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Discrete Detection of Qualitative Changes in Agricultural Land Using Heaviside Thresholds: Application to Soil Monitoring

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Abstract: Soil quality is a central indicator of sustainability in agricultural production systems. This article proposes a discrete method for the automatic detection of qualitative changes in soils, based on Heaviside threshold functions and a simple yet robust temporal analysis. The method classifies daily observations into three states: improvement, stability, or degradation, depending on their position relative to a critical threshold and a defined tolerance. A MATLAB simulation illustrates the efficiency of the model, with a graph enabling direct interpretation of soil dynamics. The approach is designed for use in precision agriculture and automated monitoring contexts.

Keywords: Soil quality; Discrete detection; Heaviside functions; Critical threshold; MATLAB; Precision agriculture.

1. Introduction

The qualitative evolution of soils plays a fundamental role in maintaining agricultural productivity and environmental resilience [1]. Parameters such as pH, organic matter, or moisture are recognized indicators of fertility and potential degradation [2]. In this context, the ability to automatically detect significant changes becomes crucial, especially in real-time monitoring systems.

Conventional soil analysis methods are often based on continuous, statistical, or spectral approaches, which sometimes lack clarity and robustness to small natural fluctuations [3]. To address these limitations, we introduce a discrete method based on modified Heaviside functions, enabling direct qualitative classification of trends from univariate time series.

2. Scientific Context and Problem Statement

Intensive farming practices, climate change, and chemical inputs affect soil quality. It is therefore essential to implement simple and reliable tools to identify long-term trends [4]. In precision agriculture, detection systems must meet several criteria:

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computational simplicity, embedded integration capability, robustness to noise, and ease of interpretation. This study proposes a model based on discrete logic and MATLAB coding that meets these requirements.

3. Methodology

3.1 Basic Parameters

In modern agricultural systems, continuous monitoring of soil quality is essential for optimizing yields while preserving natural resources. Common quality indicators include soil pH, organic matter content, and moisture. The critical threshold is a reference value above which soil quality is considered optimal or degraded. This threshold is set according to crop type, agronomic context, or environmental standards.

- Number of observation days: 50
- Critical threshold: 7.0 pH
- Tolerance margin: ±1

3.2 Simulated Time Series Generation

The series simulates three phases:

- Days 1–15: pH increase → improvement
- Days 16–25: stability
- Days 26–50: gradual decline → degradation

3.3 Threshold Detection

Discrete Heaviside functions are used to identify positive or negative crossings of the critical threshold.

3.4 Classification Algorithm

Classification values:

- +2: significant improvement
- -2: significant degradation
- 0: stability

4. Simulation Results

The proposed method was tested using MATLAB simulations. The results show the evolution of the soil quality index over time.

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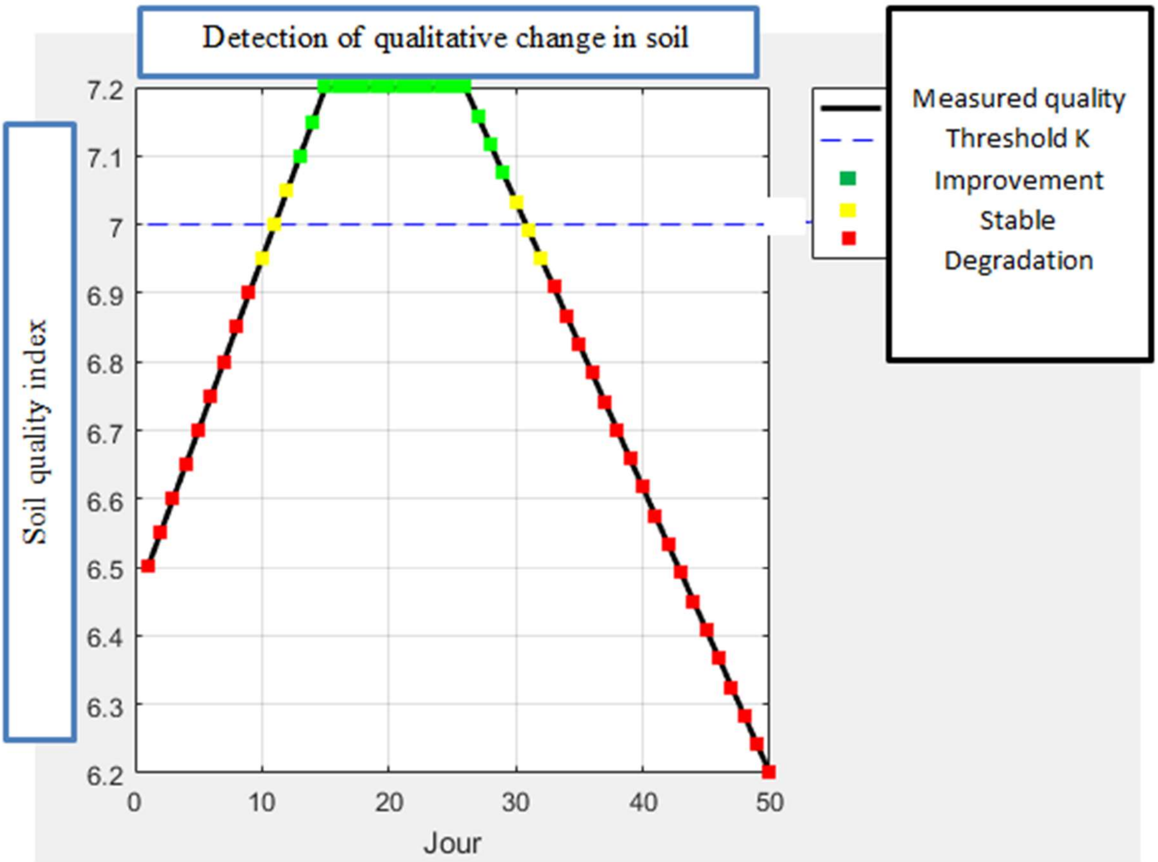

Figure 1: Result of the soil quality index on cultivated land.

4.2 Interprétation du graphique

- Black line: simulated soil quality (e.g., pH)
- Blue line: reference critical threshold
- Green squares: improvement (values above k+ε)
- Red squares: degradation
- Yellow squares: stability around the threshold

5. Discussion

5.1 Advantages

- Algorithmic simplicity: easy to implement on microcontrollers.
- Robustness: the ε tolerance avoids errors due to noise.
- Direct interpretability: each day is categorized into three classes.

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5.2 Limitations

- Threshold k is predefined without learning.
- The method does not consider local dynamics (multi-day trends).
- Deterministic approach without probabilistic modeling.

6. Perspectives

- Multivariate extension: combine multiple parameters (moisture, C/N ratio, etc.)
- Machine learning: dynamically adjust k based on historical data.
- Embedded deployment: integration into connected sensors or drones.
- Temporal improvement: use of a sliding filter or discrete derivative to detect long-term trends.

7. Conclusion

The discrete approach using Heaviside thresholds provides an efficient tool for detecting significant changes in agricultural soil quality. It offers a good compromise between simplicity, robustness, and field applicability. As part of the automation of agro-environmental monitoring, this method can become a key component of smart agriculture.

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