



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

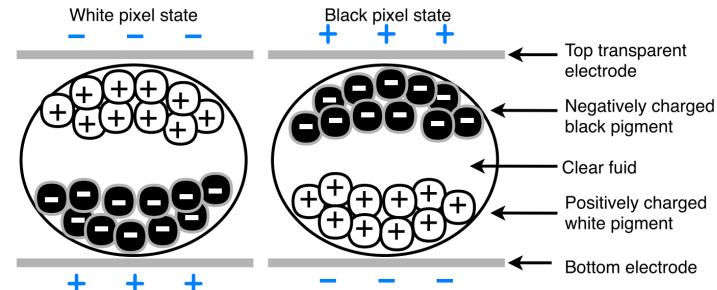


Fig. 2. Basic overview of an electrophoretic display cell.



Tag: months
without replacing battery



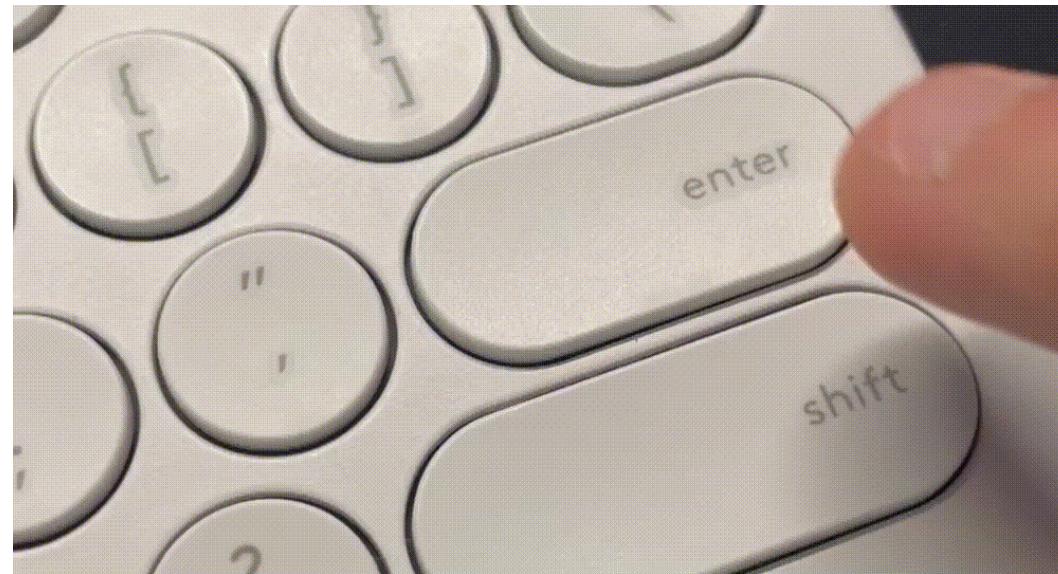
Notebook: weeks
without charging



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.

