PERCRO Perceptual Robotics Laboratory

HUMAN MOTION ENERGY HARVESTING USING A PIEZOELECTRIC MFC PATCH

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What

We propose a method to test the **Macro-Fiber composites (MFC)** power output thanks to a mechanical framework specifically designed to replicate the kinematic of a knee joint and actuated using recorded human motion patterns.

Why

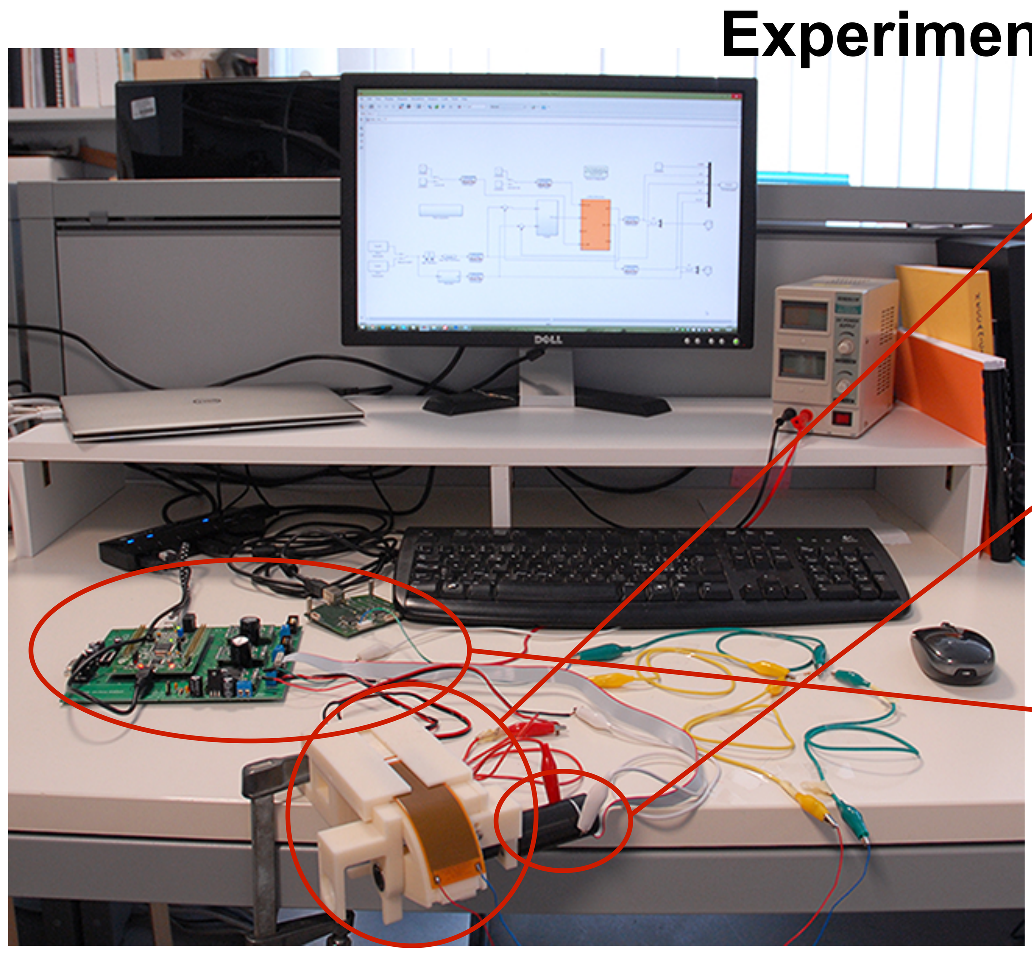
Smart wearable systems, are emerging as a solution to the challenges of monitoring people anywhere and at anytime in applications such as healthcare, well-being and lifestyle [3].

Kinetic human energy harvesting is a way to power these components reducing the need for batteries replacement since walking or running is how humans already expend much of their daily energy.

