SoilTile: Soil-based Ground Sensing

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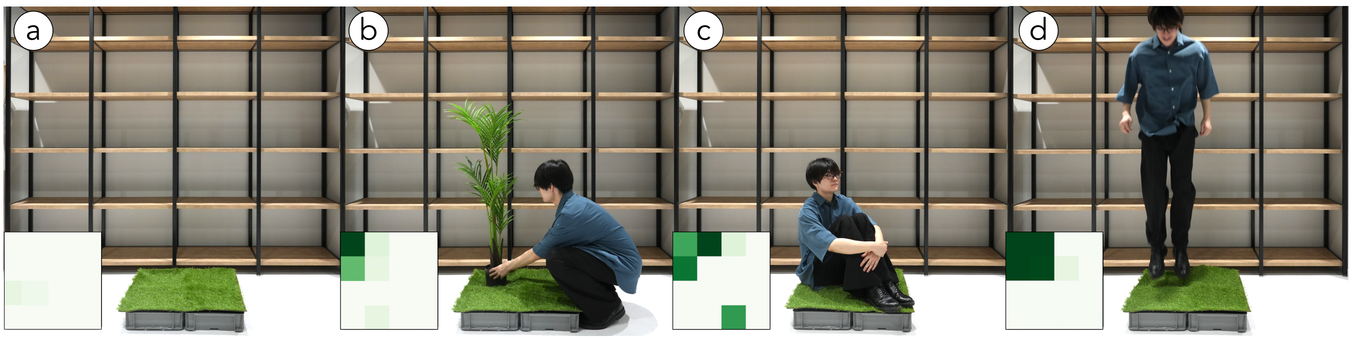

Figure 1: a. A 2 x 2 SoilTile matrix; b. User putting potted plant on the matrix; c. User sits on the matrix; d. User jumps on the matrix. The heatmaps show the voltage output from each cathode, representing the force distribution.

Abstract

We present *SoilTile*, a novel ground sensing approach that explores soil as an interactive medium. Built upon the principles of Soil-based Microbial Fuel Cells (SMFCs), *SoilTile* draws on the natural electrochemical interactions between soil and embedded electrodes—not as a source of energy, but as a way to sense physical contact through electrical response. When pressure applied to the cathode, SMFC produce measurable variations in output voltage. Building on this phenomenon, we construct modular ground sensing units that detect localized pressure through a matrix of electrodes, structured to respond under human activities or object placement. With its minimalist structure, DIY-friendly fabrication, and potential for seamless integration into natural environments, *SoilTile* offers a simple, material-driven platform for designing interactive spaces.

CCS Concepts

• **Human-centered computing → Interaction techniques**.

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UIST Adjunct '25, September 28-October 1, 2025, Busan, Republic of Korea

ACM ISBN 979-8-4007-2036-9/2025/09
https://doi.org/10.1145/3746058.3758371

Keywords

Soil-based Microbial Fuel Cells, Ground Sensing, Sustainability

ACM Reference Format:
Yuma Tsukakoshi, Tian Min, Annemarie Spiller, Chengshuo Xia, Anusha Withana, and Yuta Sugiura. 2025. SoilTile: Soil-based Ground Sensing. In *The 38th Annual ACM Symposium on User Interface Software and Technology (UIST Adjunct '25), September 28-October 1, 2025, Busan, Republic of Korea.* ACM, New York, NY, USA, 3 pages. https://doi.org/10.1145/3746058.3758371

1 Introduction

The ground beneath us is both essential and invisible, as an ever-present surface that supports our movements, interactions, and spatial routines. Whether indoors or outdoors, human activity inevitably exerts pressure, weight, and motion onto the ground, making it a natural site for sensing [15]. In HCI, researchers have long explored the ground as an interface, designing systems that detect footsteps, gestures, or object placements through floor-based sensing [2, 12, 13, 15]. Compared to existing vision-based or wearable sensing approaches, ground-embedded solutions offer a uniquely unobtrusive and ambient alternative: they are passive, always present, require no active engagement, and often going unnoticed [8].

While existing floor sensing systems offer fine-grained capabilities and high resolution, they often rely on complex hardware architectures including dense arrays of sensors, wired networks, and custom substrates, that can be costly to build, difficult to maintain, and limited in scalability. Vezzani et al. [13] has identified key design considerations for ground-based sensing: low-cost hardware, spatial and temporal resolution, system robustness, and unobtrusiveness. Yet in practice, these systems often navigate trade-offs across these dimensions, highlighting the tension between sensing fidelity and structural complexity.

In light of these challenges, we explore an alternative approach — one that emerges not from adding more sensors, but from embracing the material and electrochemical properties of the ground (soil) itself. In this poster, we introduce *SoilTile*, a floor sensing system built primarily from soil, designed to be DIY-friendly, low-cost, and structurally simple [1]. *SoilTile* offers a materially-driven alternative for detecting pressure through natural voltage responses. We describe primitive explorations of its sensing behavior, and present a series of proof-of-concept prototypes that demonstrate its potential in ambient, interactive environments.

