Motion-Powered Gameboy

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Outline

I. Background
II. Energy Solutions
III. Pre-design towards Demand
IV. Experimental Charge and Discharge Circle
V. Conclusion

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I Challenges of IoT

- Features of electronics deployment
  - Large-scale → Too many batteries and wires
  - Scattered → Hard to maintain

I Challenges of Battery-Free HCI

- Advances in hardware and algorithms have improved the energy efficiency of computing exponentially. Most researches and applications of battery-free IoT focus on sensor nodes.

- Human-Computer Interaction (HCI) electronics are generally **screen-centered**, and limited by the high power consumption required by information output. Therefore, they have higher requirements for energy harvesting and management.

- LCD、OLED

- Eink

I Eink display technology

Off-the-shelf commercial Electrophoretic Display (EPD)

- Rearrange pigment particles with electric field
- Display by reflecting ambient light

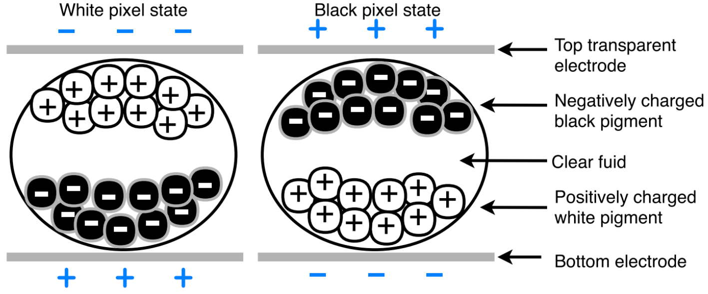


Fig. 2. Basic overview of an electrophoretic display cell.

Tag: months
without replacing battery

Notebook: weeks
without charging

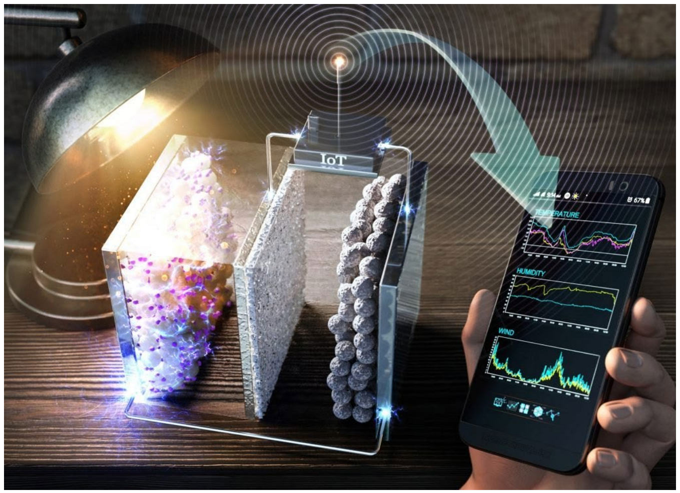
Hashan Roshantha Mendis and Pi-Cheng Hsiu. 2019. Accumulative Display Updating for Intermittent Systems. ACM Trans. Embed. Comput. Syst. 18, 5s, Article 72 (October 2019), 22 pages. https://doi.org/10.1145/3358190

I Challenges of Battery-Free HCI

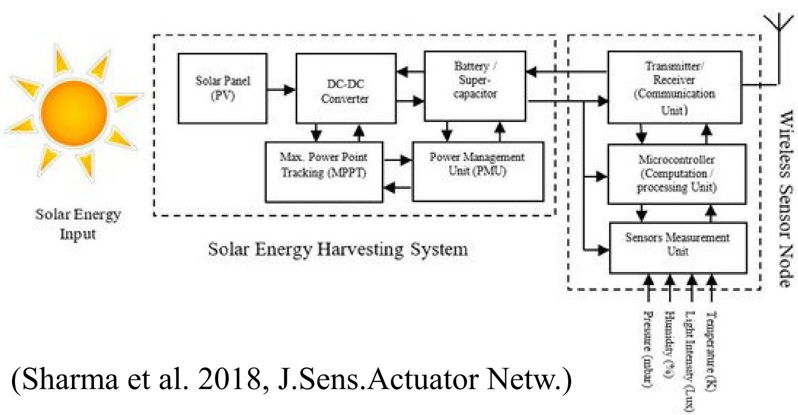
- Another challenge that battery-free HCI devices face is meeting users‘ expectations.
  - For example, upon the user pushes the key *'Enter,'* a *'Hello, world!'* should be displayed as content.

I Energy harvesting

- Solar energy

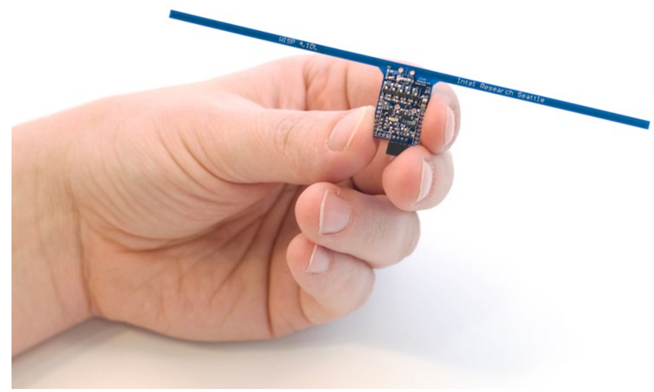


(Kim et al. 2020, EES)

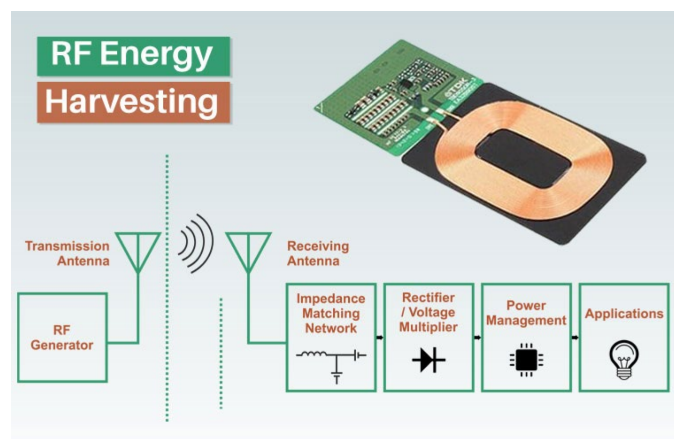


(Sharma et al. 2018, J.Sens.Actuator Netw.)

