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DEVELOPMENT OF A STANDARDIZED PROCEDURE FOR THE EVALUATION AND COMPARISON OF WEARABLE SELF-POWERED DEVICES, TO BE APPLIED IN THE DESIGN AND TESTING OF SELF-POWERED WEARABLE HEALTH SENSORS

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This project is intended to assist in the design of self-powered wearable health sensors. Namely, for self-powered devices to be able to be used medically, they must be consistent, accurate, and reliable. Because there is no standardized procedure used to evaluate these devices, each organization producing them determines the methods by which they will be tested. The methods used vary vastly from one group to the next, and many fail to mimic human motion to any degree of accuracy. Thus, it is difficult to determine which of these devices will be reliable and effective when implemented with real-world patients. The process discussed in this article will, when completed, allow these devices to be effectively compared. It will then enable self-powered devices to be used medically because designers will be certain a specific device will provide enough power to support the related equipment. In achieving these aims, the primary focus of the conducted project was to characterize the primary contributions to motion in terms of frequency and amplitude from 15 human subjects.

Characterizations of the metrics of human motion during locomotion have been documented by a variety of organizations, and these were considered during the initial design process. Most notably, Meyns *et al* [1] documented electromyographic data collected from subjects' arms and torsos during locomotion, Riemer *et al* [2] performed a metric analysis of the work done at various joints during motion, and Pontzer *et al* [3] performed analysis on shoulder, torso, and pelvic rotation during locomotion. To supplement the information discovered by these researchers, the ISS Lab at the University of Utah conducted an experiment collecting six-axis inertial data from various points on the human body during locomotion and other activities. As part of this project, each periodic signal was analyzed using Matlab and Fast Fourier Transformations were applied to analyze the frequency components present in each signal.

The 'significant frequencies'—frequencies at which the composite sinusoids are highest in magnitude—were recorded and analyzed using Matlab and Excel. Several prominent trends emerged from the examination of this data, and the following characteristics were most notably established or confirmed: when walking, the first two significant frequencies of arm swing tend to occur slightly below 1 Hz and near 2 Hz; other significant frequencies tend to be drastically lower in magnitude than the first two; and significant frequencies other than the first two tended to occur at far less regular intervals and with far less consistency between subjects.

Once general trends had been determined, a series of periodic summations was developed based upon these trends. Each equation, which consisted of as many as four summed sinusoids, represented the basic single-axis linear or rotational excitation experienced at a given body location during a specific activity. However, when a single-axis mechanical swing arm was programmed to replicate these sinusoids, the power generated by a device placed on the swing arm was, in every case, drastically lower than the power generated by the same device in a real-world test. Thus, it was concluded that a single-axis mechanical swing-arm is an insufficient evaluation method for wrist-worn energy harvesters.

Because the mechanics of human locomotion are so complex, any system that accurately represents all of them is likely to be uneconomical, making it unlikely to be widely implemented. It is thus necessary to determine which aspects of human motion most drastically contribute to the power harvested at the wrist. The analysis of these kinematics is the next crucial step in the development of an accurate and economical mechanical benchtop test for wrist-worn energy harvesters.

Examples of the graphs used to analyze data: Figure 1 shows an example FFT plot. Four 'significant frequencies' have been circled, these frequencies have been recorded and compared with those from other subjects. Figure 2 shows a comparison of significant frequencies between different subjects completing the same test. Table 1 lists the most significant frequency and the related magnitude for 15 subjects during a given test.

