PViMat: A Self-Powered Portable and Rollable Large Area Gestural Interface Using Indoor Light

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ABSTRACT
We present PViMat, a portable photovoltaic mat that can recognise six unique useful dynamic hover gestures up to 30 cm above the surface over a large area with more than 97% accuracy. We utilised an off-the-shelf portable and rollable outdoor solar tape and employed it to harvest indoor natural and artificial light energy to trickle charge a LiPo battery for self-powering. We demonstrate a low-power operation technique of continuous charging with DC photocurrent and simultaneous event-driven gesture recognition with AC photocurrent. The PViMat prototype harvests 30 mW in a general living room light level of 300 lux and consumes 0.8 mW per gesture. Lastly, we propose applications of PViMat with its large-area, flexible and rollable form-factors and the gesture set.

Author Keywords
Photovoltaic Mat; Flexible Interactive Surface; Portable Interactive Tabletop; Hand Gesture Recognition; Time Series Machine Learning.

CCS Concepts
•**Human-centered computing** → **Gestural input;**

INTRODUCTION
Rollable interfaces are attractive because they are portable and can unfurl to larger interfaces, e.g. a scroll unfurling to a phone, tablet or a tabletop display [8, 15, 21], interactive surfaces with resize and reshape capabilities [9], a rollable soundboard [3] or the LG roll-up keyboard and TV. Most of such portable and rollable devices are traditionally imagined as displays. The interaction with the rollable interfaces have been mainly tailored to their affordances, e.g. rolling [10, 20] or turning [4] the physical cylinder with interactive use-cases, e.g. navigating in and switching between applications [8]. Rollable interfaces can uniquely enable interaction over large area with their portability. They are not constrained to the installation surface, i.e. table, wall, floor [1, 14, 16, 17, 23] or other large surfaces like ceiling, window and door. Large area interaction allows these surfaces to become smart infrastructures. Camera-based approached can be portable and provide interaction over large area [6, 18, 19] with gestural interaction [5]. However, they can be bulky and difficult to setup and use.

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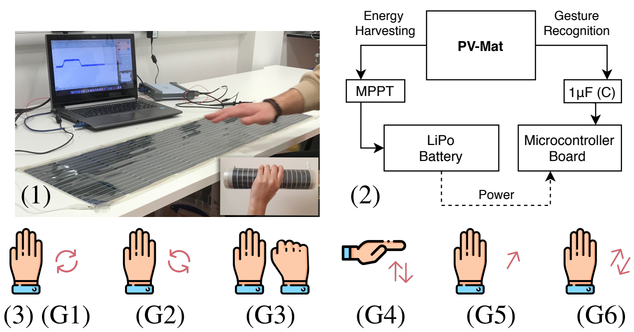

Figure 1. Top: (1) The PV sheet and the recognition signals. (2) The system diagram. Bottom: (3) Defined gestures, (G1) clockwise hand rotation, (G2) counterclockwise rotation, (G3) Fist open/close, (G4) hand up/down, (G5) swipe once, and (G6) swipe continuously.

In contrast, the mat form-factor allows deployments on many large surfaces like table, wall, floor and windows. A mat can be flexible and deployed over curved and foldable surfaces like sofas and other furniture. Project Zanzibar reported a similar rollable surface for tangible interaction with gestural input [22]. They employed wireless RF power transfer and capacitive sensing.

We present, PViMat, a portable and rollable gestural interface which comes with the above mentioned advantages due to its form-factor, and additionally offers self-powered operation, overcoming the limited battery-energy suffered by many portable and mobile devices. It harvests energy from indoor light and can simultaneously detects hand gestures from the shadows. This differentiates PViMat from light-based gestural interfaces with wearables or tablet size devices [11, 12, 13].

PViMAT OVERVIEW
The PViMat consists of a large-area photovoltaic (PV) sheet [1], an energy harvesting circuit board (InfinityPV OPV3W60V) and a microcontroller board (TI MSP430) for gesture recognition. The current prototype setup is shown in Figure 1 (1). The length and width of the PV sheet are 110 cm and 28 cm.

[1] infinityPV https://infinitypv.com/products/opv/solar-tape

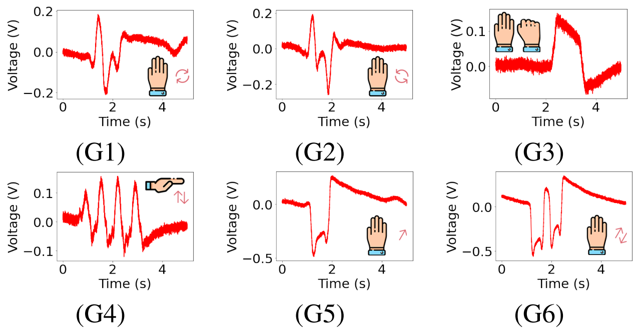

Figure 2. 50Hz filtered time-series signals corresponding to the gestures (G1) clockwise and (G2) counterclockwise rotation hand motions, (G3) making a fist (G3), (G4) raise/lower hand motions, and (G5) singular swipe and (G6) continuous swipe motions.