- RF energy



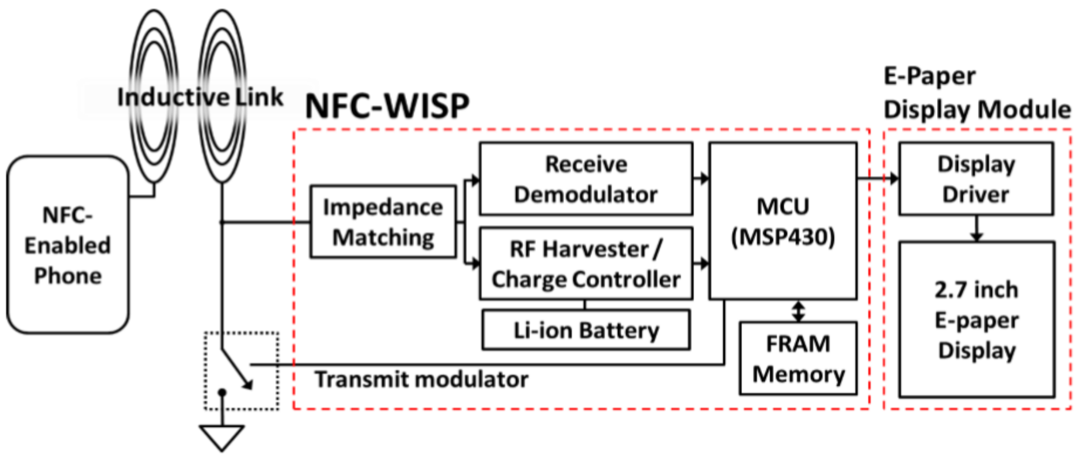
(WiSP)



(WRM483245-15F5-5V-G)

I Related Work

- NFC-WISP Tag



Display tag hardware block diagram.

Display tag without the plastic case

- Harvests energy and communicates with phone by NFC.

A. Dementyev, J. Gummeson, D. Thrasher, A. Parks, D. Ganesan, J. R.Smith, and A. P. Sample, "Wirelessly powered bistable display tags," in *Proceedings of the 2013 ACM international joint conference on Pervasive and ubiquitous computing*. ACM, 2013, pp. 383–386.

I Related Work

- Battery-free Game Boy

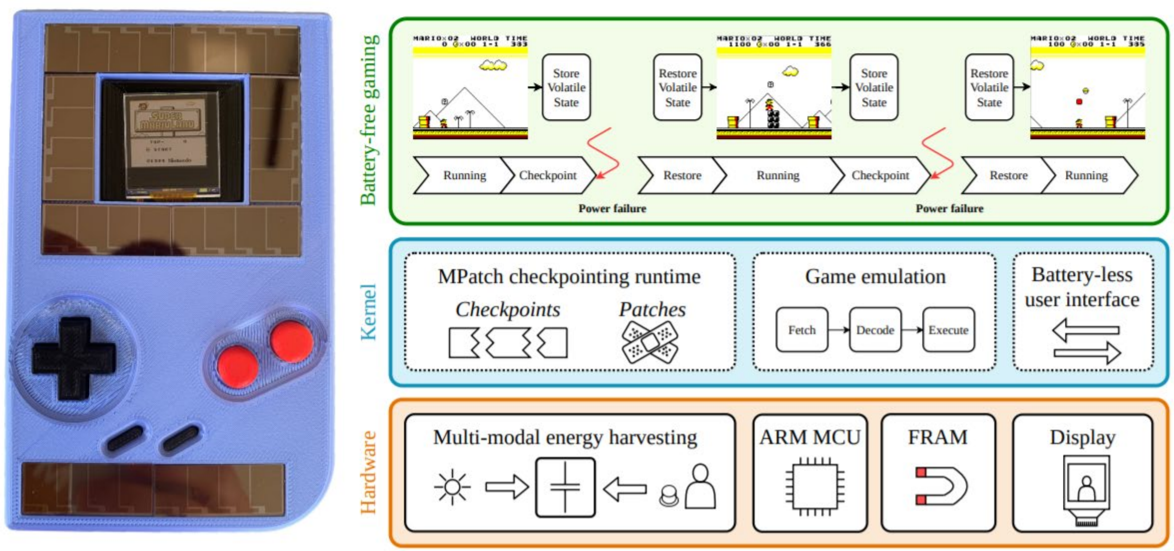


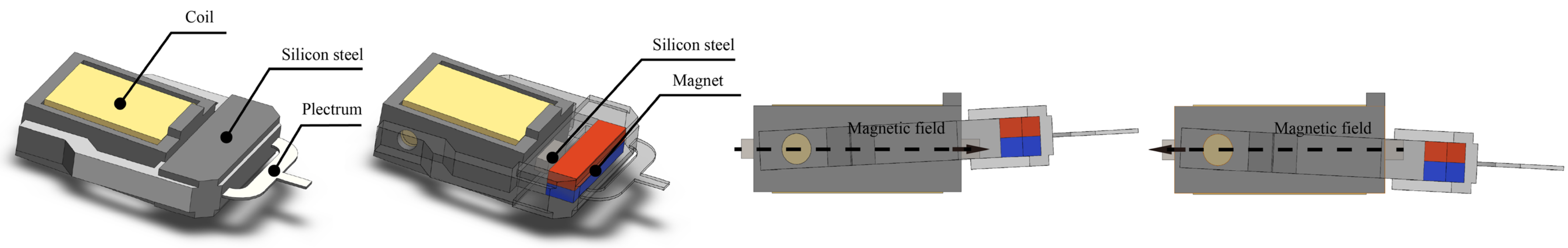
Fig. 3. ENGAGE hardware platform (left) and its internal architecture (right).

- Powered by solar energy and mechanical energy
- MPatch just-in-time checkpointing
- Non-back lit reflective LCD panel

Press button really consistently, then get 10s to play.

J. de Winkel, V. Kortbeek, J. Hester, and P. Pawełczak. Battery-free Game Boy. Proc. ACM Interact. Mob. Wearable Ubiquitous Technol., 4(3), Sept. 2020.

I Bistable Energy Harvester

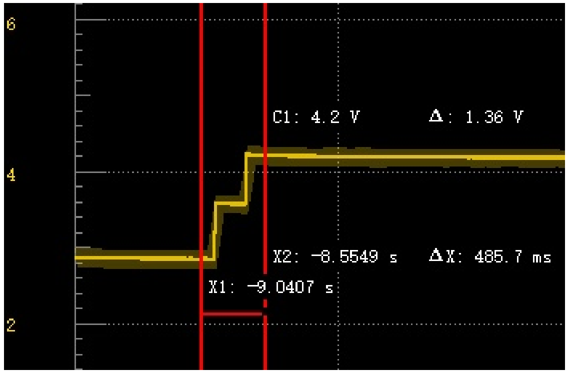


a) PM5600 Bistable energy harverster b) PM5600 Structure with Perspective c) stable position 1 d) stable position 2

Unique feature:

- The amount of energy generated can be predicted by because of potential energy pre-charging;

- Possible to design the Human-Computer Interaction process first and then design the harvester towards the demand.