2 Sensing with Soil

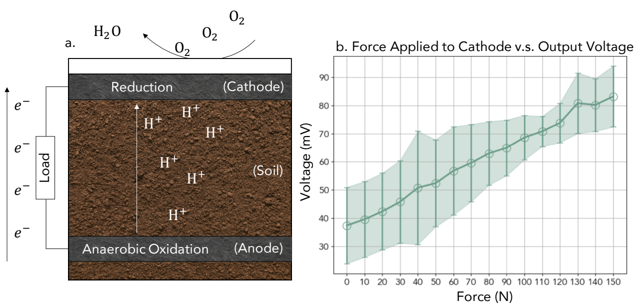

Figure 2: Basic structure of an SMFC (left); The relationship between the force applied on the cathode and the output voltage (right)

A soil-based microbial fuel cell (SMFC) is an energy harvesting device that converts chemical energy in soil into electricity through the metabolic activity of microorganisms [10, 14] (Figure 2.a). It consists of an anode buried in anaerobic soil and a cathode placed near the soil surface where it is exposed to oxygen [6, 7]. Previous studies have shown that carbon felt, with its inert chemical properties and highly porous structure, is an ideal electrode material for SMFCs [5, 16]. This porosity, however, also introduces air gaps between the cathode and the soil. Our key observation is that when external pressure is applied, it compresses the cathode against the soil, displacing air pockets and altering the contact condition, resulting in measurable fluctuations in the output voltage.

To demonstrate this effect, we conducted a simple experiment using a force gauge to apply different levels of pressure to an SMFC under 90% volumetric water content (VWC), with five repeated measurements per level. As shown in Figure 2.b, the results reveal a relationship between applied force and voltage response. By arranging multiple such SMFCs or cathodes in a grid, we can extend this principle to infer pressure distribution across a surface using voltage measurements.

3 SoilTile

SoilTile is constructed as a modular floor-sensing unit based on the standard SMFC structure, without major alteration to its electrochemical design (Figure 3.a). Each unit consists of a 30 × 30 × 10 cm plastic container filled with soil and embedded electrodes. A single 20 × 20 cm carbon felt anode is placed at the bottom of the container, while four 7 × 7 cm cathodes share the same anode and are arranged in a 2 × 2 grid at the soil surface.

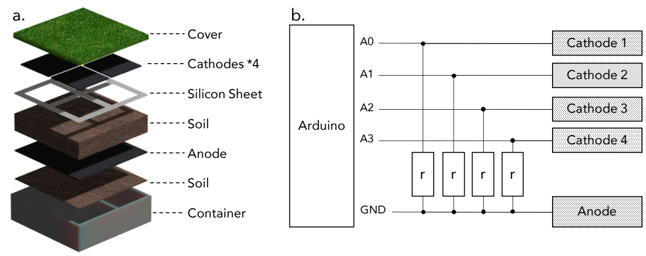

Figure 3: Layered structure of a *SoilTile* unit (Left); Schematic of connecting an unit to Arduino to measure voltage (right).

To maintain voltage responsiveness and prevent signal saturation, we introduce a rubber sheet with perforated openings between the cathodes and the soil. When a person stands on the surface, the large vertical force can press the cathodes deeply into the soil, potentially causing persistent contact, deformation, or adhesion that leads to a sustained high-voltage signal. The rubber sheet acts as a buffer, ensuring that cathode–soil contact only occurs under intentional pressure. The sheet features four 5 × 5 cm cutouts aligned with the cathodes.

The topmost layer serves as both a protective enclosure and a mounting surface for the cathodes, ensuring structural stability. The materials can be replaced for visual and tactile presentation (e.g., cork sheets, synthetic turf), which could potentially influence signal behavior [15].

Each electrode pair forms an independent SMFC circuit, which are connected via insulated wires to 2 kΩ resistors in series [9]. The voltage across each resistor is sampled using the analog input pins of an Arduino Mega, which supports multi-channel acquisition. Figure 3.b shows the wiring schematics. Excluding the Arduino board, each *SoilTile* unit can be fabricated for under $20 in material cost.

4 Example Applications

We demonstrate the feasibility of *SoilTile* for simple HAR through a set of basic scenarios, including object placement, sitting, and jumping (Figure 1). As users engage with the sensing surface, different contact patterns across the tile's electrode grid produce distinguishable voltage signatures. The heatmaps visualize regions of output voltage across a 2 × 2 *SoilTile* matrix, comprising 16 cathodes in total. In this proof-of-concept prototype, no additional calibration was performed. As with other material-driven sensing systems, fabrication variability can lead to signal inconsistencies across electrodes [3, 11]. To account for this, we visualize pressure patterns based on voltage deltas (ΔV) rather than absolute measurements.

5 Limitations & Future Work

Our proof-of-concept prototype demonstrates the feasibility of soil-based ground sensing, though several design aspects leave room for future improvement. As demonstrated in prior work [4, 12, 15], both top-layer material and electrode cell size can significantly impact pressure distribution and signal behavior. We plan to conduct systematic experiments to evaluate these design parameters in future iterations.

Another trade-off lies in sensing performance itself: while *SoilTile* is structurally minimal and cost-effective, there remains room to improve spatial resolution and signal precision, especially when compared to dense sensor arrays. Although soil is inherently suited for outdoor environments, our current prototype is housed in movable containers to support indoor development and ease of relocation. Future work will investigate long-term outdoor deployment, focusing on how to maintain signal stability and develop more robust interpretation methods under variable environmental conditions.

Acknowledgments

This work was supported by JST AIP Acceleration Research (Grant Number JPMJCR25U4).

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