Key differences with the State of Art:

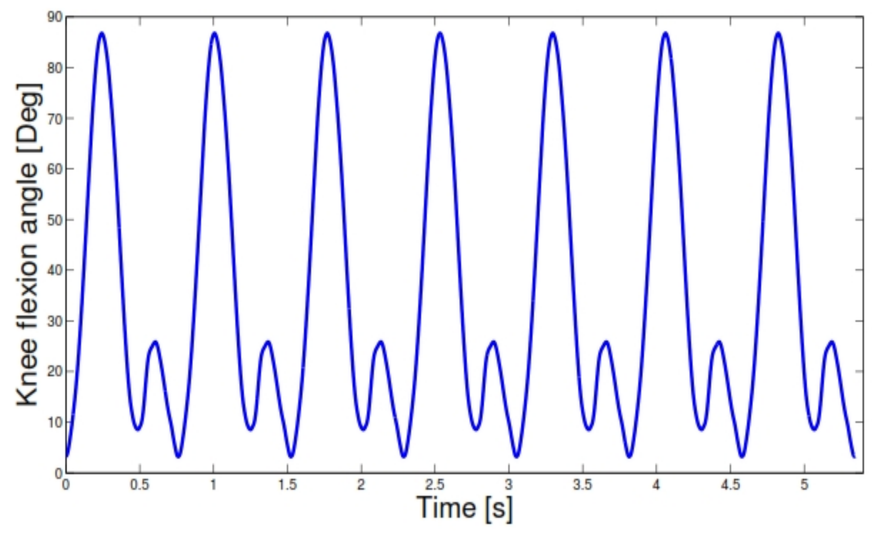
- Does not require the user to make specific actions to generate energy or to carry a cumbersome and heavy load;
- **Non-resonant energy harvesting mechanism** for collecting energy from low-frequency human joint motion.

Experimental setup



- Harvesting: P2-type MFC piezoelectric patch [12] attached to a mechanical structure purposely-built to reproduce human joints motion approaching one degree of freedom.
- Actuating and sensing: Maxon motor modular system composed of a DC brushed motor and an encoder to monitor the patch bending-angle.
- Controlling: ARM microcontroller board along with the motor driver and an ADC to acquire the MFC's power output.

Motor control input: human motion data from the **Carnegie Mellon University** motion capture database (1) a free dataset of motions recorded by means of a marker-based motion capture system. We fused and extracted the **knee flexion position data** to control the motor. Why the knee: the knee is a very important joint for energy harvesting purpose due to motion amplitude (120°+ extra range of 40°) to the imposed force and frequency of use.

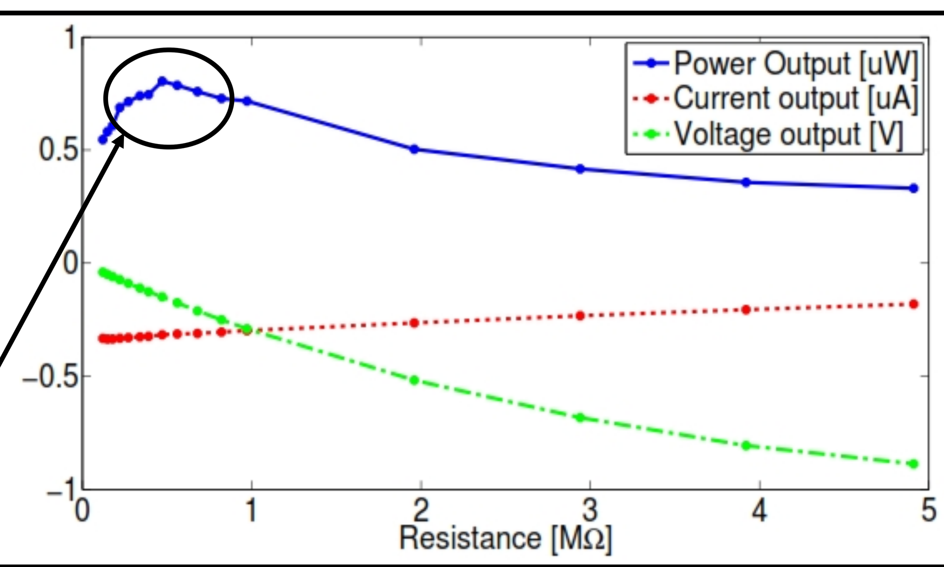


(1) http://mocap.cs.cmu.edu/

Energy transfer efficiency: The efficiency is the power transferred into the electric load related to the total power in the source as a function of the resistors. Since the inner impedance of the piezoelectric patch is fixed, to optimize the power transfer from the power source into the electric load, we tested sixteen different resistances with a run/jog activity (1.29Hz, 83.5°) system input.