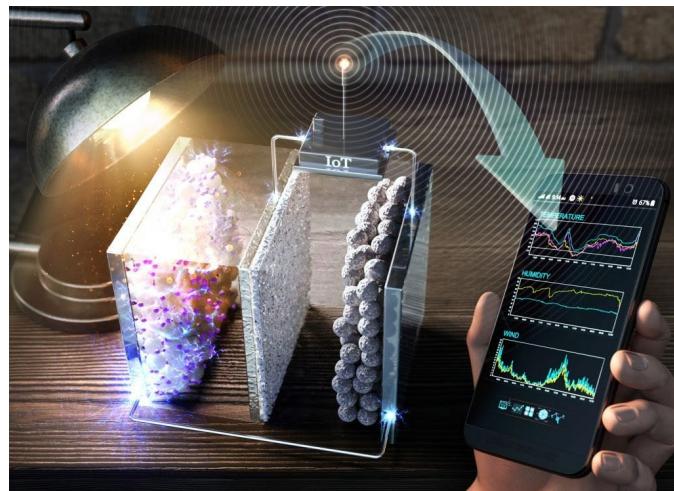


I

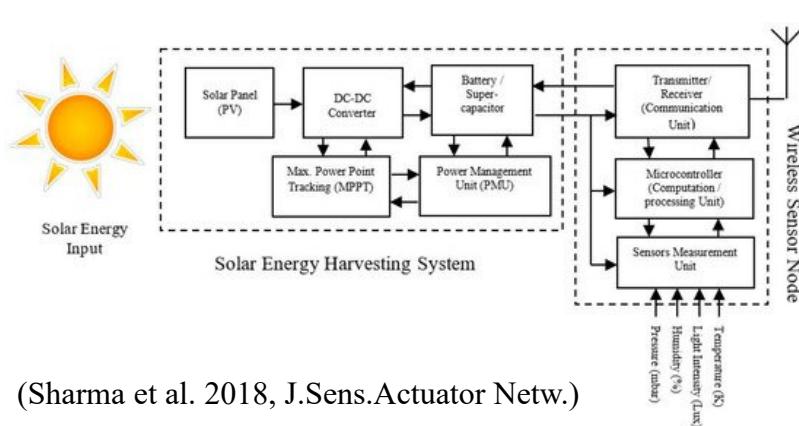
Energy harvesting



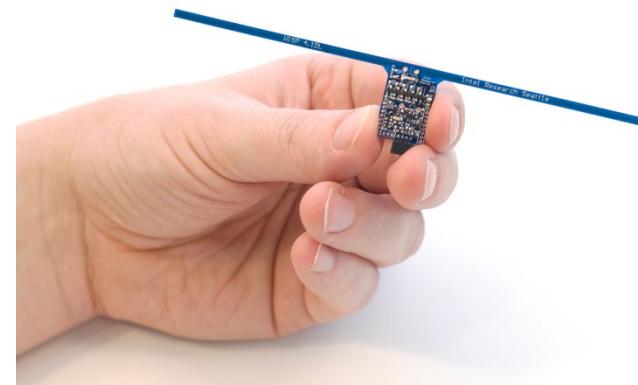
- Solar energy
- RF energy



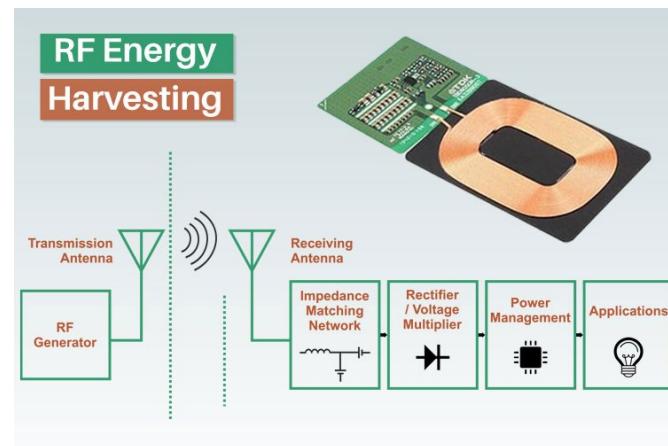
(Kim et al. 2020, EES)



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



(WiSP)

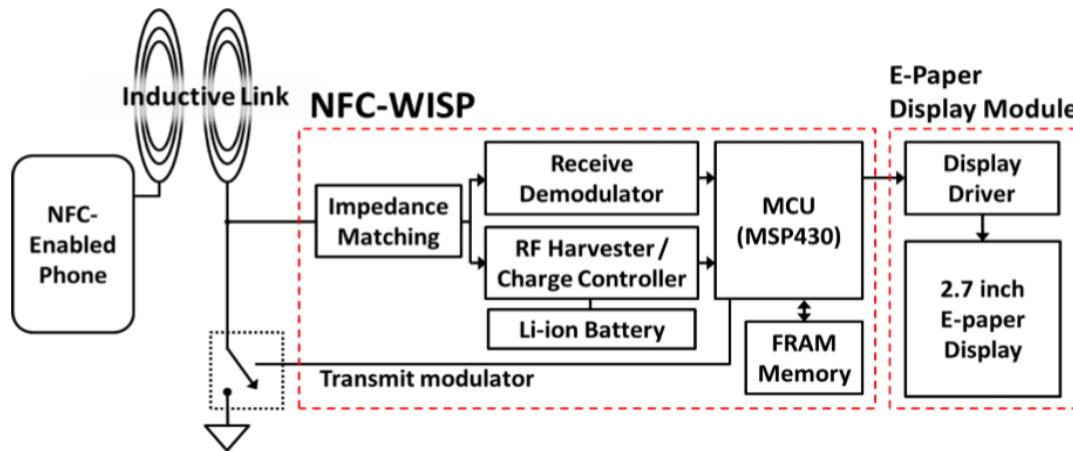


(WRM483245-15F5-5V-G)



I Related Work

- NFC-WISP Tag



Display tag hardware block diagram.

- Harvests energy and communicates with phone by NFC.



Display tag without the plastic case



I Related Work

- Battery-free Game Boy

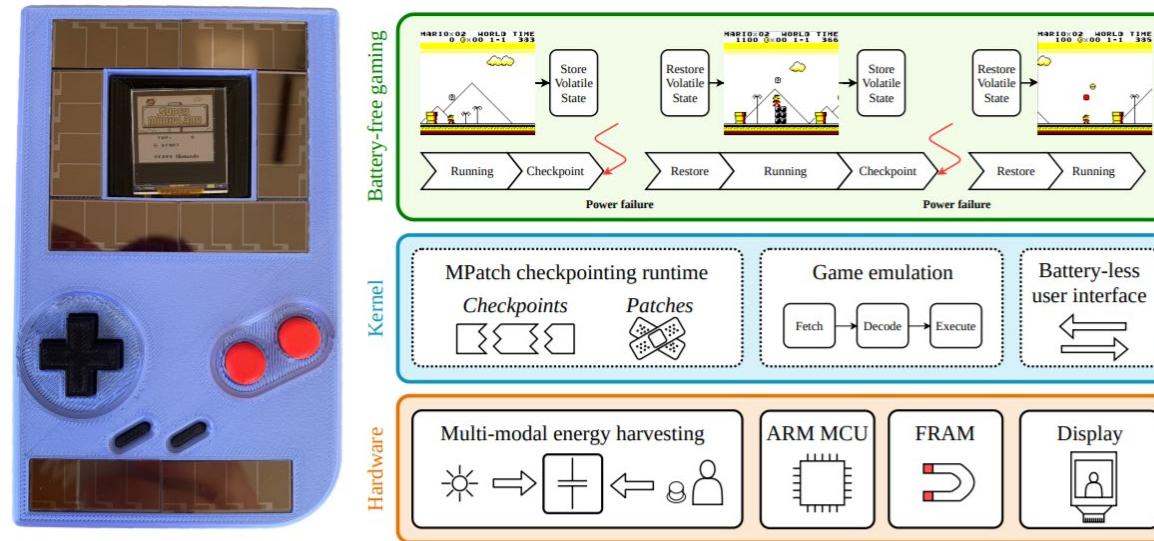


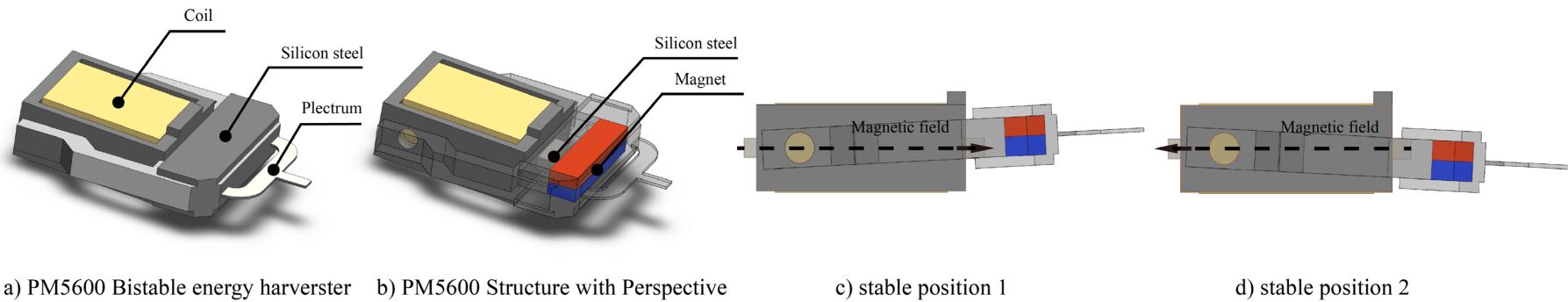
Fig. 3. ENGAGE hardware platform (left) and its internal architecture (right).