It can generate up to 12 W at 1 Sun, or back-calculated to 30 mW, i.e. 6 mA at 5V in general living room light level of 300 lux. In PViMat, both energy harvesting and gesture recognition signals are obtained from the *two* electrodes of the PV sheet. Energy harvesting is achieved by the DC component of the photocurrent from the PV sheet which is connected to a maximum power-point tracking (MPPT) module which continuously charges a rechargeable Lithium Polymer (LiPo) battery. The gesture recognition signal appears as AC modulation in the photocurrent and voltage signal from the PV sheet which are filtered by a 1 μF series capacitor and connected to an analog-to-digital (ADC) pin on the microcontroller board. The microcontroller board is powered by the LiPo battery through the load leads on the MPPT board. Low-power operation of the microcontroller is carried out by enabling the sleep-mode with a wake-up gesture and event-driven programming. In the prototype setup shown in Figure 1 (2), the gesture recognition signal is connected to a laptop through a digital oscilloscope, then sampled and processed as done in the microcontroller.

GESTURAL INPUT WITH INDOOR LIGHT

Partially shadowing the PViMat leads to reduced photocurrent and increased internal resistance which is used to develop it as a hand gestural input device using the indoor light. We created a set of six hand gestures shown in Figure 1 (3) (G1–G6) considering potential applications given below. The gestures are (G1 and G2) circular swipe clockwise and counterclockwise, (G3) fist open/close, (G4) move hand up/down, (G5 and G6) linear swipe once and continuously. We explored the gestures with natural hand motions under various light levels between 300 to 800 lux and hover distance up to 30 cm with different positions and orientations of the PViMat, hands and users. Representative gesture recognition signals are shown in Figure 2 with the unique signatures consistently observed under the various conditions given above.

We collected 30 samples for each gesture for one user, and used 76% of them to train various machine learning classifiers and the remaining 24% to test their prediction accuracy. The Random Forest (RF) ensemble learning method [2] produced the best results with an overall accuracy of 97.2% with a training time of 7.8 s. The RF classifier results are shown in Figure 3, which shows that only the clockwise circular hand

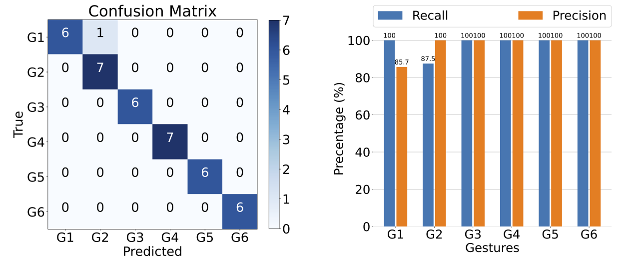

Figure 3. Recognition accuracy across six dynamic hover gestures. G1: clockwise, G2: counterclockwise, G3: fistForm, G4: raiseLower, G5: swipe, G6: swipes.

motion is sometimes mistakenly predicted as the counterclockwise circular hand motion. The recognition accuracy for each gesture is measured using precision and recall [11] and shown in Figure 3. The false-positive and false-negative in detection of clockwise and counterclockwise circular hand motions has led to their reduced precision and recall values. There are no false positives or negatives in detection of other gestures.

We considered features extracted from multilevel 1D Discrete Wavelet Transform (DWT) as well as statistical and entropy-based values. The size of the model was large and needed reduction to implement on a microcontroller. We achieved this by considering four important features, i.e. 25th percentile, mean, root mean square and minimum value, and obtained an overall accuracy of 94.5%. The MSP430 microcontroller draws 0.25 mA supply current in active mode (1 μA in standby) at 3.3 V supply voltage and 1 MHz clock frequency, i.e. 0.8 mW for one gesture (up to 5 sec. duration) with < 0.1 mW consumed by the ADC.

APPLICATIONS

We imagine that PViMat could be used on different indoor surfaces, or even in outdoor environments. For example, a PViMat could be unrolled on top of a coffee or dinner table as a table mat. Users could use fist/multiple-swipes and clockwise/counterclockwise hand gestures to show/hide and navigate through the options menu of a home system like TV. They could then use the raise/lower or swipe gestures to control menu items.

