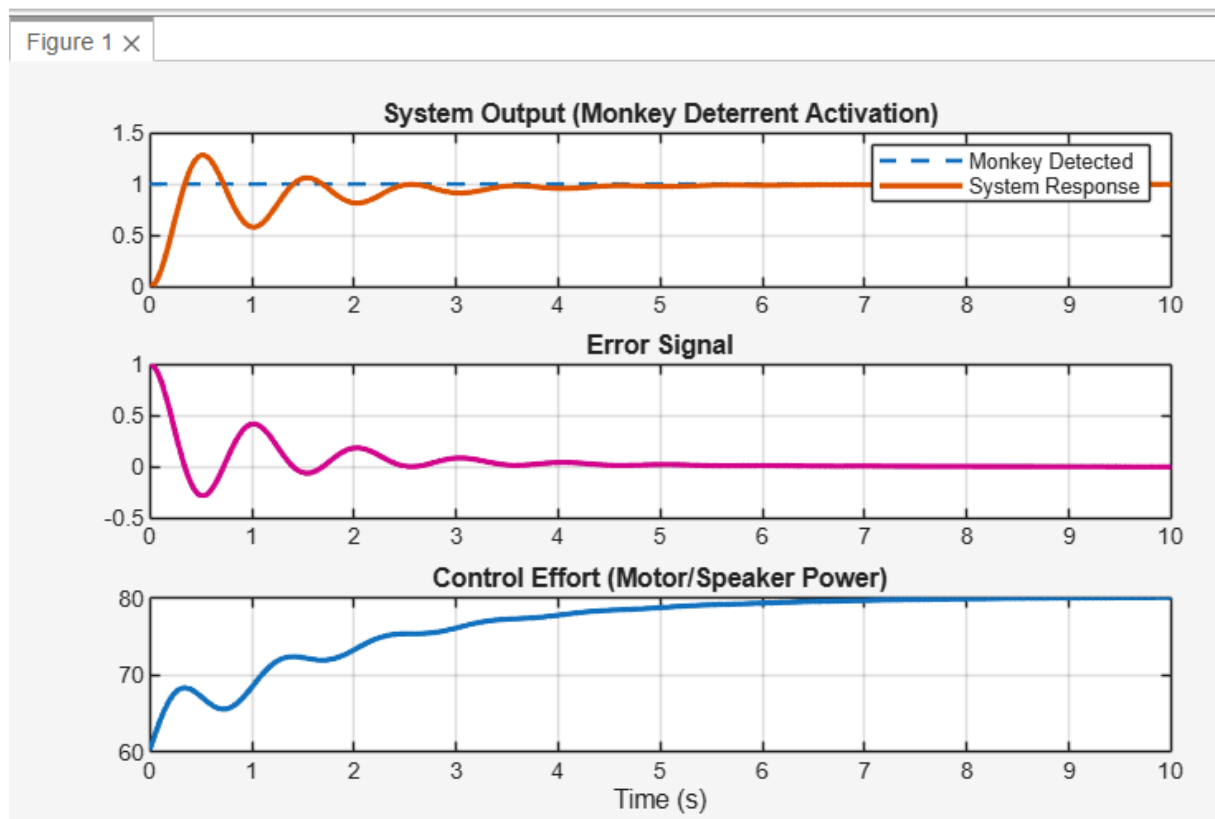
The actuator exhibits a rapid rise time, ensuring quick physical movement when monkeys are detected. The response shows controlled overshoot and stable settling behaviour, consistent with the characteristics of a well-tuned second-order system. This confirms that the selected PID gains provide an effective balance between responsiveness and stability.

6.2 Error Signal

The error signal decreases smoothly to zero as the actuator reaches the desired displacement. This demonstrates that the integral component of the PID controller successfully eliminates steady state error, ensuring full activation of the deterrent mechanism.

6.3 Control Effort

The control effort initially spikes to overcome inertia and friction, then stabilises as the system reaches steady state. This behaviour is desirable in a solar-powered system, as it concentrates energy usage during the initial activation phase while minimising long term power consumption.



7. Power Supply Design

7.1 Energy Estimation

- Microcontroller: 0.1A
- PIR sensor: 0.02A
- Light: 0.03A
- Buzzer: 0.1A
- Motor: 2A for 10s

7.2 Proposed System

- 20W Solar panel
- 12V 7Ah battery
- Charge controller

Zimbabwe's high irradiance makes this configuration feasible.