- 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.

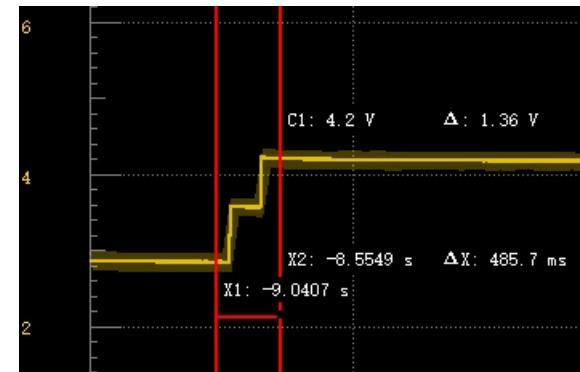
I

Bistable Energy Harvester



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

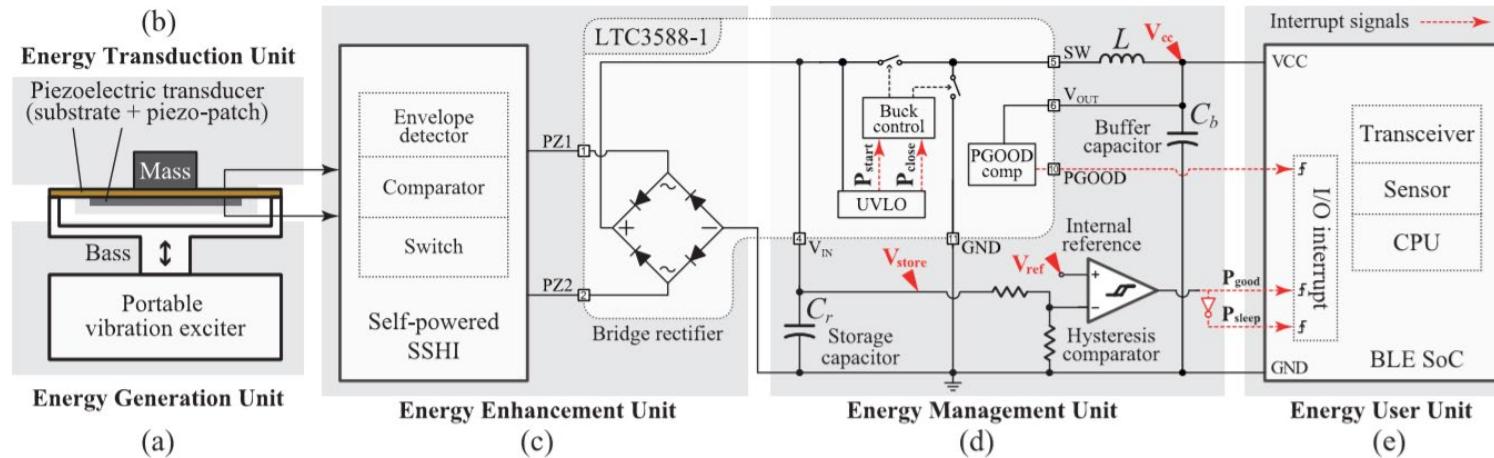


Fig. 2: ViPSN hardware architecture. (a) EGU. (b) ETU. (c) EEU. (d) EMU. (e) EUU.

