Exploring the Potential of Power Lines for Sensing Human Activities

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***Abstract*—This study explores the potential of using power lines to sense human activities. A model based on the Hertzian dipole approximation method is proposed to simulate the sensing mechanism, involving the calculation of the radiated field and the estimation of the Doppler frequency of the echoes. Simulations conducted with the proposed model demonstrate its effectiveness. Additionally, measurements performed with a universal software radio peripheral (USRP) follow the simulation results closely. These preliminary findings illustrate the feasibility of utilizing power lines for sensing human activities.**

Keywords—human sensing, power line, radio frequency, Hertzian dipole, Doppler

I. Introduction

Power lines, commonly known for their wide availability and cost-effectiveness, can be configured to transmit and receive radio frequency (RF) signals. Consequently, many studies have focused on power lines for communications and RF applications. Research has examined power line radiation through experimental means, using loop antennas to capture the radiated signals within frequency ranges of 150 kHz to 30 MHz and 2.4 GHz [1]-[2]. Additionally, investigations into power line functionality have demonstrated its ability to transmit and receive signals across the spectrum from 1.7 MHz to 100 MHz [3].Building upon the aforementioned research, the concept of utilizing power lines to sense human presence has garnered increasing interest recently. This concept is based on the understanding that power lines, due to their lack of full shielding, can function similarly to elongated antennas [4]-[5]. Consequently, they can transmit electromagnetic (EM) energy into their surroundings and receive the reflected echoes from humans.

This study explores the feasibility of sensing human activities via power lines. An analytical simplified model based on the Hertzian dipole approximation to the radiation of the power lines is proposed, incorporating the Doppler estimation to sense human activities by analyzing the received signal. A case study is conducted through a simulation and a measurement, demonstrating the potential of power lines for human sensing applications.

II. Model of Human Sensing via Power Lines

In the considered scenario, a power line is excited by a monotone signal at an RF frequency. The cable radiates EM energy into its surrounding space and another cable is used to receive the echo reflected by the human.

A. Radiation of the Power Line

The line current anywhere on the power line on a ground plane is calculated using [6]

$$I(x) = \frac{e^{-\gamma x} - \rho_2 e^{\gamma(x-2l)}}{2Z_0\left(1-\rho_1\rho_2 e^{-2\gamma l}\right)}(1-\rho_1)V_0, \quad (1)$$

where γ and Z_0 are the propagation constant and characteristic impedance of the power line, respectively; l is the length of the power line; ρ_1 and ρ_2 are the reflection coefficients at the source and load ends, respectively; V_0 is the voltage amplitude of source at the terminal of the power line.

To model the γ and Z_0 of the power line correctly, the input impedances of the power line for the open-circuit and short–circuit terminations, Z_{0c} and Z_{sc}, are measured via vector network analyzer and used to calculate γ and Z_0 via [7]-[8]

$$\gamma = \frac{1}{l}\tanh^{-1}\sqrt{\frac{Z_{sc}}{Z_{oc}}}, \quad (2)$$

$$Z_0 = \sqrt{Z_{sc}Z_{oc}}. \quad (3)$$

By substituting (2) and (3) into (1), the current along the power line can be obtained. The current on the power line is assumed to be modeled by Hertzian dipoles, which generate the radiated fields in the power lines' surroundings [9]. By summing up the radiation by each dipole and its image due to the ground plane, the radiation anywhere in the space excited by a power line can be calculated via

$$E_x = \left(\frac{-jkIdl\eta_0 e^{-jkr}}{4\pi r^2}\right) \times\left[\frac{xz\sin\beta}{u}\left(\frac{1}{k^2r^2}+\frac{j}{kr}-1\right)+2x\cos\beta\left(\frac{1}{k^2r^2}+\frac{j}{kr}\right)\right] \quad (4)$$

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$$E_y = \left(\frac{-jkIdl\eta_0 e^{-jkr}}{4\pi r^2} \right) \times \left[\frac{yz \sin\beta}{u} \left(\frac{1}{k^2 r^2} + \frac{j}{kr} - 1 \right) + 2y \cos\beta \left(\frac{1}{k^2 r^2} + \frac{j}{kr} \right) \right] \quad (5)$$

$$E_z = \left(\frac{-jkIdl\eta_0 e^{-jkr}}{4\pi r^2} \right) \times \left[-u \sin\beta \left(\frac{1}{k^2 r^2} + \frac{j}{kr} - 1 \right) + 2z \cos\beta \left(\frac{1}{k^2 r^2} + \frac{j}{kr} \right) \right] \quad (6)$$

where E_x, E_y, and E_z are the components of the radiated electric fields along x, y, and z directions, respectively; $k = \omega(\mu_0\varepsilon_0)^{1/2}$ is the wavenumber, ω is the angular frequency, μ_0 and ε_0 denote the vacuum permeability and permittivity, respectively; I is current on dipole; dl is the length of dipole; $\eta_0 = (\mu_0/\varepsilon_0)^{1/2}$ is the intrinsic impedance of free space; (x, y, z) is the coordinate position in Euclidean coordinates; $r = (x^2+y^2+z^2)^{1/2}$, $u = (x^2+y^2)^{1/2}$ and $\beta = \arcsin(u/r)$.