I Related Work

- Vibration-Powered IoT Platform——ViPSN

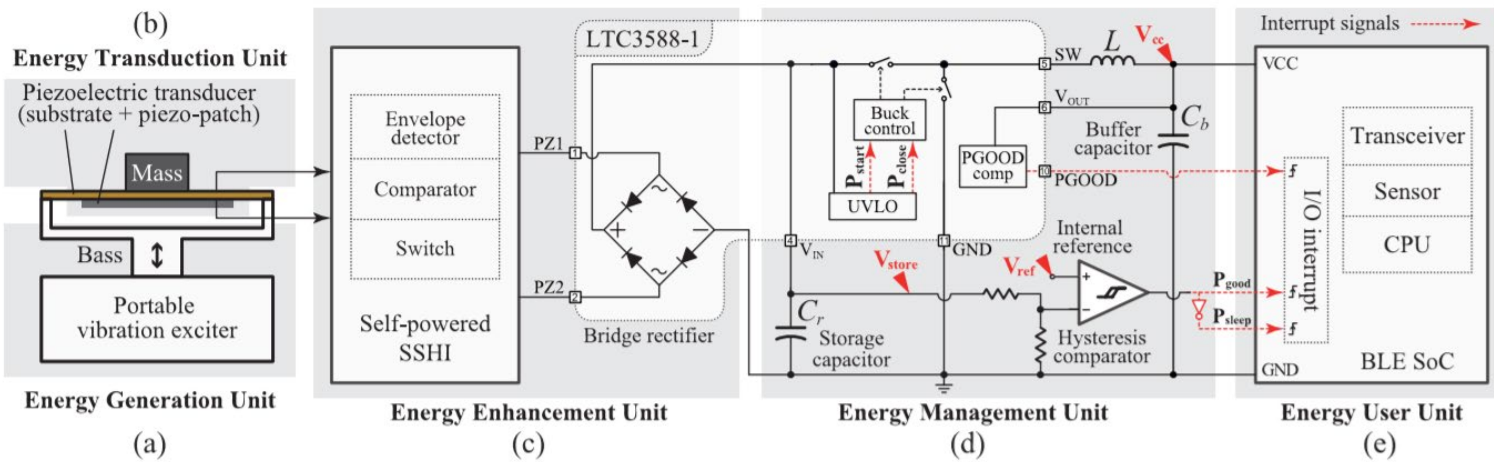


Fig. 2: ViPSN hardware architecture. (a) EGU. (b) ETU. (c) EEU. (d) EMU. (e) EUU.

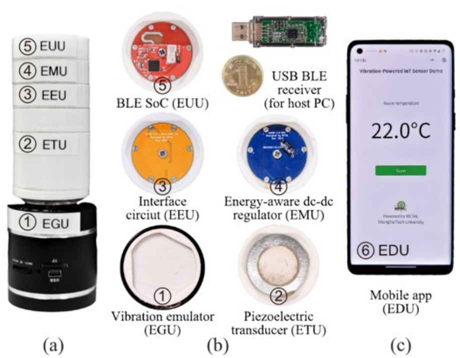
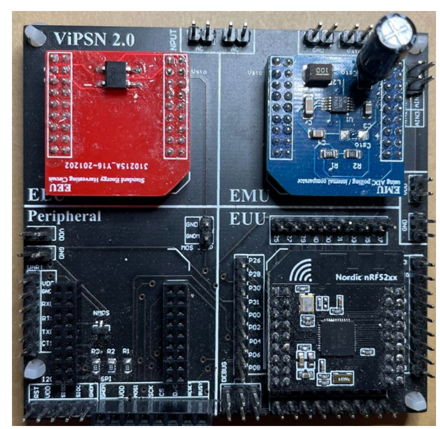
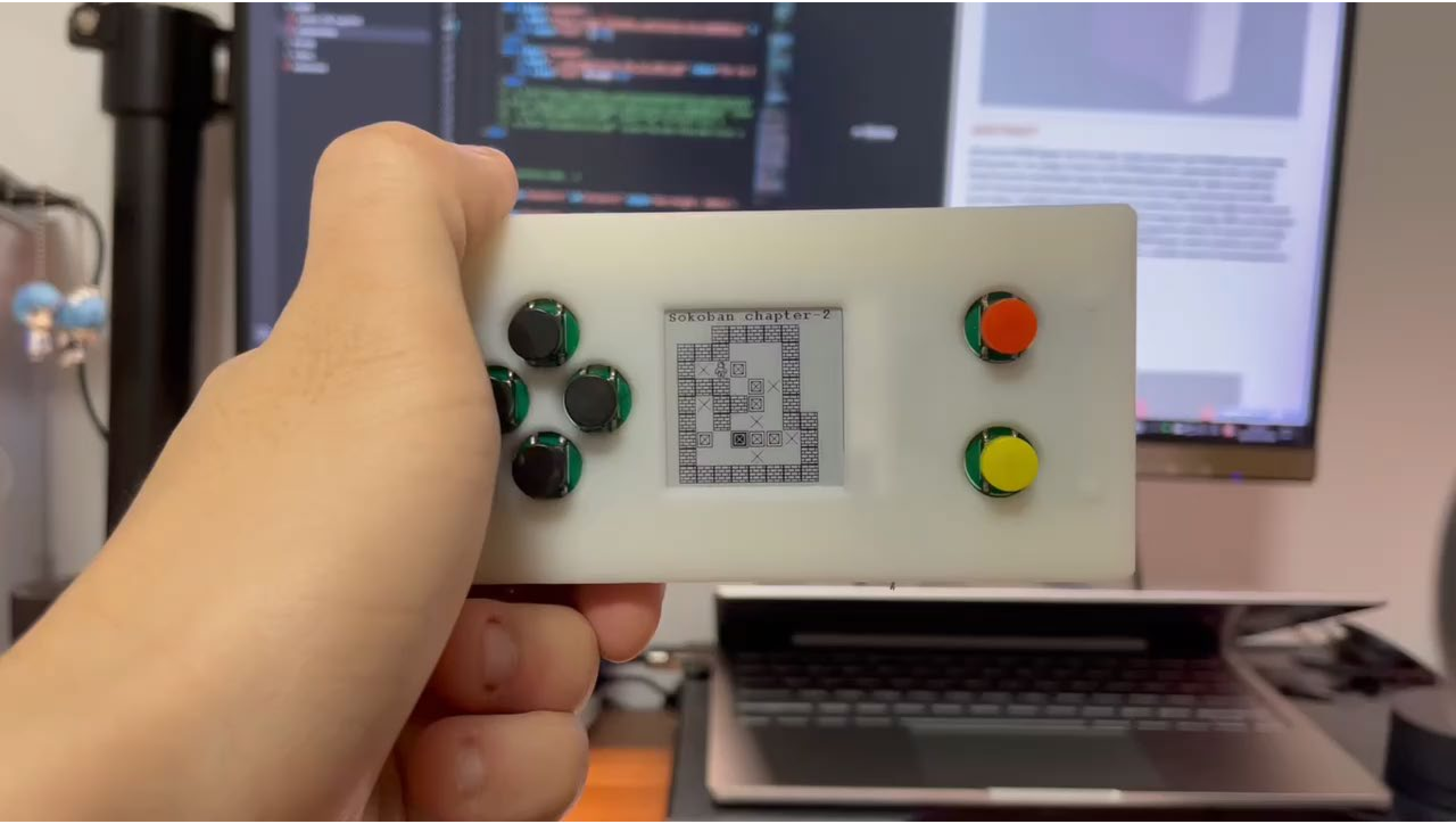


