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Human Activity Detection Using Radio Waves

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April 18, 2017

1 Introduction

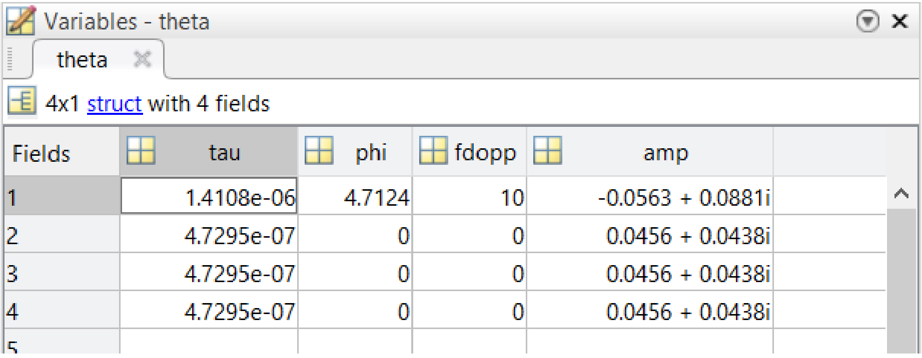
Radio waves are typically infomation carriers in wireless communication. In this report, however, we make use of the radio waves to extend human sense, by exploiting the channel state information in a multipath channel. We try to detect the movement in indoor environments by a pair of transmitter and receiver. The detection is divided into two procedures. First, we need to obtain the channel state information based on the received signal and prior known transmitted signal. In order to achieve that we implmented two techniques, one is a high resolution channel parameter estimation algorithm SAGE, another is making use of the concept of Wiener filter to model the channel as a filter. The next procedure is movement detection. We exploit the correlation of successive CSIs in time to extract the movement in the channel.

In this report, our works on CSI estimation will be given in chapter 2. In chapter 3, movement detection scheme is presented along with simulated results. Then conclusion will be presented in chapter 4.

2 Channel Estiamtion

2.1 SAGE Algorithm

We first decided to apply Maximum Likelihood Estimator to calculate the CSI since it's reasonable to assume the noise is Gaussian distributed, which makes the logarithm likelihood function easy to obtain. In order to calculate likelihood function for each path, the received signal along each path shall be extracted. But it is not possible physically because the



Variables - theta

theta

4x1 struct with 4 fields

Fields	tau	phi	fdopp	amp
1	1.4108e-06	4.7124	10	-0.0563 + 0.0881i
2	4.7295e-07	0	0	0.0456 + 0.0438i
3	4.7295e-07	0	0	0.0456 + 0.0438i
4	4.7295e-07	0	0	0.0456 + 0.0438i
5				

Figure 1: Estimated CSI using SAGE

signals along each path at receiving end are superimposed. We decompose the superimposed received signal y proposed in [2] by

$$x_l(t;\theta_l) = s(t;\theta_l) + [y(t) - \sum_{l=1}^{L} s(t;\theta_l)] \tag{1}$$

where $\theta_l = [\tau_l,\ \alpha_l,\ \phi_l,\ \nu_l]$ denoted the parameters of lth path (time delay, complex amplitude, direction of arrival and doppler frequency), and

$$\begin{aligned} s(t;\theta_l) &= [s_1(t;\theta_l), ..., s_M(t;\theta_l)]^T \\ &= c(\phi_l)\alpha_l e^{j2\pi\nu_l t} u(t-\tau_l) \end{aligned} \tag{2}$$

is the expected received signal along path l at each receiving antenna m. $c(\phi) = [c_1(\phi), ..., c_M(\phi)]^T$, whose component is $c_m(\phi) = e^{j2\pi/\lambda(m-1)dcos(\phi)}$ representing phase shift among receiving antennas due to the direction of arrival with respect to the antenna array. With signal decomposed, the log-likelihood function for this model is [3]

$$z(\tau,\phi,\nu;x_l) = \int u^*(t'-\tau)e^{-j2\pi\nu t'} c^H(\phi) x_l(t')dt' \tag{3}$$

Thus the coordinate ascend iteration is

$$\begin{aligned} \tau_l'' &= arg \max_{\tau} \{z(\tau,\phi_l',\nu_l';x_l(t;\theta'))\} \\ \phi_l'' &= arg \max_{\phi} \{z(\tau_l'',\phi,\nu_l';x_l(t;\theta'))\} \\ \nu_l'' &= arg \max_{\tau} \{z(\tau_l'',\phi_l'',\nu;x_l(t;\theta'))\} \\ \alpha_l'' &= \frac{1}{I||c(\phi_l'')||^2 T_a P_u} z\{\tau_l'',\phi_l'',\nu_l'';x_l(t;\theta')\} \end{aligned} \tag{4}$$

The initialization of the iteration adopts the successive interference cancellation proposed in [4].