B. Doppler Estimation of Echoes

After the radiated power is reflected by the moving human, the echo will couple into the power line. By doing so, all radiating dipoles modeled on the power line will receive signals with Doppler shift. The Doppler shift can be calculated via [10].

$$f_d = \frac{2f}{c} \times v \times \cos\theta \,, \quad (7)$$

where f is the carrier frequency of the signal; c is the speed of the light; v is the velocity of the human; θ is the angle between the direction of the human velocity vector and the range vector from each dipole. Since each dipole has different positions on the power line and different θ angles, the Doppler frequency fluctuates in a range of f_d at a given instant. In addition, the amplitude of f_d at each moment is influenced by the radiated field, which is calculated using the expressions in the previous subsection. Regardless of transmission loss and coupling efficiency, the Doppler frequency and its amplitude represented by the radiation field can be used to sense humans.

III. Case Study

A. Simulation

A case study of a human walking along a three-meter-long power line with a velocity of 2 m/s is investigated [Fig. 1]. The distance between the human and the power line is 1 m. The power line is excited by a signal at 2 GHz.

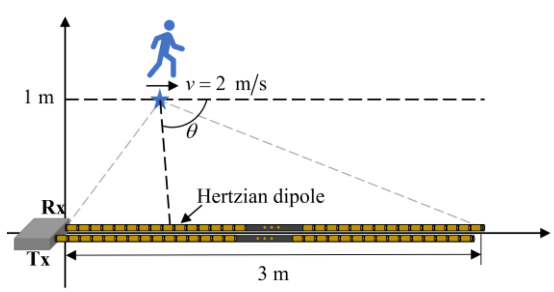

Fig. 1 The scenario of a human walking parallel to a 3m-long power line.

Based on the proposed model, the estimated Doppler signature and the amplitudes of the radiated fields are shown in Fig. 2.

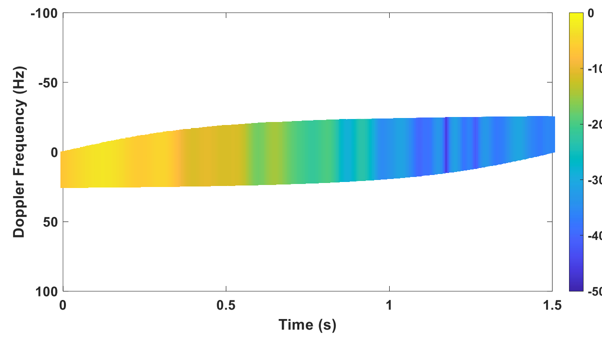

Fig. 2 Estimated Doppler signature of a human walking parallel to a 3 m long power line.

It is clear from the figure that Doppler frequency varies in a range at a given time instant. It increases from positive to negative when the subject moves from the power line's source end to its load end. In particular, when the subject is moving from the source end, it is equivalent to approaching all dipoles and when a human is at the load end, it is equivalent to moving away from all the dipoles. The amplitude of Doppler decreases as the radiation of the power line decreases along the power line from the source end to the load end.

B. Measurement

A measurement study via a universal software radio peripheral (USRP) is carried out based on the scenario in Fig. 1. Using Labview, the USRP is programmed to transmit and receive RF signals by modulation and demodulation. The Doppler signature is shown in Fig. 3.

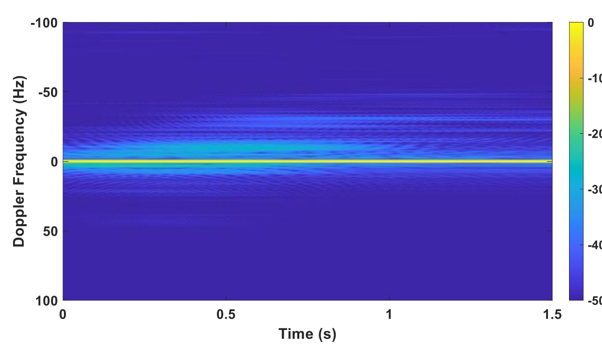

Fig. 3 The measured Doppler signature of a human walking parallel to the power line.

Based on Fig. 3, the main tendency of measured Doppler frequency also increases from positive to negative, which is similar to the simulation result. As there are related movements of the four limbs and head, micro-Doppler also exists in the measurement result, which causes a wider Doppler frequency range than the simulation. Doppler frequency amplitude also attenuates as humans walk away from the signal source. The ignorance of reflection and transmission loss may also result in differences between measurement and simulation results.

IV. Conclusion

In this study, an approximate Hertzian dipole method was employed to estimate the radiation by power lines. By combining the radiated fields and Doppler frequency estimation, the echo due to human activity was investigated. In particular, a case study involving a human walking along a power line was conducted through a simulation and measurement. The preliminary results demonstrate the feasibility of using power lines to sense human presence and movement.

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