

Demo: Towards Fine-Grained Deformation Sensing through Naturally Occurring Moiré Patterns in Everyday Woven Surfaces

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Abstract

Everyday interactions, such as sitting and leaning, deform compliant surfaces that support the body. Sensing these deformations can reveal physical interactions, body motion, and physiological activity such as respiration. However, small deformations are difficult to observe without instrumenting the surface or the user. We present MoiréDeform, which exploits naturally occurring woven textures to amplify the visual response to deformation through Moiré patterns. An undeformed reference frame and a current frame serve as two virtual periodic layers, whose relative deformation produces larger fringe shifts. We demonstrate this mechanism using a commodity camera to observe an unmodified mesh chair back at two deformation scales. Users first steer a 2D cursor by leaning, demonstrating continuous input from coarse backrest deformation reflecting seated upper-body posture. They then observe their reconstructed respiratory waveform and breathing rate, demonstrating physiological sensing through subtle deformation without directly imaging the body. MoiréDeform reduces mean absolute respiratory-rate error from 2.07 to 0.71 breaths/min relative to physical-marker tracking.

CCS Concepts

• Human-centered computing → Ubiquitous and mobile computing systems and tools.

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MobiCom '26, Austin, TX, USA

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ACM ISBN 979-8-4007-2505-0/2026/10

<https://doi.org/10.1145/3795866.3848426>

Keywords

Moiré-based sensing, Respiration monitoring.

ACM Reference Format:

Linzhen Zhu, Zuchen Li, Weihaio Jin, Hyunmin Park, Alanson Sample, and Ke Sun. 2026. Demo: Towards Fine-Grained Deformation Sensing through Naturally Occurring Moiré Patterns in Everyday Woven Surfaces. In *The 32nd Annual International Conference on Mobile Computing and Networking (MobiCom '26)*, October 26–30, 2026, Austin, TX, USA. ACM, New York, NY, USA, 3 pages. <https://doi.org/10.1145/3795866.3848426>

1 Introduction

People deform the compliant surfaces they sit on and lean against. These deformations encode physical interactions, body motion, and physiological activity, making everyday surfaces a potential sensing medium. However, fine-grained deformations from subtle motion and respiration can be difficult to observe without instrumentation. Existing approaches measure respiration through direct body imaging or dedicated hardware [1, 2, 4–6, 12, 13]. This demo explores *whether existing visual structures in everyday woven surfaces can make these deformations easier to observe with a camera*.

Prior systems deliberately explore periodic patterns to amplify subtle motion or deformation [3, 7–11, 15–19]. Building on the same principle, we exploit the naturally occurring periodic structure of woven surfaces. Conventionally, Moiré patterns arise from overlapping two periodic layers with slightly different spatial periods or orientations [19]. We instead use an undeformed reference frame and a current frame of the deformed surface as two virtual layers. Combining these frames reveals deformation-induced Moiré patterns, allowing the surface's existing texture to serve as the sensing pattern without adding physical gratings.

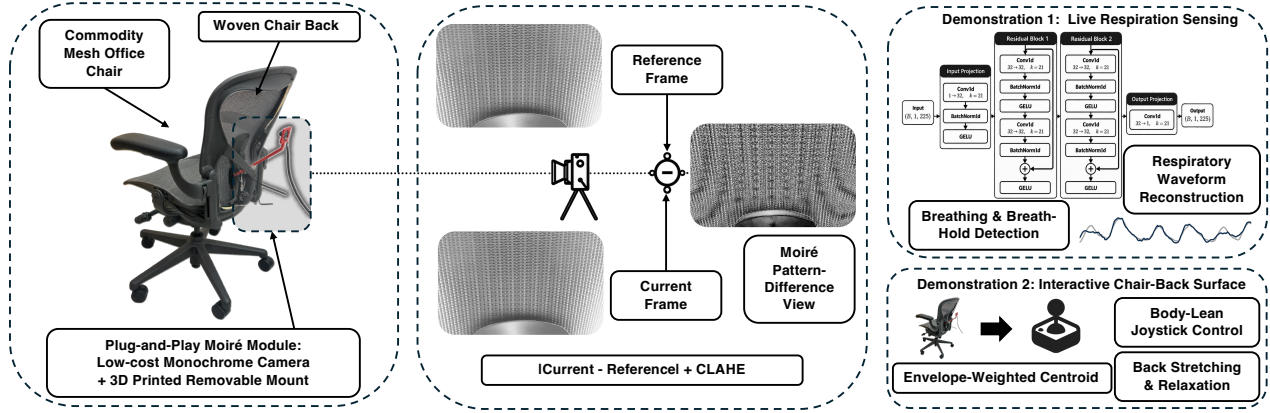


Figure 1: MoiréDeform: a clip-on camera observes an unmodified mesh chair back (user never in frame); empty-chair reference subtraction yields the Moiré pattern-difference view, which drives live respiratory-waveform reconstruction model with breath-hold detection and body-lean joystick interaction.