Fig. 1: ViPSN prototype including six modules. (a) System assembly. (b) Module breakdown. (c) Edge demonstration unit.



Xin Li, Li Teng, Hong Tang, Jingying Chen, Haoyu Wang, Yu Liu, Minfan Fu and Junrui Liang, "ViPSN: A Vibration-Powered IoT Platform", *IEEE Internet of Things Journal (Early Access)*, 17 August 2020, ISSN: 2327-4662

Demo



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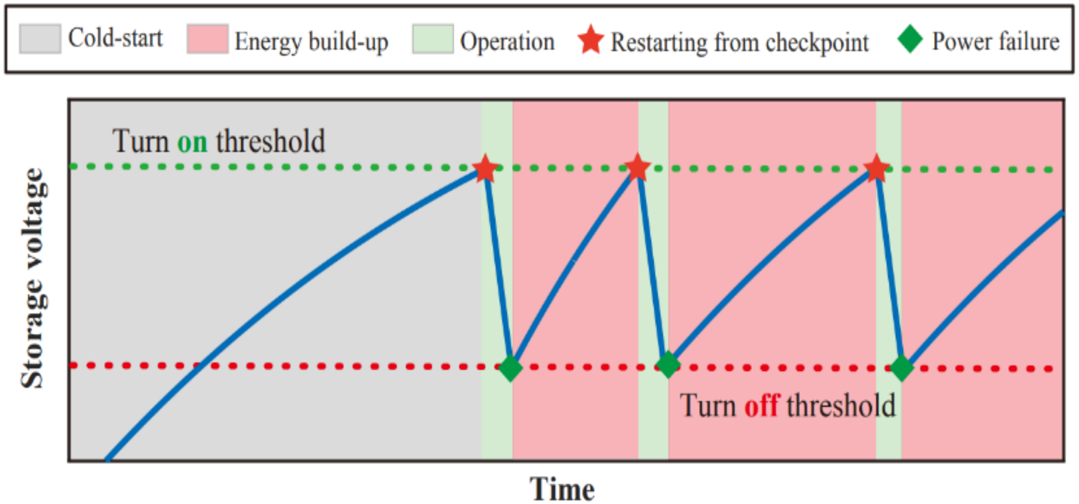
I Intermittent computing



Intermittent execution of VEH-powered IoT systems.[1]

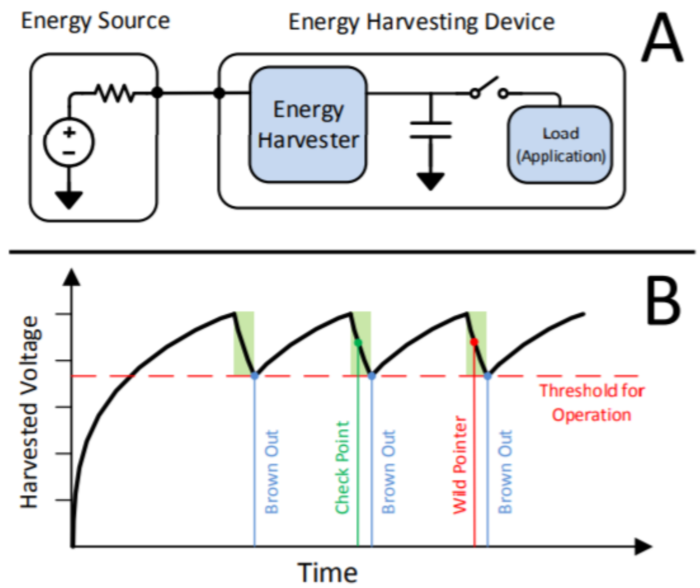
- An intermittent execution proceeds in bursts when energy is available
- Intermittent execution may lead to [2]:
  - Unpredictable control-flow
  - Compromising an application's forward progress
  - Inconsistent memory
  - leaving a device inconsistent with its environment
  - Complicating device-to-device communication

[1]Xin Li, Hong Tang, Yiyao Zhu, Haoyu Wang, and Junrui Liang*, "Power solution of a vibration-powered sensing node," Proceedings of the 9th International Power Electronics and Motion Control Conference, Nanjing, China, May 31-June 3, 2020. (IPEMC - ECCE Asia 2020)
[2]B. Lucia, V. Balaji, A. Colin, K. Maeng, and E. Ruppel, "Intermittent computing: Challenges and opportunities," in 2nd Summit on Advances in Programming Languages (SNAPL 2017). Schloss Dagstuhl-Leibniz- Zentrum fuer Informatik, 2017

II Motion-Powered Gameboy

- Out-of-box Solution:

- Energy-aware checkpointing
- Possible to achieve battery-free by being equipped with strong enough energy storage;
- More than 70 mJ is needed running sample code from manufacturer;
- Suffering when powering the device.



