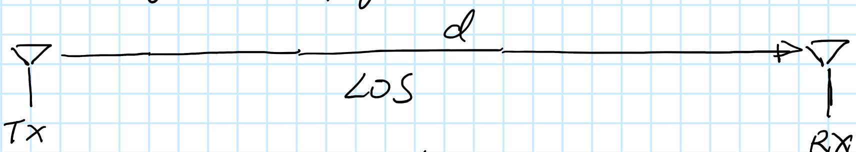
Week 05

Sunday, September 19, 2021 12:24

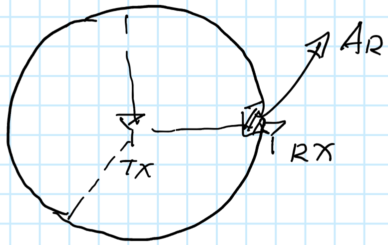
Wireless Sensing for Human Activity: A Survey
Liu et al. IEEE CS&T 2020

def: leverage the effect of environment toward wireless signal propagation (e.g. reflection diffraction and scattering) to perform radar functions (direction finding, localization, motion detection

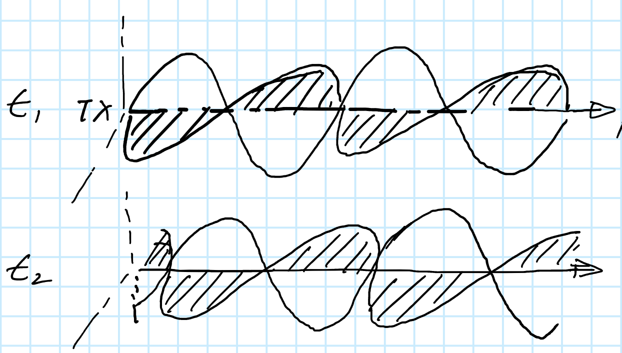
Wireless signal propagation



free space: $P_R = P_T G_T \frac{1}{4\pi d^2} A_R$ (Friis's Law)



$$\Delta\theta_R = \frac{d}{\lambda} = \frac{df}{c}$$



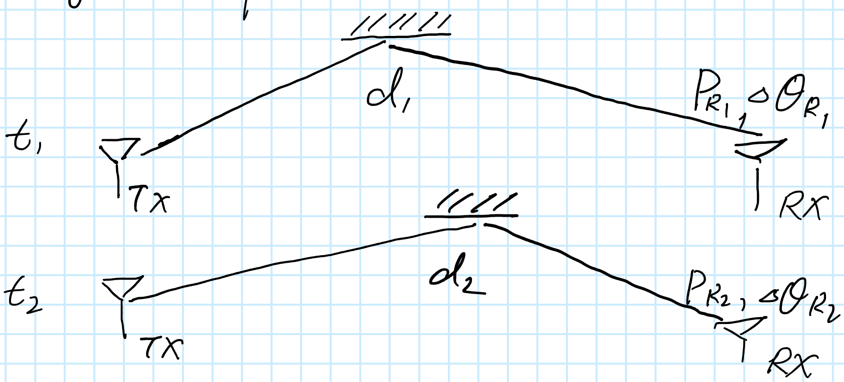
TX: $x \in \mathbb{C}$ RX: $x \frac{P_R}{P_T} e^{i(\frac{df}{c})}$, Euler's identity

$$= x\frac{P_R}{P_T}\left(\cos\left(\frac{df}{c}\right) + i\sin\left(\frac{df}{c}\right)\right)$$