The simulated channel in our case is shown in figure 1, which contains 2 clusters of paths with time delay of $0.625\mu s$ and $1.56\mu s$. The amplitudes of each cluster is 0.2 and 0.5 respectively. The Doppler frequencies and directions of arrival can be arbitrary since it's irrelevant to the movement detection. The transmitted signal that is used in the simulation must be wide-band with respect to the coherence band-width of underlying channel only if which the multi-path can be resolved. The symbol rate is chose to be $3.2MHz$ because this

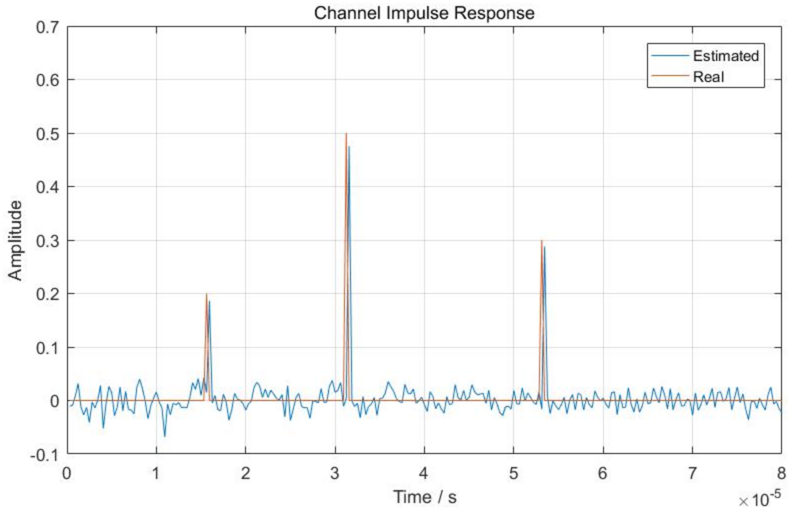


Figure 2: Estimated CSI using Wiener Filter

is the maximum stable sampling rate of our SDR. The signal is a random binary sequence of 1000 bits repeated by 100 times. The result shows two paths. The estimated time delay is $0.473\mu s$ and $1.411\mu s$ respectively, and amplitude is 0.063 and 0.105. This is far from ideal.

2.2 Wiener Filter

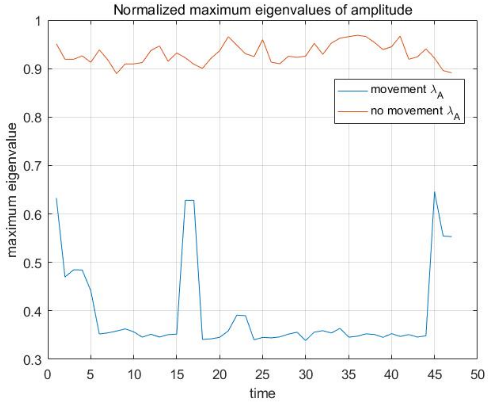
The idea of Wiener is to calculate the Channel's frequency response using the power spectral density of the signal in a minimum mean square error sense. In this case we model the channel as a IIR filter. As illustrated in [5],

$$h(k) * r_x(k) = r_{dx}(k) \tag{5}$$

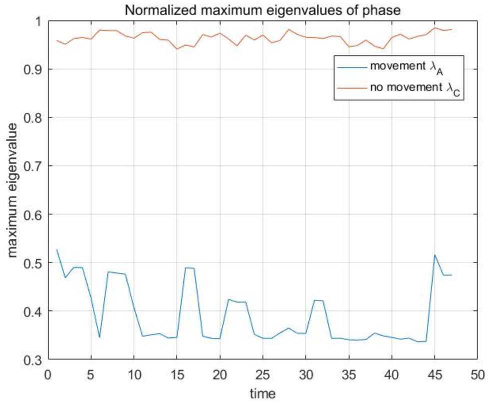
where h(k) is the impulse response of the channel, r_x is the autocorrelation of received signal and r_{dx} the cross correlation of transmitted signal and received signal. And the estimated frequency response of the channel is