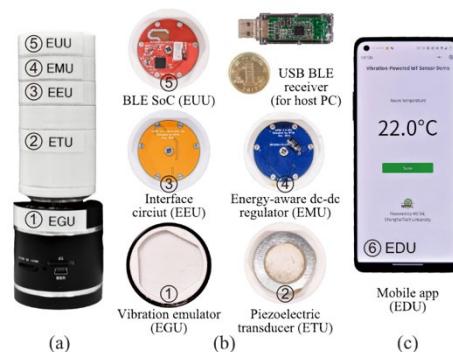
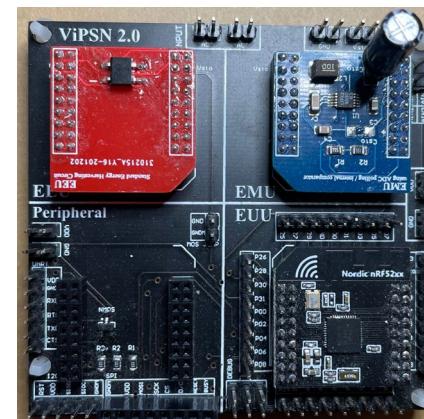
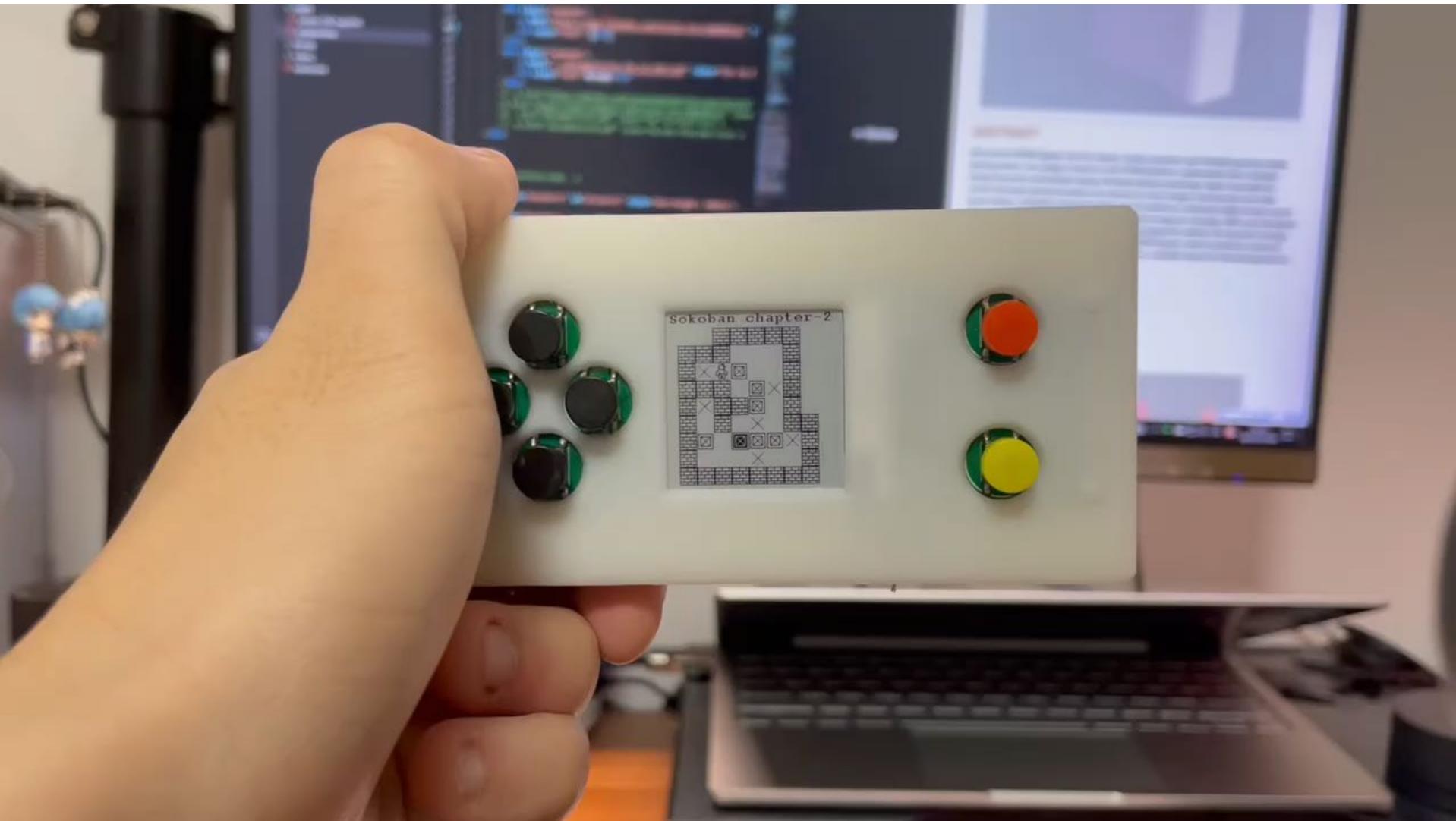


Fig. 1: ViPSN prototype including six modules. (a) System assembly. (b) Module breakdown. (c) Edge demonstration unit.





Demo



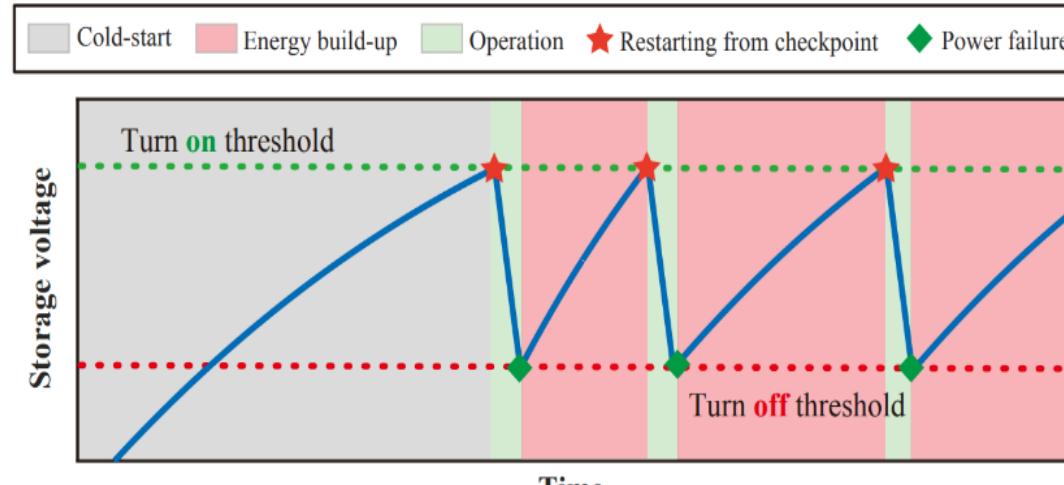


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Intermittent computing



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

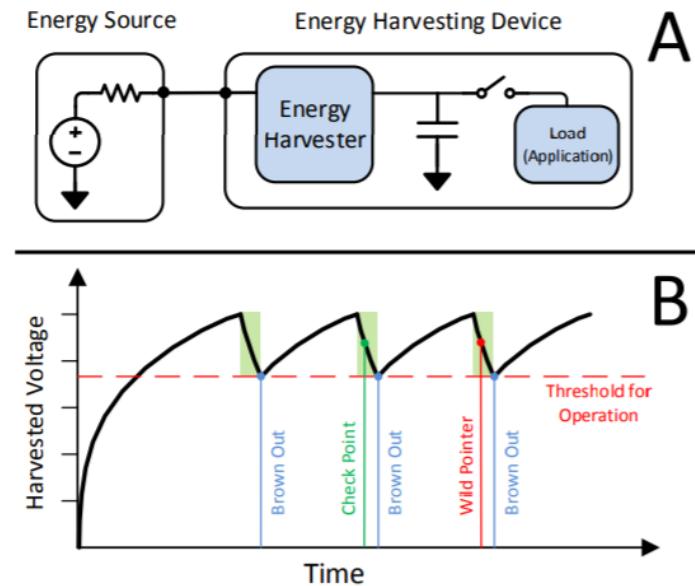
[1]Xin Li, Hong Tang, Yiyao Zhu, Haoyu Wang, and Junrui Liang*, “Power solution of a vibration-powered sensing node,” Proceedings of the 9th International Power Electronics and Motion Control Conference, Nanjing, China, May 31-June 3, 2020. (IPEMC - ECCE Asia 2020)

[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.