Likewise, PViMat could be imagined on the floor or outdoors as a yoga mat. While doing yoga, a user could perform different gestures for context-aware fitness personalisation and interaction [7]. PViMat could make smart infrastructures when hung from a ceiling as a room divider, on a door or window as a curtain or on a wall as a wallpaper [17, 23].

CONCLUSION AND FUTURE WORK

We presented PViMat, a self-powered portable and rollable gestural interface using indoor light for both energy harvesting and gesture recognition. It detected six unique hand gestures with >97% accuracy over a 110×28 cm area. We presented techniques for continuous low and self power operation and implementation on a microcontroller. Future work includes a formal user evaluation of the PViMat trained for multiple users, and deployments of the proposed indoors and outdoors applications.

REFERENCES

[1] Thomas Augsten, Konstantin Kaefer, René Meusel, Caroline Fetzer, Dorian Kanitz, Thomas Stoff, Torsten Becker, Christian Holz, and Patrick Baudisch. 2010. Multitoe: High-Precision Interaction with Back-Projected Floors Based on High-Resolution Multi-Touch Input. In *Proceedings of the 23nd Annual ACM Symposium on User Interface Software and Technology (UIST '10)*. Association for Computing Machinery, New York, NY, USA, 209–218. DOI: http://dx.doi.org/10.1145/1866029.1866064

[2] Maximilian Christ, Nils Braun, Julius Neuffer, and Andreas W. Kempa-Liehr. 2018. Time Series FeatuRe Extraction on basis of Scalable Hypothesis tests (tsfresh – A Python package). *Neurocomputing* 307 (2018), 72 – 77. DOI: http://dx.doi.org/10.1016/j.neucom.2018.03.067

[3] Vanessa Cobus, Nikolai Bräuer, Armin Pistoor, Hauke Precht, Abdallah El Ali, and Susanne Boll. 2016. Badum Tss! A DIY Paper-Based Interaction to Augment Everyday Situations with Sound Effects. In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction (NordiCHI '16)*. Association for Computing Machinery, New York, NY, USA, Article 94, 6 pages. DOI:http://dx.doi.org/10.1145/2971485.2996729

[4] Antonio Gomes, Lahiru Lakmal Priyadarshana, Aaron Visser, Juan Pablo Carrascal, and Roel Vertegaal. 2018. Magicscroll: A Rollable Display Device with Flexible Screen Real Estate and Gestural Input. In *Proceedings of the 20th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '18)*. Association for Computing Machinery, New York, NY, USA, Article 6, 11 pages. DOI: http://dx.doi.org/10.1145/3229434.3229442

[5] Celeste Groenewald, Craig Anslow, Junayed Islam, Chris Rooney, Peter Passmore, and William Wong. 2016. Understanding 3D Mid-Air Hand Gestures with Interactive Surfaces and Displays: A Systematic Literature Review. In *Proceedings of the 30th International BCS Human Computer Interaction Conference: Fusion! (HCI '16)*. BCS Learning & Development Ltd., Swindon, GBR, Article 43, 13 pages. DOI:http://dx.doi.org/10.14236/ewic/HCI2016.43

[6] Otmar Hilliges, Shahram Izadi, Andrew D. Wilson, Steve Hodges, Armando Garcia-Mendoza, and Andreas Butz. 2009. Interactions in the Air: Adding Further Depth to Interactive Tabletops. In *Proceedings of the 22nd Annual ACM Symposium on User Interface Software and Technology (UIST '09)*. Association for Computing Machinery, New York, NY, USA, 139–148. DOI:http://dx.doi.org/10.1145/1622176.1622203

[7] Kuk Jin Jang, Jungmin Ryoo, Orkan Telhan, and Rahul Mangharam. 2015. Cloud Mat: Context-aware personalization of fitness content. In *2015 IEEE International Conference on Services Computing*. IEEE, 301–308. DOI: http://dx.doi.org/doi:10.1109/SCC.2015.49

[8] Mohammadreza Khalilbeigi, Roman Lissermann, Max Mühlhäuser, and Jürgen Steimle. 2011. Xpaaand: Interaction Techniques for Rollable Displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. Association for Computing Machinery, New York, NY, USA, 2729–2732. DOI: http://dx.doi.org/10.1145/1978942.1979344

[9] Johnny C. Lee, Scott E. Hudson, and Edward Tse. 2008. Foldable Interactive Displays. In *Proceedings of the 21st Annual ACM Symposium on User Interface Software and Technology (UIST '08)*. Association for Computing Machinery, New York, NY, USA, 287–290. DOI: http://dx.doi.org/10.1145/1449715.1449763