Alexei Colin, Graham Harvey, Brandon Lucia, and Alanson P. Sample. 2016. An Energy-interference-free Hardware-Software Debugger for Intermittent Energy-harvesting Systems. In Proceedings of the Twenty-First International Conference on Architectural Support for Programming Languages and Operating Systems (ASPLOS '16). https://doi.org/10.1145/2872362. 2872409

II Reduce power consumption

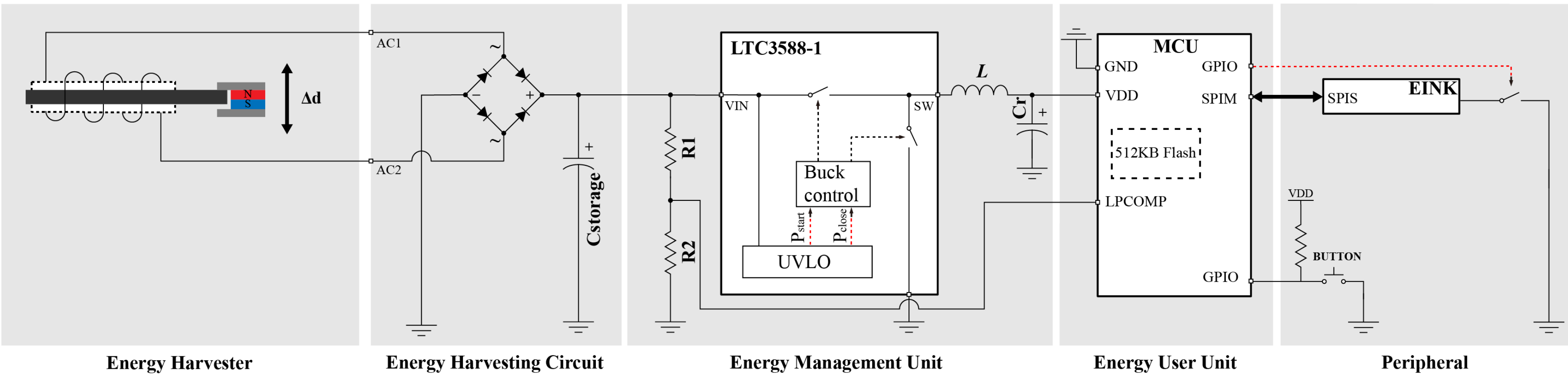
- Generally how to reduce power consumption:
  1. Maximizing time in low-power modes
  2. Switching on peripherals only when needed
  3. Reduce extra control flow.

- What we did:
  1. Interrupts to wake the processor and control program flow
  2. Modification in communication protocol
  3. MOS to switch on/off peripherals
  4. Optimization of state machine and peripheral operation flow

- Two iterations:
  - Flash-based Solution
  - FRAM-based Solution

II Flash-based Solution

- Low-power mode Power Consumption



Low-power mode Power Consumption					
Operation	Unit	Part	Average current (uA)	voltage(V)	Average power (uW)
Sleeping	EMU	Capacitor	0.867	8	6.936
		LTC3588-1	0.081	8	0.648
		Resistors(9MΩ)	0.889	8	7.112
	EUU	Nordic 52832	1.9	3.3	6.27
	Peripheral	NMOS AO-3414	1	3.3	3.3
Operation	**Units**	**Part**	**Average current (uA)**	**voltage(V)**	**Average power (uW)**
LPCOMP	EUU	Nordic 52832	0.5	3.3	1.65
SUM					**25.916**