Reduce power consumption

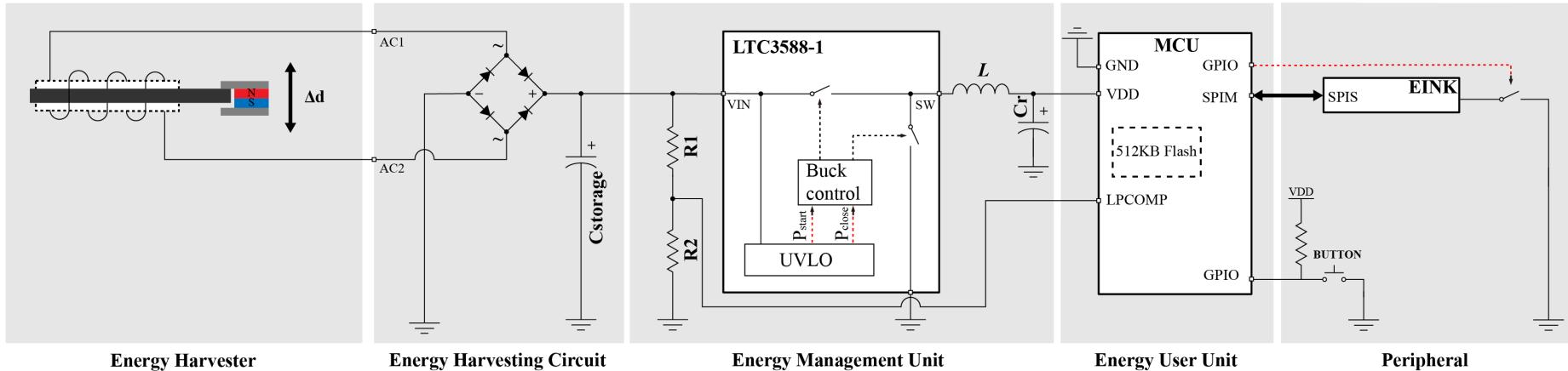


- Generally how to reduce power consumption:
 1. Maximizing time in low-power modes
 2. Switching on peripherals only when needed
 3. Reduce extra control flow.
- What we did:
 1. Interrupts to wake the processor and control program flow
 2. Modification in communication protocol
 3. MOS to switch on/off peripherals
 4. Optimization of state machine and peripheral operation flow
- Two iterations:
 - Flash-based Solution
 - FRAM-based Solution