$$\eta = \frac{P_{out}}{P_{in}} = \frac{R_{out}}{R_{in} + R_{out}}$$

Optimal load value (R = 470 KΩ)



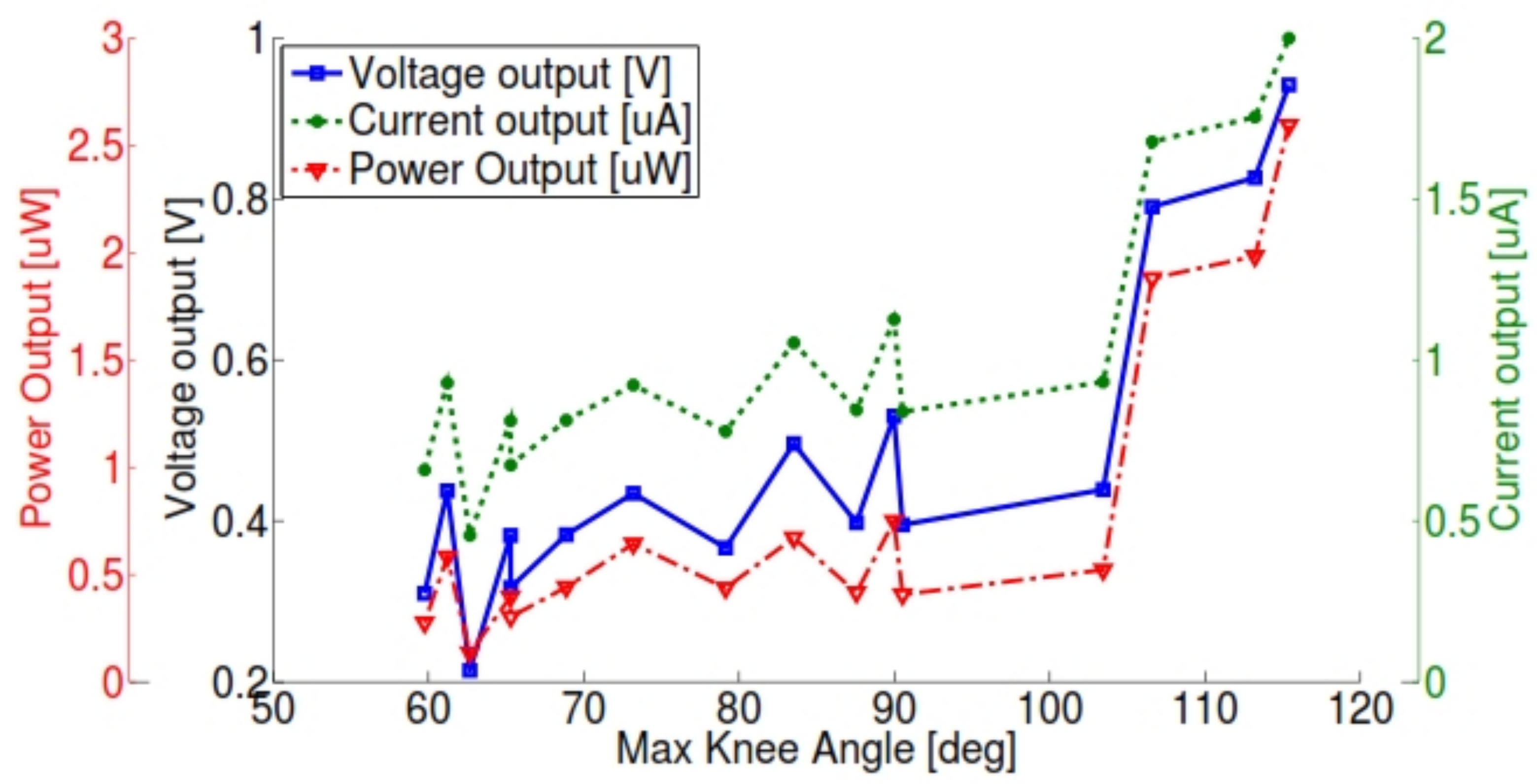
Acquisition trials with data belonging to 7 different subjects with different walking or running styles (different motion amplitude and frequency values). **Long range of knee flexion motions, spanning from 0.8Hz to 2Hz and from 60°to 115° as excitation sources for the energy harvester system.**