We demonstrate this idea using an unmodified mesh chair back (Fig. 1). A low-cost camera behind the chair observes the woven surface without viewing the user. MoiréDeform reduces mean absolute respiratory-rate error from 2.07 to 0.71 breaths/min compared with physical-marker tracking. Demo video: <https://tinyurl.com/MoireDeformDemo26>.

2 System Design

Reference-based pattern extraction. MoiréDeform captures an undeformed reference image and treats this reference and each subsequent frame as two virtual periodic layers. Reference-frame subtraction reveals pattern changes caused by surface deformation, using the woven texture already present on the surface without adding physical gratings. The resulting difference frames generate Moiré patterns for deformation sensing.

Coarse deformation sensing. Local loading of a tensioned woven surface produces a broad deformation footprint. We extract the pattern-change envelope within the frequency band of the mesh to suppress noise associated with mesh openings. The weighted centroid of this envelope summarizes the loading location. Normalizing the centroid to the sensing region and subtracting a calibrated neutral position yields a continuous two-dimensional input signal representing seated upper-body posture.

Fine deformation sensing. Respiration induces smaller deformation that may barely shift the whole-field centroid. MoiréDeform therefore estimates subpixel temporal displacement within a central image band. The difference frames are enhanced using contrast-limited adaptive histogram equalization (CLAHE), followed by Eulerian temporal band-pass amplification [14].

FFT-based phase correlation produces a displacement estimate for each frame, and a causal band-pass filter isolates the respiratory component.

Respiratory-waveform reconstruction. A lightweight residual one-dimensional CNN, trained with a correlation loss, maps 15-s windows of the processed signal to respiratory waveforms. During streaming, overlapping predictions are averaged, and each output sample is finalized after approximately 3 s of future context. A peak detector constrained to physiologically plausible breathing intervals estimates respiratory rate from the reconstructed waveform. To reduce model-induced oscillations, MoiréDeform monitors the signal amplitude before learned reconstruction and suppresses learned oscillations when this amplitude falls well below the user’s calibrated breathing level.

3 Preliminary Evaluation

We recorded 10 seated sessions (10 min each session, 100 min total) from five users, against a commercial chest-belt reference (Go Direct GDX-RB). MoiréDeform recovers session-level respiratory rate within 0.72 ± 0.45 bpm of the chest belt across these sessions. Under leave-one-session-out cross-validation, the reconstructed respiratory waveform achieves a correlation of $r = 0.69$ with the chest belt. To isolate the contribution of the Moiré mechanism itself, three of these sessions additionally included a physical marker on the chair back, tracked by the same camera in the same recording. Marker tracking yields rate errors of 2.13, 2.76, and 1.31 bpm (mean 2.07), while the raw Moiré signal yields 0.81, 0.89, and 0.42 bpm (mean 0.71).

4 Demonstration

4.1 Demo Setup

The demonstration uses an unmodified mesh office chair, a clip-on Arducam OV9281 monochrome camera, and a laptop. The camera is mounted behind the chair and records the woven backrest at 1280×800 resolution and 30 FPS while keeping the user outside its field of view. The laptop processes the video and displays the camera view, a lean-controlled cursor, and the reconstructed respiratory waveform and estimated breathing rate. No markers or sensing elements are attached to the woven surface or the user.

4.2 Live Demonstration

The demonstration progresses from visible deformation to interactive input and subtle physiological sensing.

Visualizing deformation. Pressing the woven backrest by hand produces visible changes in the reference-subtracted pattern view, illustrating how the surface's existing texture reveals deformation.

Lean-based interaction. A seated user steers an on-screen cursor by leaning against the backrest and following guided paths. We design an interactive body-lean joystick control game for this stage.

Respiration visualization. The user then sits still and breathes normally while observing the reconstructed respiratory waveform, detected breaths, and running respiratory-rate estimate on the display.

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