reflection path

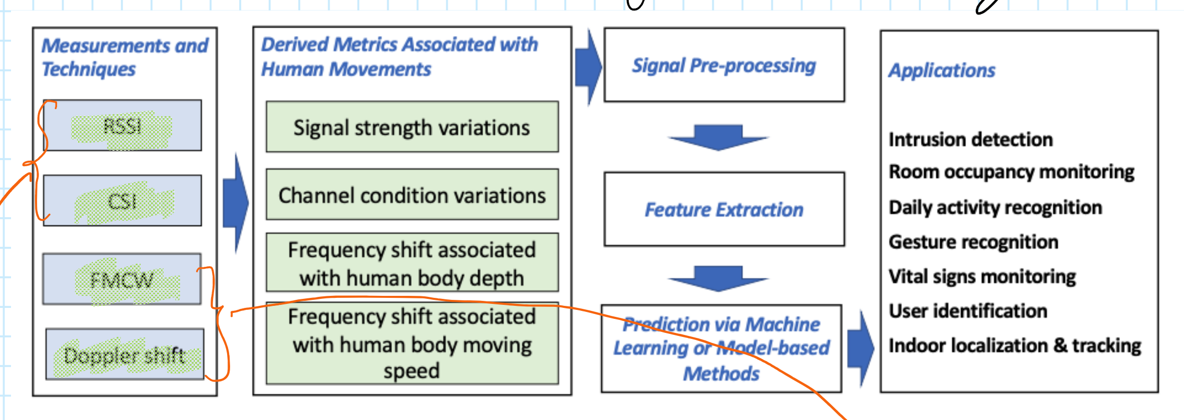
scatter changes

reflection path



scatter changes modulate receiving signal in phase and amplitude

application: human activities detection
behavior analysis / authentication
physiological monitoring
emotion detection
localization & tracking



Measurements and techniques

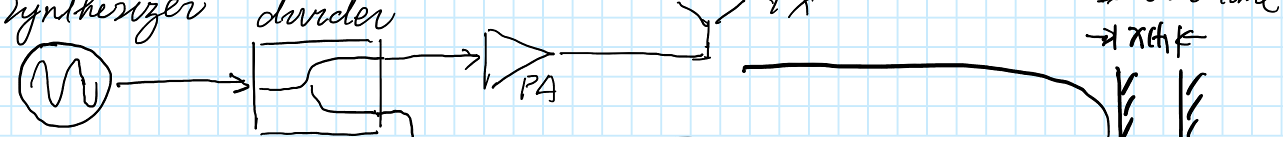
wireless sensing

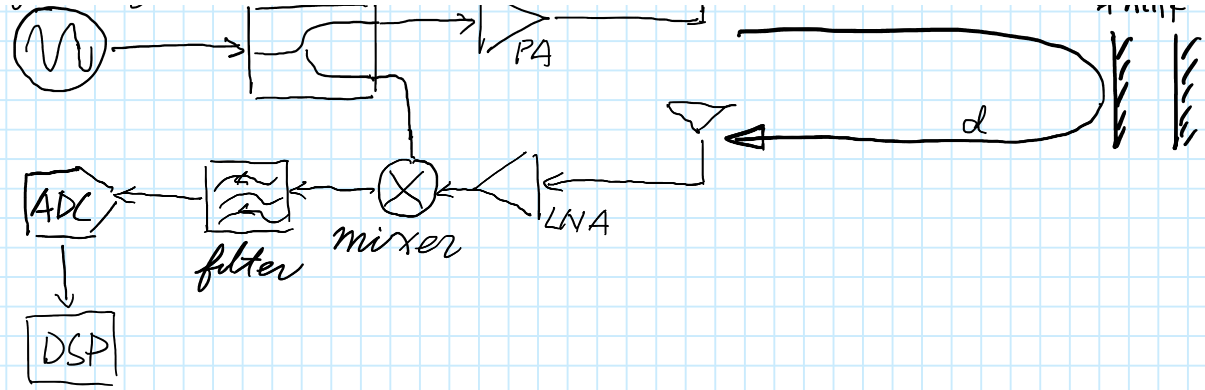
use communication system (integrated sensing and communication system [~~I~~S&C])

use radar sensors (physiological monitoring sensors)

(1) radar sensors

i. monostatic continuous-wave (CW) radar





mixer: center frequency f_c

TX : $\cos(2\pi f_c t)$ RX : $\cos(2\pi f_c t + \frac{2\pi}{\lambda}(2x(t) + d))$