8. Cost Analysis

Component	Quantity	Description	Estimated Cost (GBP)
Solar Panel	1	20W Solar Panel	£20
Battery	1	12v Rechargeable, 7Ah	£15
Arduino Uno	1	Microcontroller board	£20
PIR (HC-SR501)	1	White dome sensor, detects motion	£2
Motor	1	Actuator arm to move and vibrate	£15
Frame	1	Wooden frame to hold everything	£10
Wiring & Misc	1	Breadboard, jumper cables and misc	£10
Buzzer 5v	1	Simple plug in buzzer, makes sound	£2
LED & Resistor	1	LED light and resistor to protect it	£3
USB Power Bank	1	10000mAh power bank to power Arduino	£10
Solar Charge Controller	1	Regulates current to battery	£12
Total			£119

9. Sustainability and Implementation

The system:

- Requires minimal maintenance
- Uses clean, renewable energy
- Can be repaired locally and cheaply
- Reduces workforce demand
- Adaptability measures prevent monkeys from becoming accustomed to the deterrent

10. Discussion and Evaluation

10.1 Strengths

A significant advantage of the system is that it has a rapid response to dynamic changes. It can be seen from the simulation results that it takes a very short time to react when a monkey approaches. The use of solar power means it's environmentally friendly and the use of easily accessible equipment means it's cheap to build and repair.

10.2 Limitations

Although the system has many benefits, there are limitations associated with it. The mechanical parts of the system may show wear and tear, especially as they are used outdoors in a rural environment. Prolonged exposure means the sensor components may become less sensitive or stop operating.

10.3 Potential Improvements

To improve the system, implementing adaptive PID tuning would give maximum performance. Adding advanced detection systems, such as cameras or learning systems could improve detection and reduce false triggers.

10.4 Evaluation

Overall, the proposed system demonstrates a sound and economically practical application of control engineering principles. It balances performance, cost and sustainability, making it suitable for rural agricultural use and gives scope for improvement.

11. Conclusion

This project successfully developed, modelled, and simulated a low cost monkey deterrent system tailored to the needs of the Chomzangari Women's Cooperative. By applying principles of mechanical dynamics and control engineering, the system was designed around a second order actuator model regulated by a PID controller, ensuring fast, stable, and reliable activation when monkey activity is detected. The use of MATLAB and Simulink enabled detailed analysis of system behaviour, including actuator response, error convergence, and control effort, confirming that the chosen controller parameters provide an effective balance between responsiveness and energy efficiency.

The integration of detection, a 5-second validation delay and night/day logic enhances the system's practicality in real agricultural environments by reducing false triggers and conserving power. The inclusion of multi deterrent outputs, mechanical motion, strobe lighting, and a high frequency buzzer, supports long-term effectiveness by introducing variability that reduces the likelihood of monkey habituation. The solar powered design further ensures sustainability, low operating cost, and independence from grid infrastructure, making the system suitable for remote rural locations.

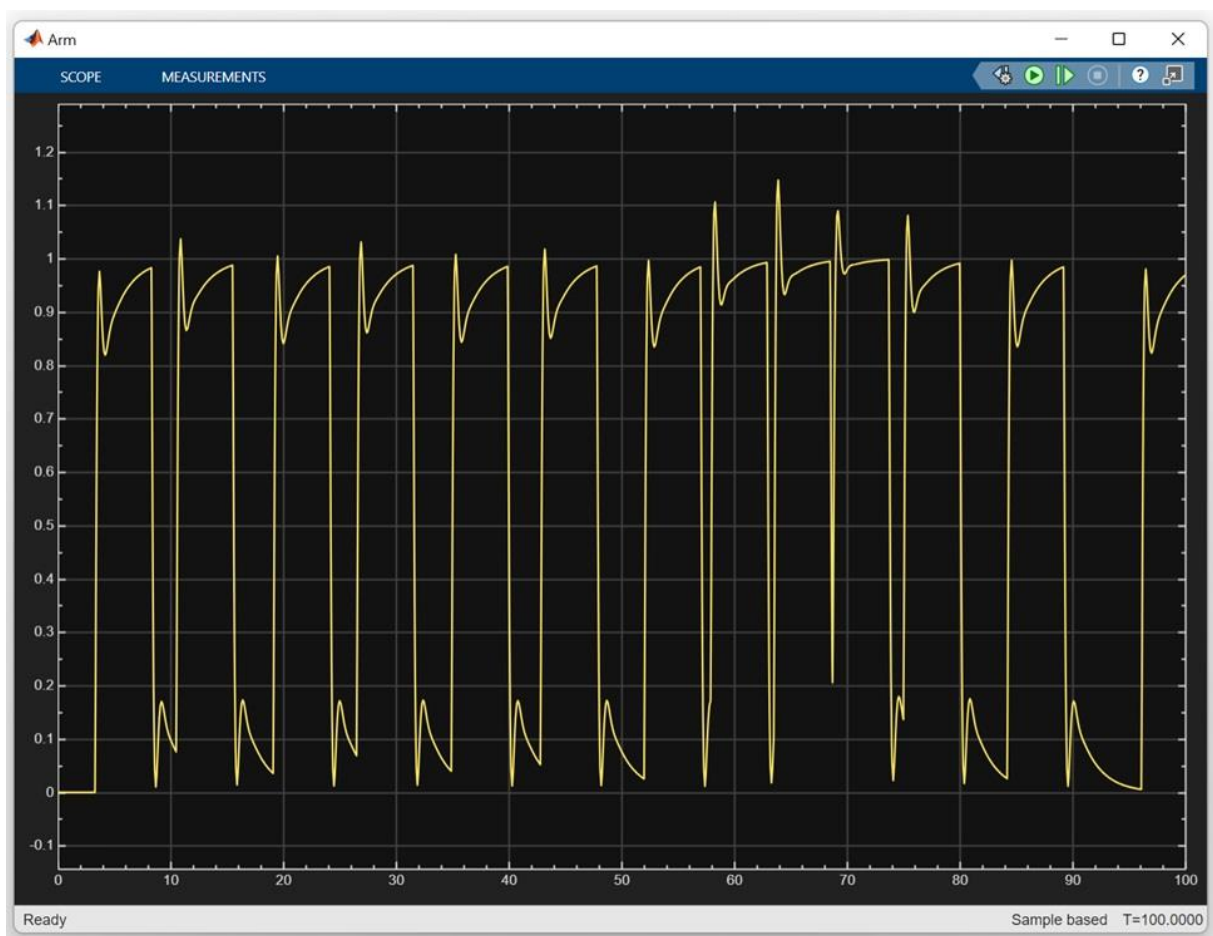
Overall, the project demonstrates how dynamic modelling, feedback control, simulation, and practical engineering considerations can be combined to create a robust and affordable wildlife deterrent solution. The system meets the requirements for technical rigour, real world applicability, and sustainability, while also providing a foundation for future enhancements such as adaptive control, improved sensing, and more advanced behavioural deterrent strategies.