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

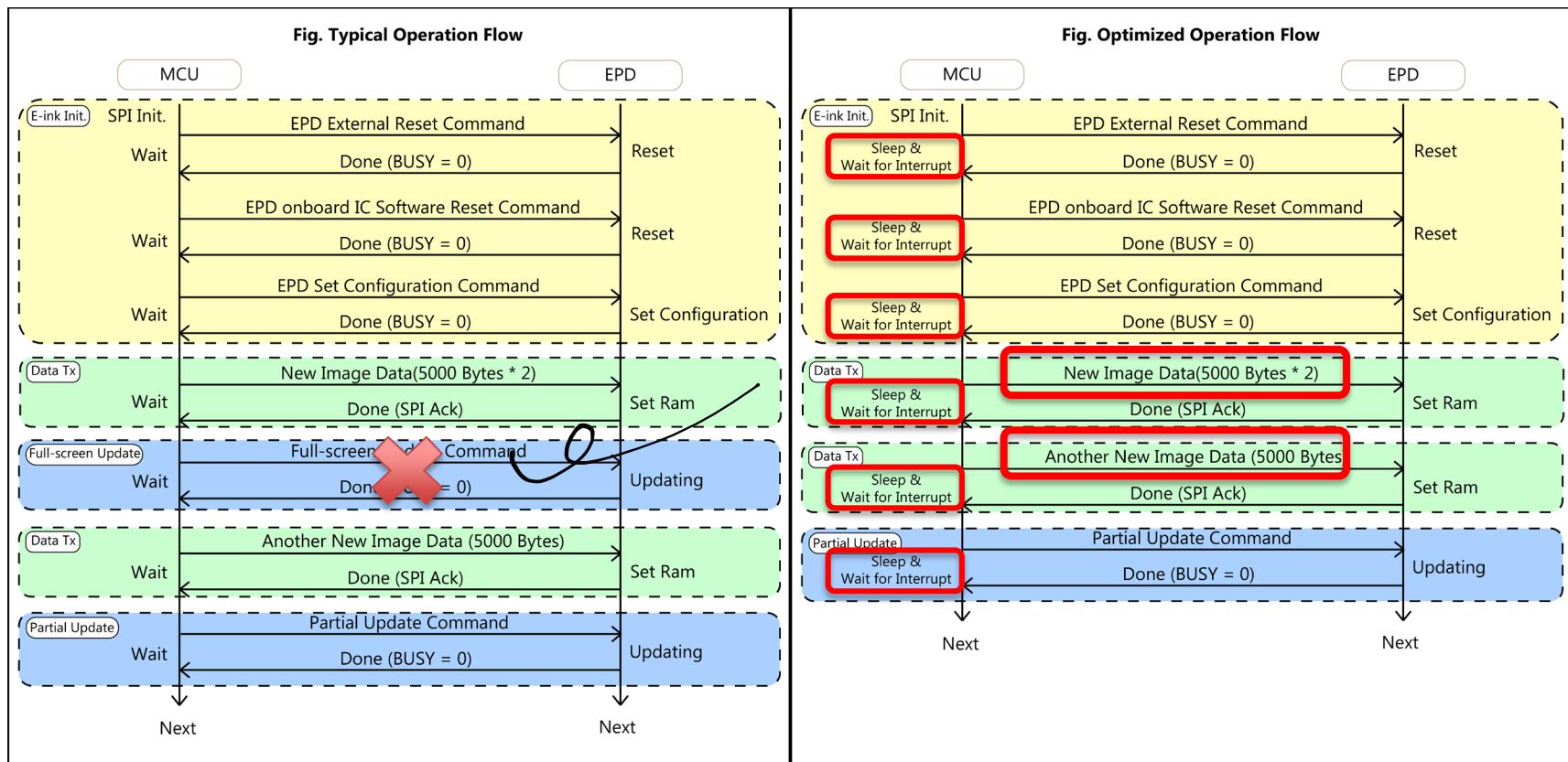


Chart. Energy Consumption under Different Update Modes

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

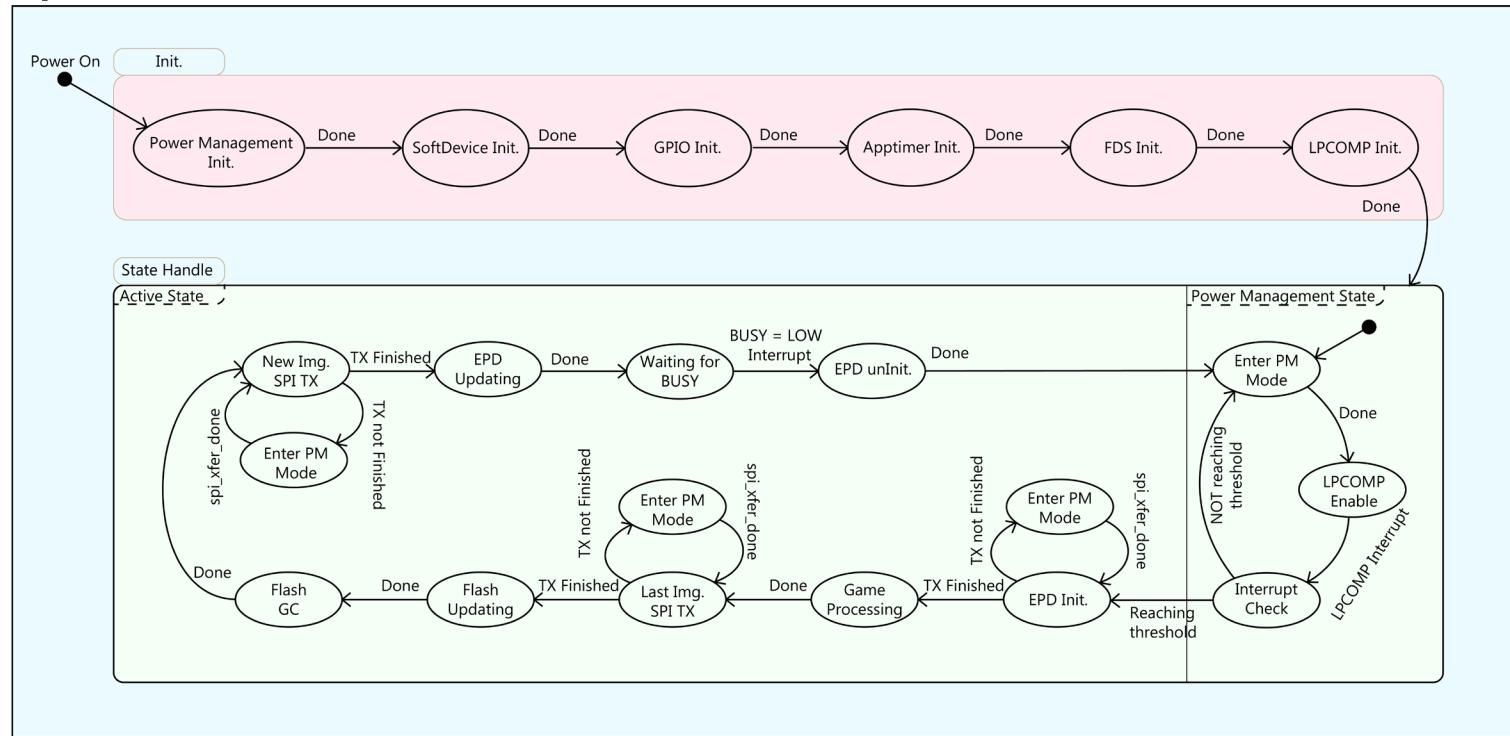
71.03mJ to 3.325mJ!