Figure 1

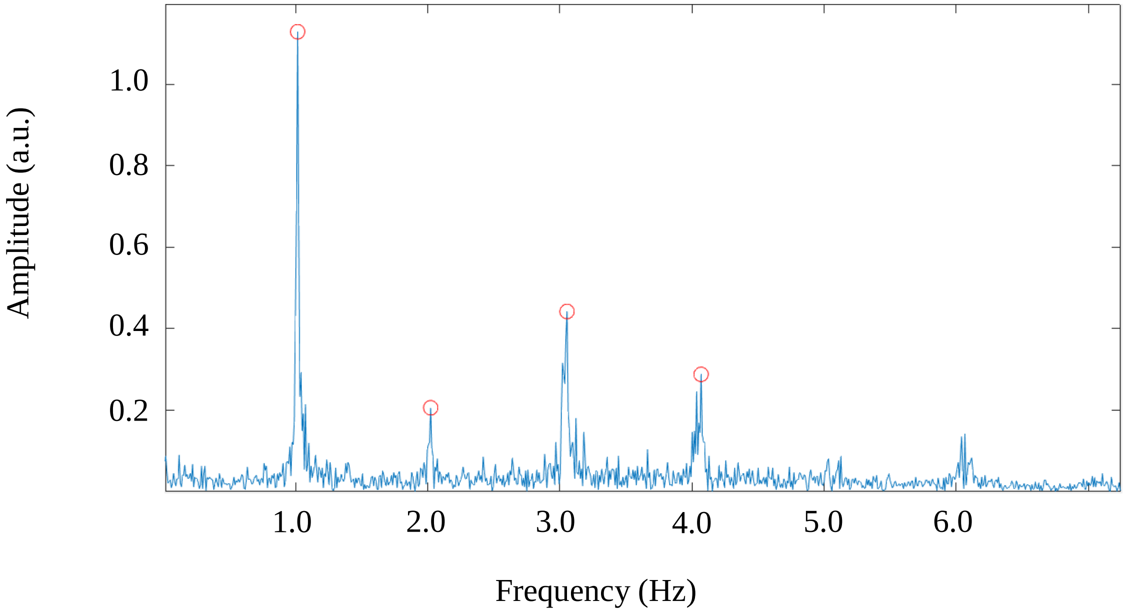

Figure 2

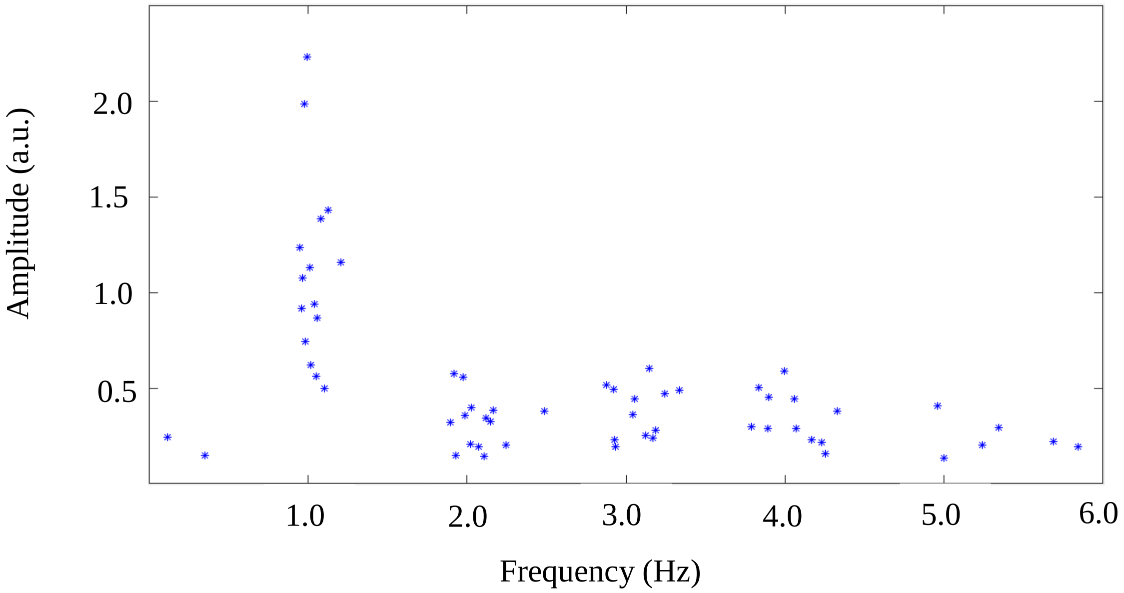

Table 1		
Subject	Frequency (Hz)	Amplitude (a.u.)
1	1.126	1.428
2	0.9784	1.985
3	1.015	1.129
4	1.017	0.6185
5	1.084	1.382
6	0.9518	1.232
7	1.04	0.9404
8	0.9838	0.7428
9	3.145	0.6039
10	1.054	0.563
11	0.9615	0.9174
12	1.057	0.865
13	0.968	1.077
14	1.206	1.159
15	0.994	2.228

[1] P. Meyns, S. M. Brujin, and J. Duysens, “The how and why of arm swing during human walking,” *Gait and Posture,* vol 38, no. 4. Pp. 555-562, 2013.

[2] R. Riemer and A. Shapiro, “Biomechanical energy harvesting from human motion: theory, state of the art, design guidelines, and future directions,” *J. Neuroeng. Rehabil.*, vol. 8, no. 1, p. 22, 2011.

[3] H. Pontzer, J. H. Holloway, D. A. Raichlen, and D. E. Lieberman, “Control and function of arm swing in human walking and running,” *J. Exp. Biol.*, vol 212, no. 6, pp. 894-894, 2009.