[10] Sang-Su Lee, Sohyun Kim, Bopil Jin, Eunji Choi, Boa Kim, Xu Jia, Daeeop Kim, and Kun-pyo Lee. 2010. How Users Manipulate Deformable Displays as Input Devices. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10)*. Association for Computing Machinery, New York, NY, USA, 1647–1656. DOI: http://dx.doi.org/10.1145/1753326.1753572

[11] Yichen Li, Tianxing Li, Ruchir A. Patel, Xing-Dong Yang, and Xia Zhou. 2018. Self-Powered Gesture Recognition with Ambient Light. In *Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology (UIST '18)*. ACM, New York, NY, USA, 595–608. DOI: http://dx.doi.org/10.1145/3242587.3242635

[12] Dong Ma, Guohao Lan, Mahbub Hassan, Wen Hu, Mushfika B. Upama, Ashraf Uddin, and Moustafa Youssef. 2019. SolarGest: Ubiquitous and Battery-Free Gesture Recognition Using Solar Cells. In *The 25th Annual International Conference on Mobile Computing and Networking (MobiCom '19)*. Association for Computing Machinery, New York, NY, USA, Article Article 12, 15 pages. DOI: http://dx.doi.org/10.1145/3300061.3300129

[13] Y. K. Meena, K Seunarine, D. Sahoo, S. Robinson, J. Pearson, A. Pockett, A. Prescott, S. Thomas, K. Lee, and M. Jones. 2020. PV-Tiles: Towards Closely-Coupled Photovoltaic and Digital Materials for Useful, Beautiful and Sustainable Interactive Surfaces. *Proceedings of ACM CHI* 2020 (– 2020), –. DOI: http://dx.doi.org/10.1145/3313831.3376368

[14] Jon Moeller and Andruid Kerne. 2012. ZeroTouch: An optical multi-touch and free-air interaction architecture. *Conference on Human Factors in Computing Systems - Proceedings* (05 2012). DOI: http://dx.doi.org/10.1145/2207676.2208368

[15] Samudrala Nagaraju. 2013. Novel User Interaction Styles with Flexible/Rollable Screens. In *Proceedings of the Biannual Conference of the Italian Chapter of SIGCHI (CHItaly '13)*. Association for Computing Machinery, New York, NY, USA, Article 20, 7 pages. DOI:http://dx.doi.org/10.1145/2499149.2499152

[16] Joseph Paradiso, K. Hsiao, Joshua Strickon, J. Lifton, and A. Adler. 2000. Sensor systems for interactive surfaces. *IBM Systems Journal* 39 (02 2000), 892 – 914. DOI:http://dx.doi.org/10.1147/sj.393.0892

[17] Jun Rekimoto. 2002. SmartSkin: An Infrastructure for Freehand Manipulation on Interactive Surfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '02)*. Association for Computing Machinery, New York, NY, USA, 113–120. DOI: http://dx.doi.org/10.1145/503376.503397

[18] Jun Rekimoto and Nobuyuki Matsushita. 1997. Perceptual surfaces: Towards a human and object sensitive interactive display. In *Workshop on Perceptual User Interfaces (PUI'97)*. 30–32.

[19] Alireza Shirazi, Yomna Abdelrahman, Niels Henze, Stefan Schneegaß, Mohammadreza Khalilbeigi, and Albrecht Schmidt. 2014. Exploiting thermal reflection for interactive systems. *Conference on Human Factors in Computing Systems - Proceedings* (04 2014). DOI: http://dx.doi.org/10.1145/2556288.2557208

[20] David Small and Hiroshi Ishii. 1997. Design of Spatially Aware Graspable Displays. In *CHI '97 Extended Abstracts on Human Factors in Computing Systems (CHI EA '97)*. Association for Computing Machinery, New York, NY, USA, 367–368. DOI: http://dx.doi.org/10.1145/1120212.1120437

[21] Jürgen Steimle and Simon Olberding. 2012. When Mobile Phones Expand into Handheld Tabletops. In *CHI '12 Extended Abstracts on Human Factors in Computing Systems (CHI EA '12)*. Association for Computing Machinery, New York, NY, USA, 271–280. DOI: http://dx.doi.org/10.1145/2212776.2212805

[22] Nicolas Villar, Daniel Cletheroe, Greg Saul, Christian Holz, Tim Regan, Oscar Salandin, Misha Sra, Hui-Shyong Yeo, William Field, and Haiyan Zhang. 2018. Project Zanzibar: A Portable and Flexible Tangible Interaction Platform. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–13. DOI: http://dx.doi.org/10.1145/3173574.3174089

[23] Yang Zhang, Chouchang (Jack) Yang, Scott E. Hudson, Chris Harrison, and Alanson Sample. 2018. Wall++: Room-Scale Interactive and Context-Aware Sensing. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–15. DOI:http://dx.doi.org/10.1145/3173574.3173847