II

Flash-based Solution

- Optimize the state machine



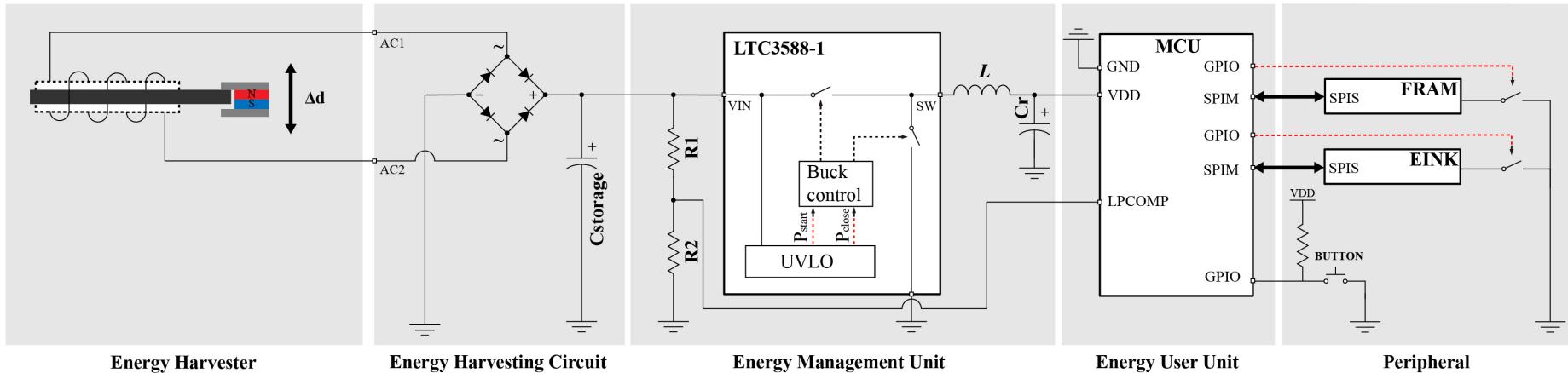
Operation	Out-of-box solution		Flash Based Solution		Energy Reduced	
	Duration(ms)	Energy(mJ)	Duration(ms)	Energy(mJ)	Amount (mJ)	Percentage
Eink Initialization	34	0.546	50	0.335	0.211	39%
Game Processing	8.5	0.145	8.5	0.145	-	-
Last Img. SPI TX	104	1.494	14	0.105	1.389	93%
Flash Updating	90	1.320	90	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



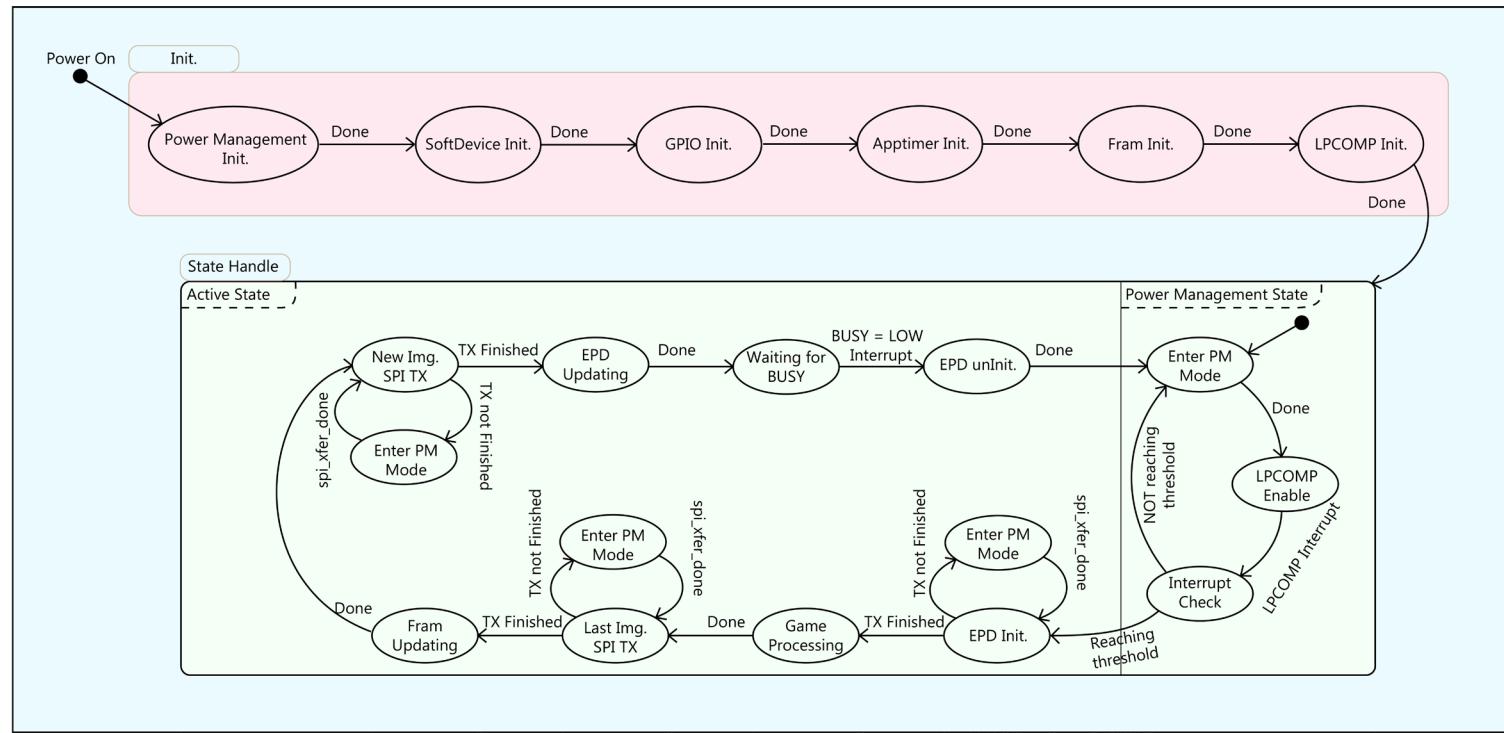
Low-power mode Power Consumption					
Operation	Unit	Part	Average current (uA)	voltage(V)	Average power (uW)
Sleeping	EMU	Capacitor	0.867	8	6.936
		LTC3588-1	0.081	8	0.648
		Resistors(9MΩ)	0.889	8	7.112
	EUU	Nordic 52832	1.9	3.3	6.27
		Eink NMOS	1	3.3	3.3
	Peripheral	Fram NMOS	1	3.3	3.3
Operation	Units	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	34	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	7	0.058	0.857	94%
New Img. SPI TX	55	0.915	Eink Updating	553	3.325	12.97	80%
Eink Updating	553	16.295	SUM	667.5	4.510	17.643	80%
SUM	949.5	22.153					