12. References

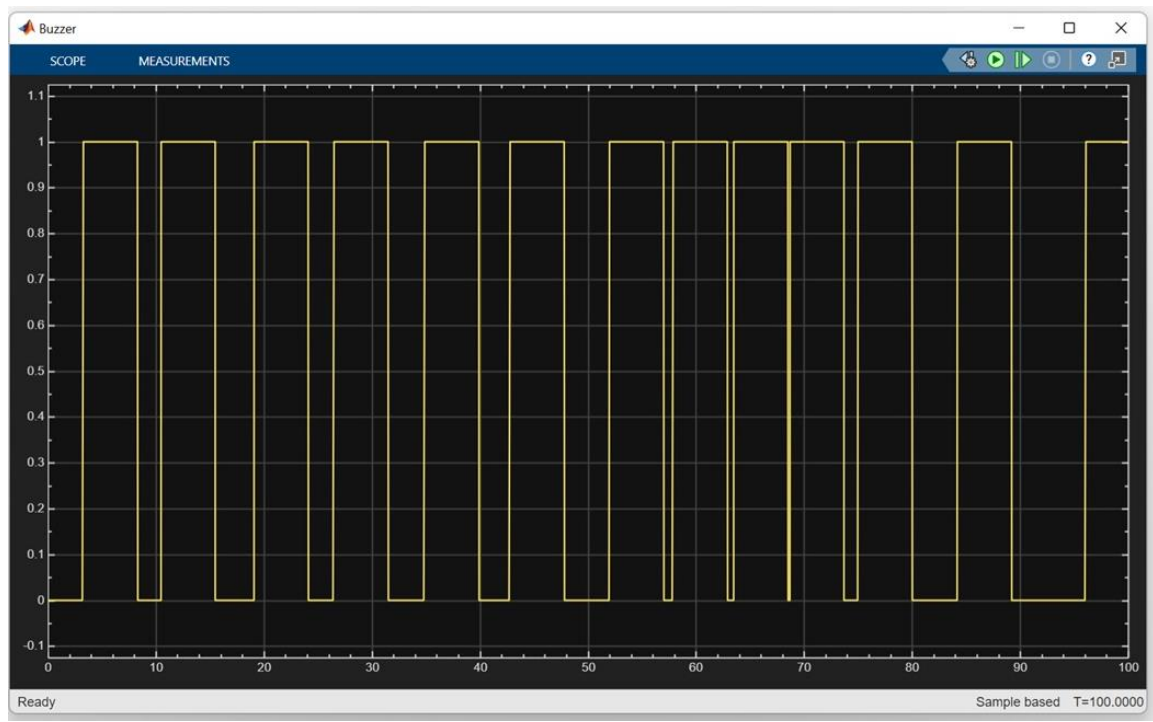
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13. Appendix

Actuator Arm



Buzzer



Light