Results and Discussion

Output signals: voltage drop across the optimum resistance and angular position are measured simultaneously in order to correlate the output power with the angular position of the joint. **There is an almost monotonic dependency on the motion amplitude, the bigger it is the bigger the power output** is and, when the movement range is over 100°, there is a power output boost of one order of magnitude. Instead, the frequency is not very influencing and the higher frequencies did not generate the bigger amount of energy.

- The maximum power output is from the nineth subject knees associated to the run activity at 1.35Hz frequency with 115° motion amplitude, we obtained 2.6 µW;
- **By employing two MFC flexible patches per knee, one in the front and one on the back of the joints, it results about 10.4µW output power** that can be temporarily accumulated in a storage system (battery or capacitor);

CMU_name	Action	Amax (deg)	f (Hz)	Vpp (V)	Vavg (V)	Pavg (uW)	Iavg (uA)
35_01_Left	Fast Walk	59.7	1.79	1.358	0.3099	0.2766	0.6579
08_01_Right	Fast Walk	61.2	1.96	2.428	0.4373	0.5823	0.9282
06_01_Left	Walk	62.7	0.82	1.318	0.2143	0.1354	0.4549
16_36_Left	Run	65.3	1.29	1.472	0.3819	0.3954	0.8107
35_01_Right	Fast Walk	65.3	1.79	1.435	0.3172	0.3024	0.6732
06_01_Right	Walk	68.9	0.83	2.187	0.3827	0.4416	0.8124
08_01_Left	Fast Walk	73.2	1.99	3.212	0.4342	0.6436	0.9218
16_36_Right	Run	79.14	1.26	1.919	0.3665	0.4376	0.7779
02_03_Right	Run/Jog	83.5	1.29	1.983	0.4960	0.6713	1.0528
02_03_Left	Run/Jog	87.6	1.41	1.451	0.3977	0.4170	0.8443
35_26_Left	Run/Jog	89.9	1.41	2.293	0.5301	0.7482	1.1253
35_26_Right	Run/Jog	90.5	1.41	1.460	0.3952	0.4066	0.8388
09_02_Right	Walk/Wonder	103.4	1.29	1.744	0.4387	0.5215	0.9313
09_02_Left	Walk/Wonder	106.6	1.35	3.408	0.7901	1.8794	1.6772
09_06_Right	Run	113.2	1.35	3.448	0.8262	1.9822	1.7538
09_06_Left	Run	115.4	1.35	4.150	0.9414	2.5921	1.9984



Conclusion and Future Work

- Power output levels are sharply over those of similar devices [14] currently at the state-of-the-art in research on piezoelectric energy harvesting systems exploiting human joints motion;
- Seen the rising low power microelectronics and power management approaches it is a valid starting point to grow a zero-power wearable device for monitoring people anywhere.
- **The subject wearing the device is not bound to walk or jog at a specific frequency or as fast as he can, and even post-traumatic patients can produce energy during their rehabilitation therapy.**

Future developments will focus on the wearable assessment in order to evaluate harvestable energy from different human activities (non-periodic) along with the development of an ultra-low-power sensing system for human motion detection.

[3] P. Bonato et al., "Wearable sensors/systems and their impact on biomedical engineering," IEEE Engineering in Medicine and Biology Magazine, vol. 22, no. 3, pp. 18–20, 2003.
[12] Y. Yang, L. Tang, and H. Li, "Vibration energy harvesting using macrofiber composites," Smart materials and structures, vol. 18, no. 11, p. 115025, 2009.
[14] G. De Pasquale and A. Somà, "Energy harvesting from human motion with piezo fibers for the body monitoring by mems sensors," in IEEE Symp. on Design, Test, Integration and Packaging of MEMS (DTIP), 2013, pp. 1–6.