$$H(e^{jw}) = \frac{P_{dx}(e^{jw})}{P_x(e^{jw})} \tag{6}$$

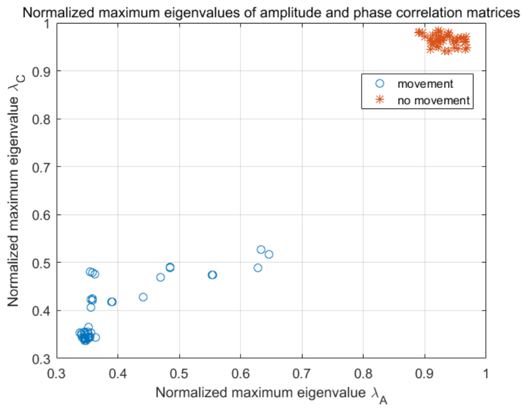
In the simulation, the signal that is sent is a PN sequence. Because of the PN sequence's autocorrelation property, the path delay resolution is the symbol rate of the PN sequence. Thus in this case we set three paths whose time delays are larger than transmitted signal's symbol time. This is shown by red line in figure 2, with amplitude 0.2, 0.5 and 0.3 respectively. Time delay are $15.6\mu s$, $31.3\mu s$ and $53.2\mu s$. Corresponding estimated amplitude is 0.186, 0.455 and 0.288. This result has a error of 7.0%, 9.0% and 4.0%. In terms of time delay, the estimated result is $15.9\mu s$, $31.5\mu s$ and $53.6\mu s$, whose error is 1.9%, 0.6% and 0.8%. Compared with result estimated by SAGE, this result is much closer to the real value.



(a)



(b)



(c)

Figure 3: (a)Normalized Maximum Eigenvalues of Amplitude, (b)Normalized Maximum Eigenvalues of Phase, (c) Normalied Maximum Eigenvalues of Amplitude and Phase.

3 Movement Detection

3.1 Scheme

CSI exhibits larger variations in case of moving humans than in case of static humans. In this part, we deal with estimated CSIs. To test the method, we first use a sequence of simulation data with high and low correlation instead of real data.

In case of moving human, we generated 50 groups of CSIs with the information of 10 paths. We use the initial CSI as a standard. In each time slot, we update the CSI by only changing three or four paths' parameters, which are chosen randomly. What's more, the path closing to the chosen paths may also change. And 1/n is used as the attenuation index in multi-path propagation. In case of static humans, we only make minor changes to the initial CSI so that the data has high correlation.

In order to obtain the correlation factor between each column of CSI samples H, we generate two n-by-n matrix A and C for amplitudes and phases, where each element denotes the correlation coefficient between H_i and H_j. Afterwards, we derive the eigenvectors of matrix

A and C and exert the normalized maximum eigenvalues for moving human detection.

3.2 Result and Potential Improvements

From the simulation, stationary channel results in large eigenvalues (close to 1) as elaborated in figure 3. In the opposite case of moving channel, the eigenvalues tend to be small. In practice, one can set different thresholds for maximal eigenvalues of both amplitude and phase correlation to make a decision on whether there is movement or not. Since the different speed of movement will lead to different level of correlation, one can gather empirical thresholds from measurement at different moving speeds in a fixed environment to improve detection accuracy and provide the ability of roughly estimating moving speed. Since we only test this scheme in simulation phase, we are not able to provide empirical thresholds.

4 Summary

In this work, we present a framework of how to use radio waves to detect human activity in simulation phase only. We explored both amplitude and time delay information of CSI. And since the result from SAGE algorithm is not reliable, we finally choose the result estimated by Wiener Filter. To detect moving people, we calculate eigenvalues of correlation matrix whose element is CSI samples. Results show that moving channel tend to have smaller eigenvalues. Further improvements can be determining movement detection thresholds on maximum eigenvalues for both amplitude and phase correlations by empirical measurement.

References

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