Outline

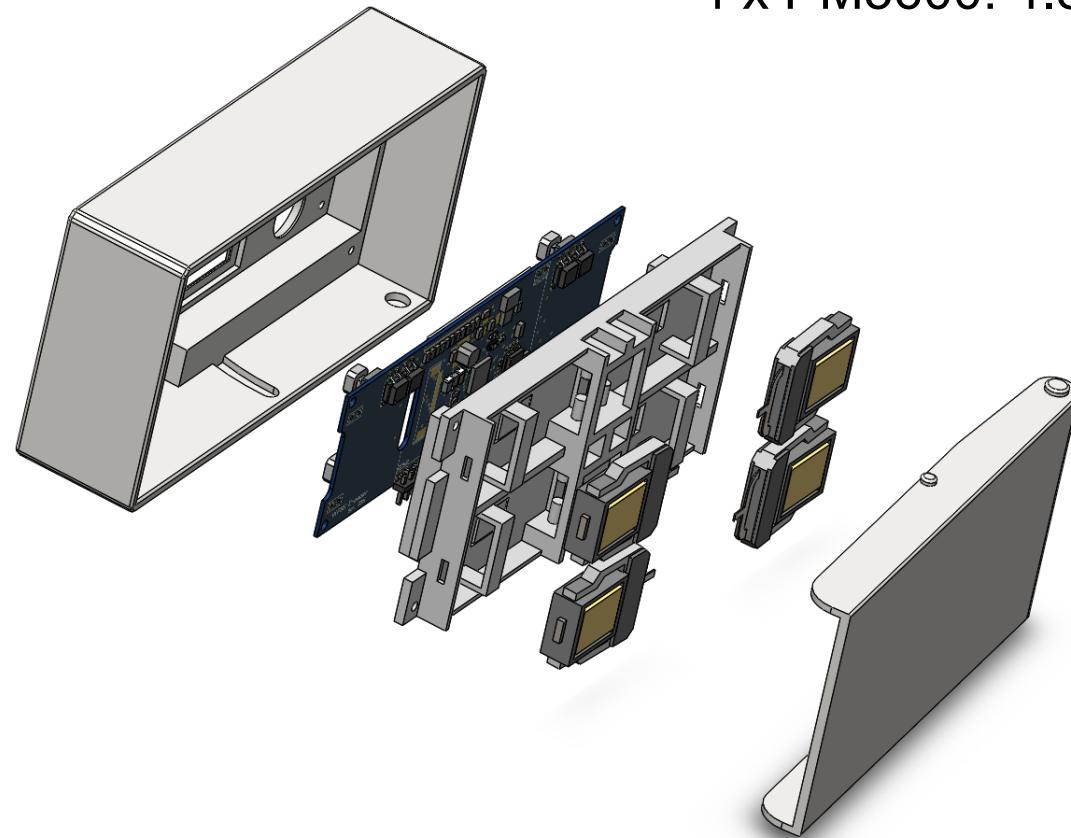
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Pre-design towards Demand



- 4 x PM5600: 4.8mJ per click



- Lever structure: maximum 36N to trigger



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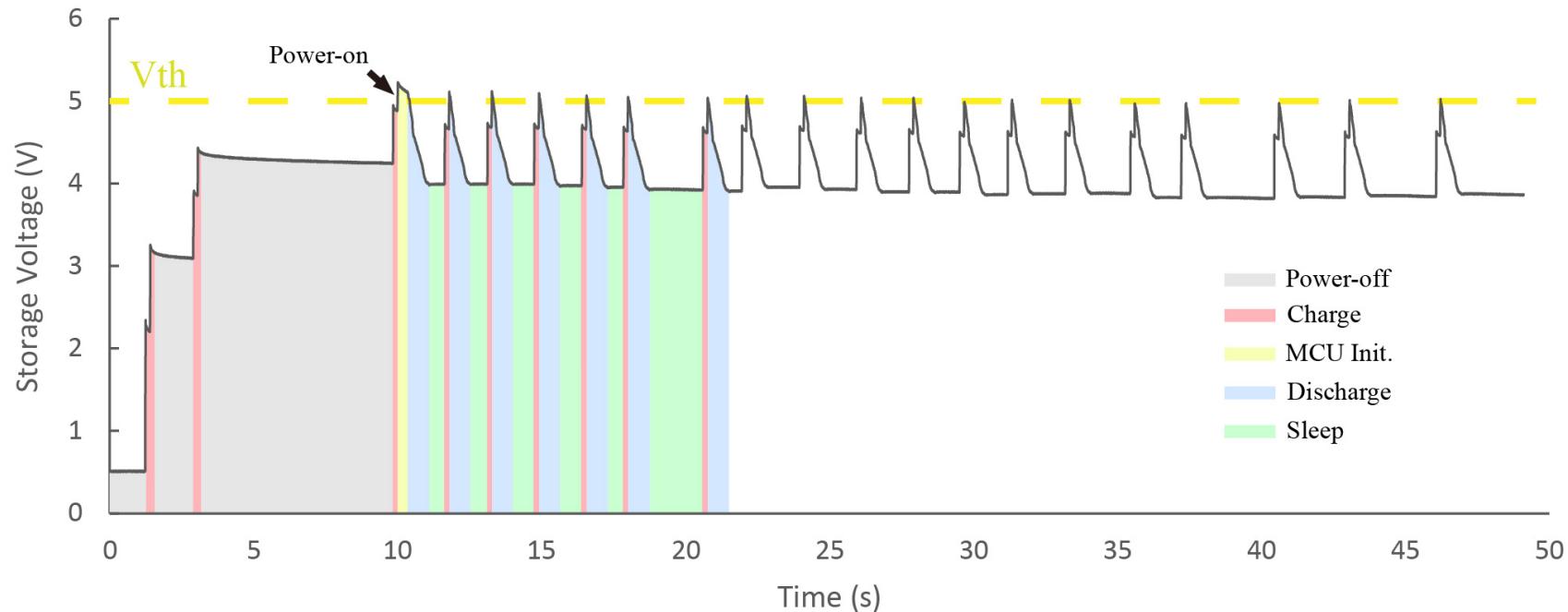
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Experiments Work Cycle



Experimental Charge and Discharge Cycles





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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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