II Flash-based Solution

- Optimize the operation flow of Eink

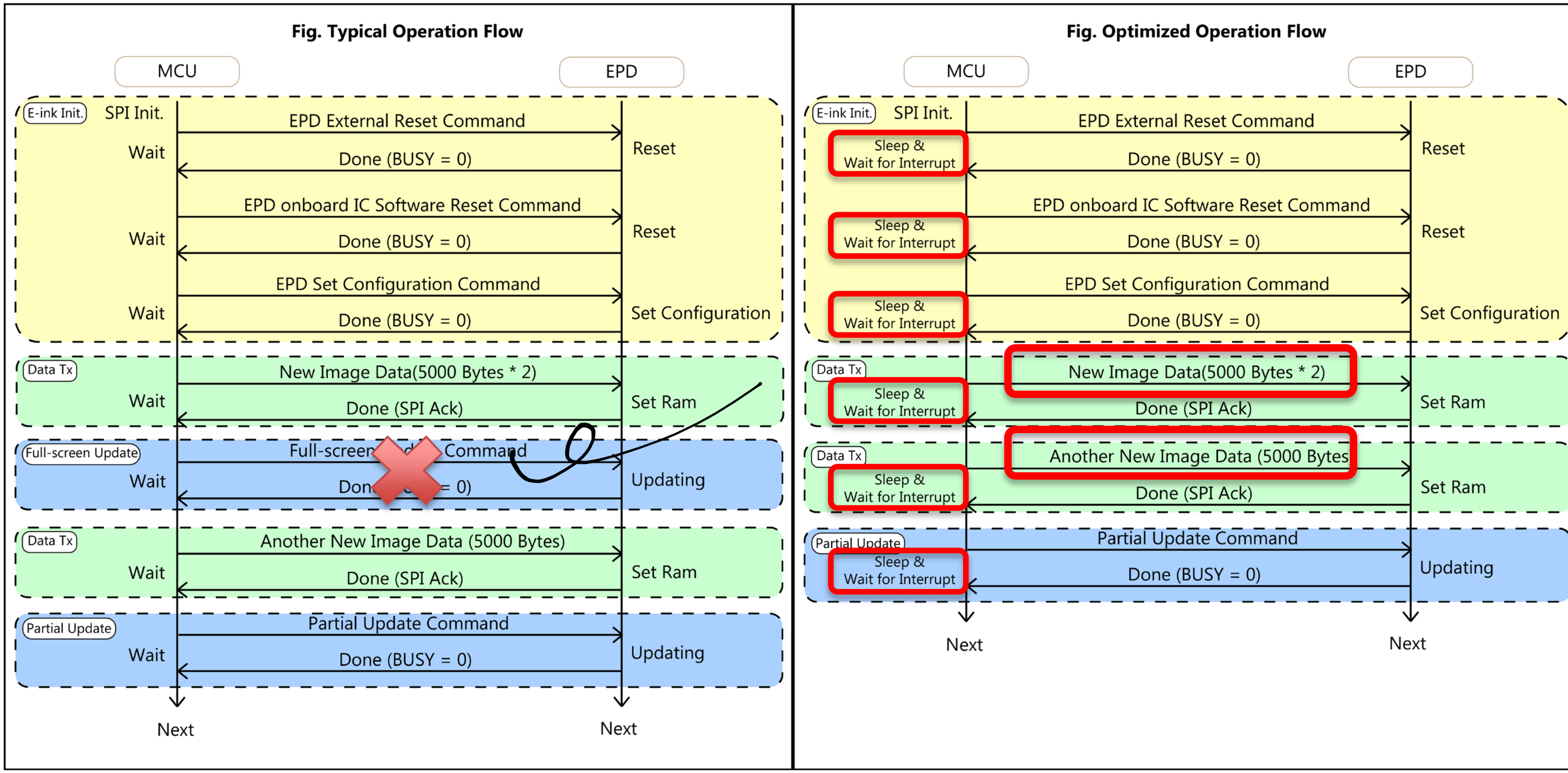


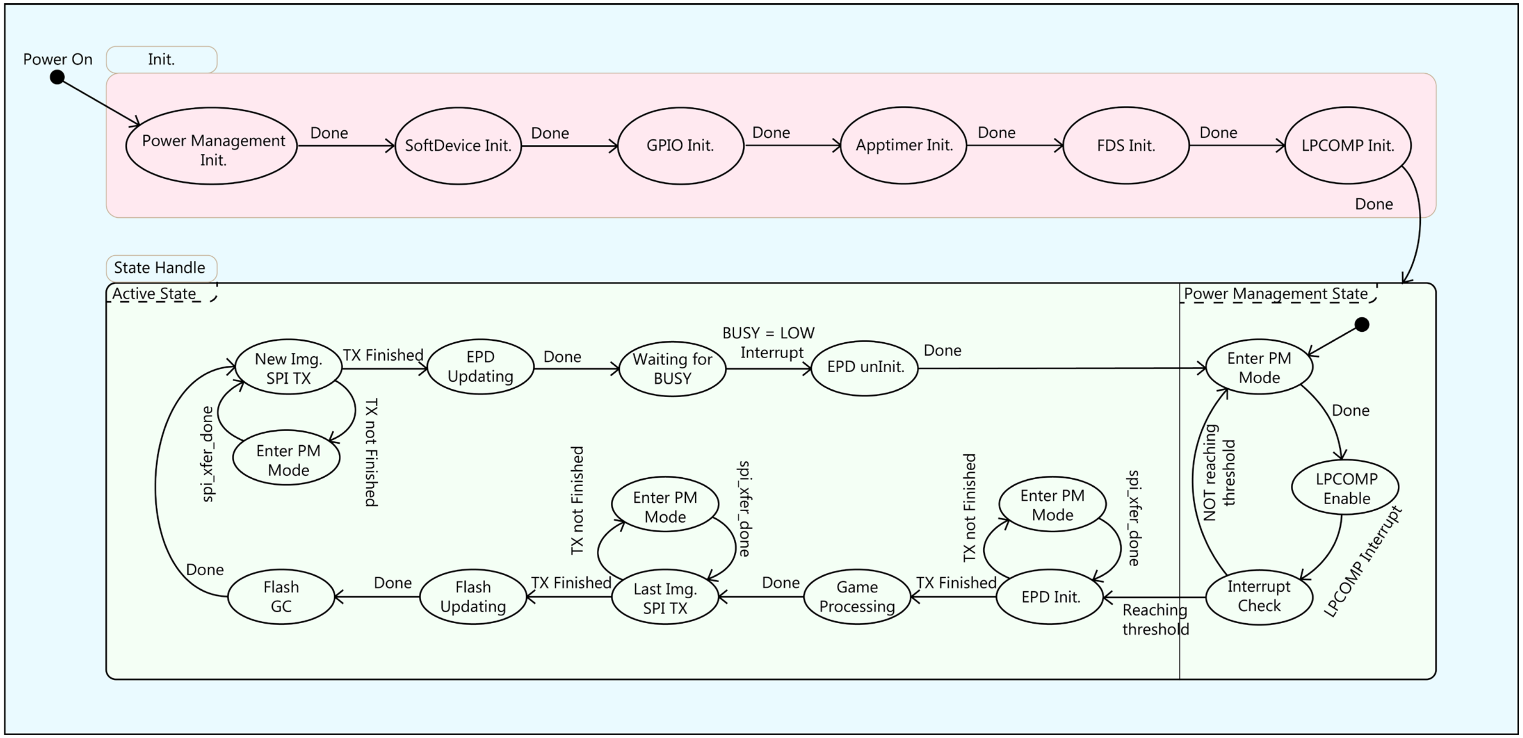
Chart. Energy Consumption under Different Update Modes

Update Mode	Energy Consumption(mJ)	
	Sample Code	Optimized Code
Full-screen Update	71.03	10.507
Partial Update	16.295	3.325

71.03mJ to 3.325mJ!

II Flash-based Solution

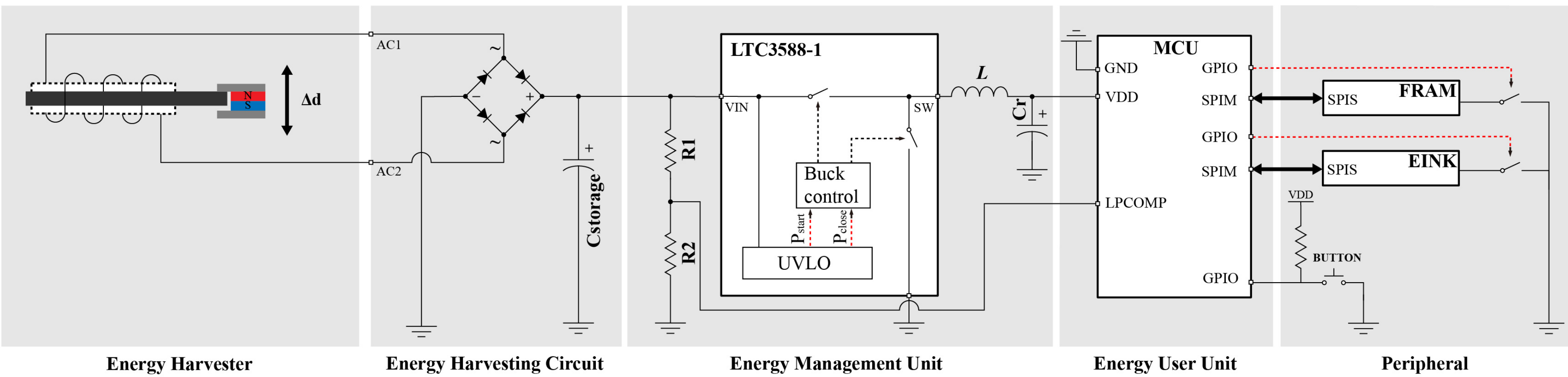
- Optimize the state machine



Operation	Out-of-box solution		Flash Based Solution		Energy Reduced	
	Duration(ms)	Energy(mJ)	Duration(ms)	Energy(mJ)	Amount (mJ)	Percentage
Eink Initialization	34	0.546	50	0.335	0.211	39%
Game Processing	8.5	0.145	8.5	0.145	-	-
Last Img. SPI TX	104	1.494	14	0.105	1.389	93%
Flash Updating	90	1.320	90	1.320	-	-
Flash Garbage Collection	105	1.438	105	1.438	-	-
New Img. SPI TX	55	0.915	7	0.058	0.857	94%
Eink Updating	553	16.295	553	3.325	12.97	80%
SUM	**949.5**	**22.153**	**827.5**	**6.726**	**15.427**	**70%**

II FRAM-based Solution

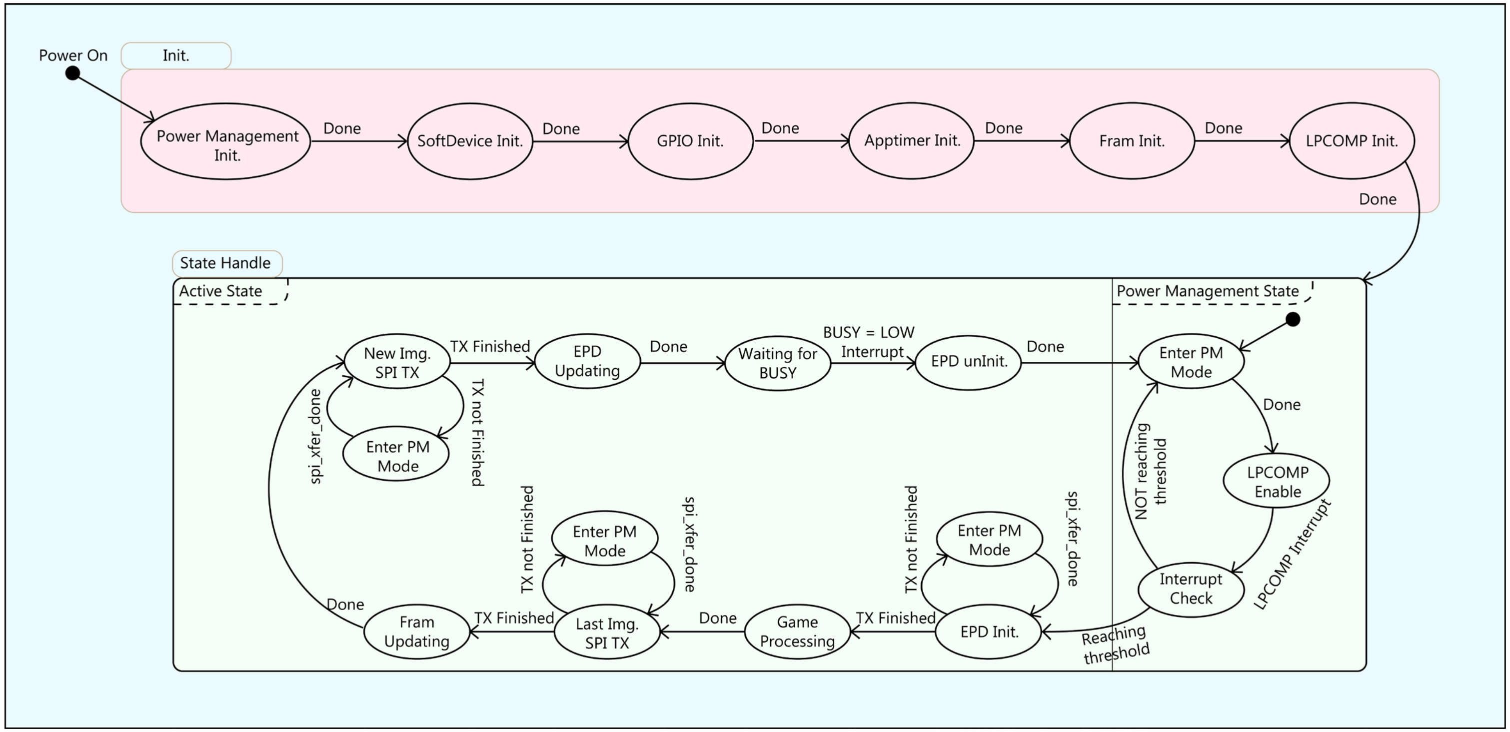
- Low-power mode Power Consumption



Low-power mode Power Consumption					
Operation	**Unit**	**Part**	**Average current (uA)**	**voltage(V)**	**Average power (uW)**
Sleeping	EMU	Capacitor	0.867	8	6.936
		LTC3588-1	0.081	8	0.648
		Resistors(9MΩ)	0.889	8	7.112
	EUU	Nordic 52832	1.9	3.3	6.27
	Peripheral	Eink NMOS	1	3.3	3.3
		Fram NMOS	1	3.3	3.3
Operation	**Units**	**Part**	**Average current (uA)**	**voltage(V)**	**Average power (uW)**
LPCOMP	EUU	Nordic 52832	0.5	3.3	1.65
SUM					**29.216**

II FRAM-based Solution

- Optimize the state machine



Operation	Out-of-box solution		Operation	FRAM Based Solution		Energy Reduced	
	Duration(ms)	Energy(mJ)		Duration(ms)	Energy(mJ)	Amount (mJ)	Percentage
Eink Initialization	34	0.546	Eink Initialization	50	0.335	0.211	39%
Game Processing	8.5	0.145	Game Processing	8.5	0.145	-	-
Last Img. SPI TX	104	1.494	Last Img. SPI TX	14	0.105	1.389	93%
Flash Updating	90	1.320	FRAM Operation	51	0.542	2.216	80%
Flash Garbage Collection	105	1.438					
New Img. SPI TX	55	0.915	New Img. SPI TX	7	0.058	0.857	94%
Eink Updating	553	16.295	Eink Updating	553	3.325	12.97	80%
SUM	**949.5**	**22.153**	**SUM**	**683.5**	**4.510**	**17.643**	**80%**

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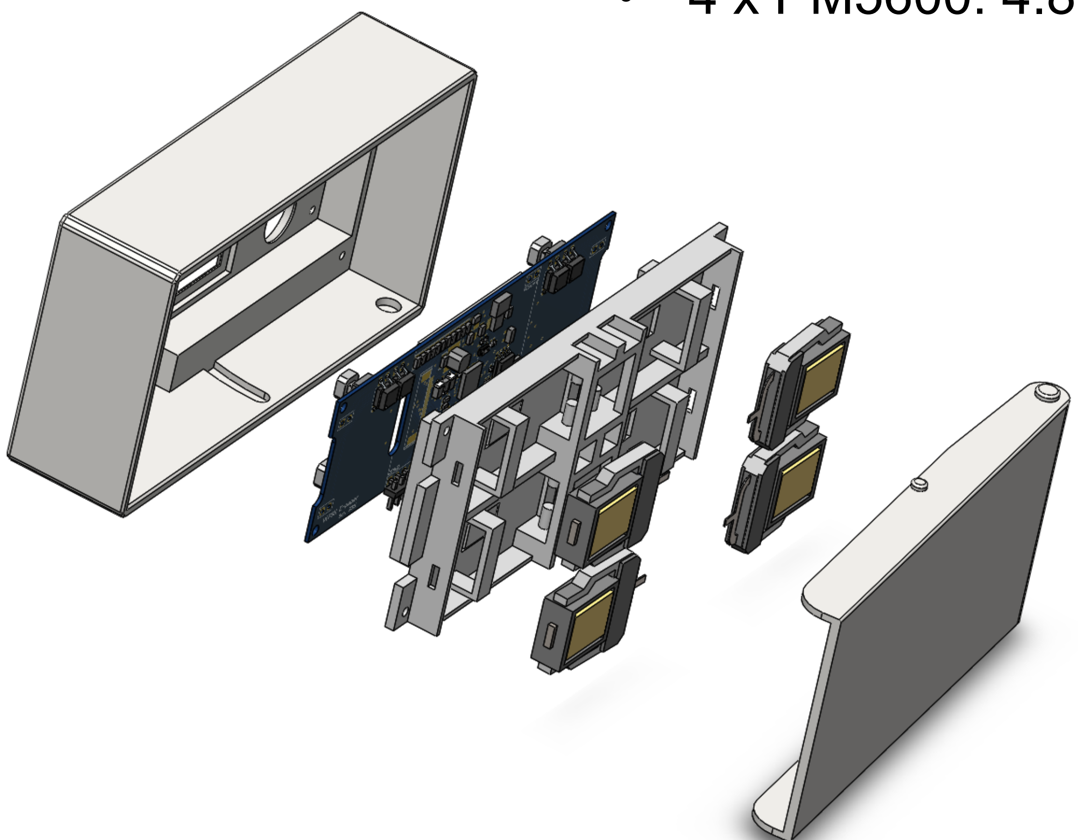
IV Pre-design towards Demand

- 4 x PM5600: 4.8mJ per click



- Lever structure: maximum 36N to trigger

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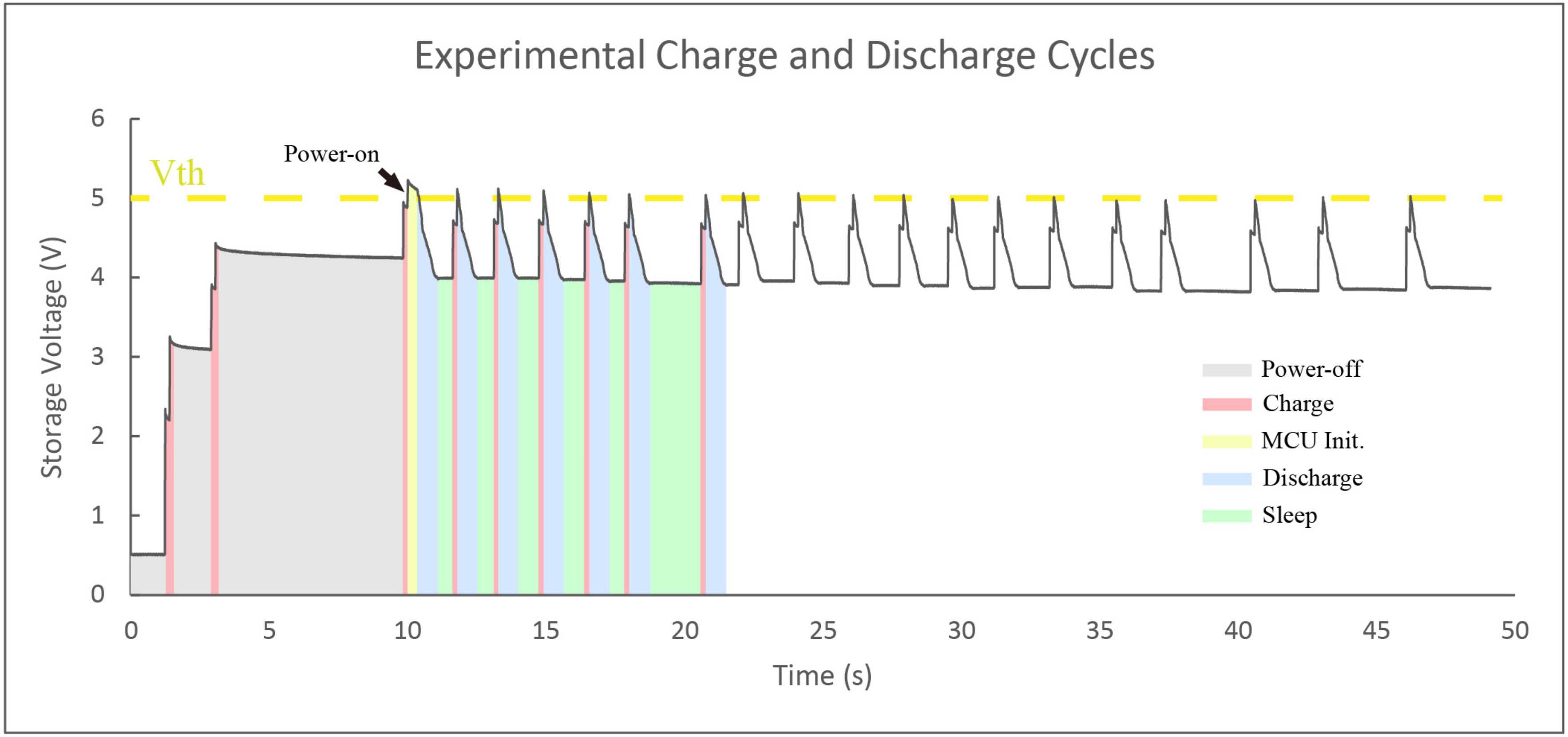
IV Experiments Work Cycle



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V Conclusion

- Achievements and contributions：
  - Presented the first robust, motion-powered and user-friendly personal mobile gaming device
  - Designed and built up hardware and software platform for developing new games
  - Provided a methodology to design the battery-free HCI device that pre-design the harvester towards energy demand of application

Thank you!

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