I $\cos(2\pi f_c t)\cos(2\pi f_c t + \frac{2\pi}{\lambda}(2x(t) + d))$

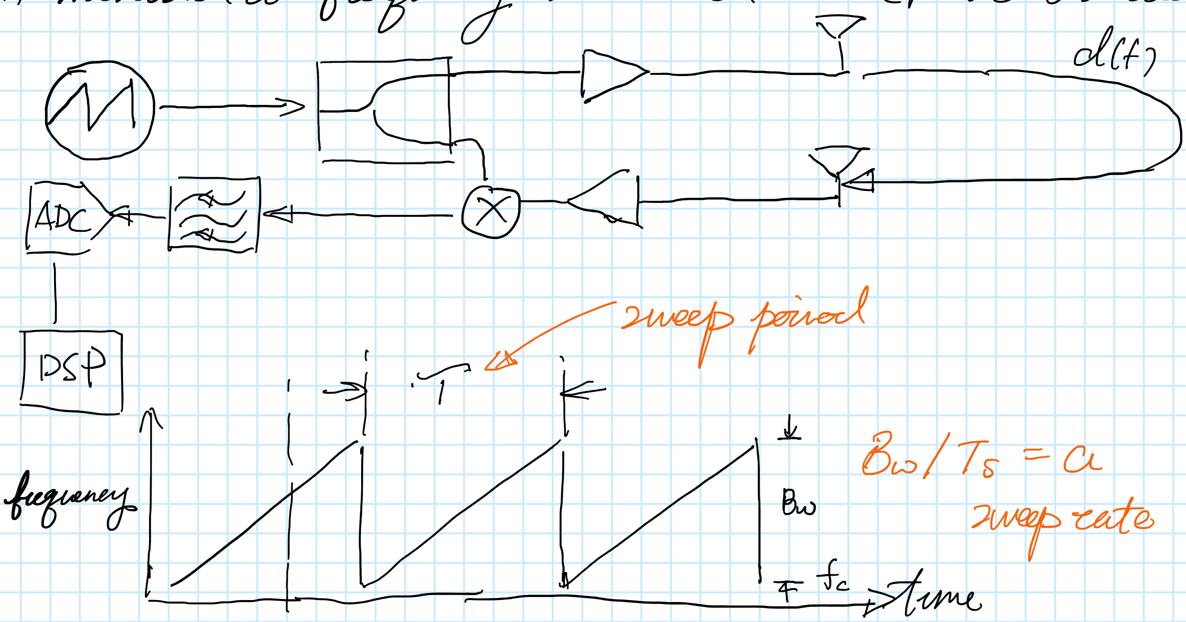
$= \frac{1}{2}\left[\cos\left(\frac{2\pi}{\lambda}(2x(t)+d)\right) + \cos\left(4\pi f_c t + \frac{2\pi}{\lambda}(2x(t)+d)\right)\right]$

Q $\frac{1}{2}\sin\left(\frac{2\pi}{\lambda}(2x(t)+d)\right)$

$\arctan\left(\frac{I}{Q}\right) = \frac{2\pi}{\lambda}(2x(t)+d)$

can only detect relative change in distance since phase wraps around

ii, monostatic frequency modulated CW (FMCW) radar



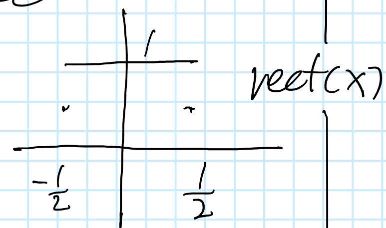
mixer: (f_{TX}, ϕ_{TX})

TX : instantaneous frequency is the derivative of

Tx : instantaneous frequency is the derivative of the instantaneous phase

$$f_{Tx} = \frac{1}{2\pi}\frac{d\phi_{Tx}}{dt} = f_c + at$$

$$\phi_{Tx} = f_c t + \frac{1}{2} a t^2$$



$$S_{Tx}(t) = \text{rect}\left(\frac{t}{T}\right)\cos(2\pi\phi_{Tx})$$

only one is non zero $\rightarrow$ $\tilde{S}_{Tx}(t) = \sum_{n=-\infty}^{\infty} S_{Tx}(t-nT)$

Rx : $S_{Rx}(t) = S_{Tx}(t-\tau)$, $\tau = \frac{2d(t)}{c}$

let $\phi_{Rx} = f_c(t-\tau) + \frac{1}{2}a(t-\tau)^2$

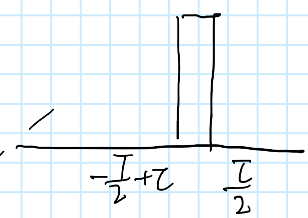
$$S_{Rx}(t) = \text{rect}\left(\frac{t}{T}\right)\cos(2\pi\phi_{Rx})$$

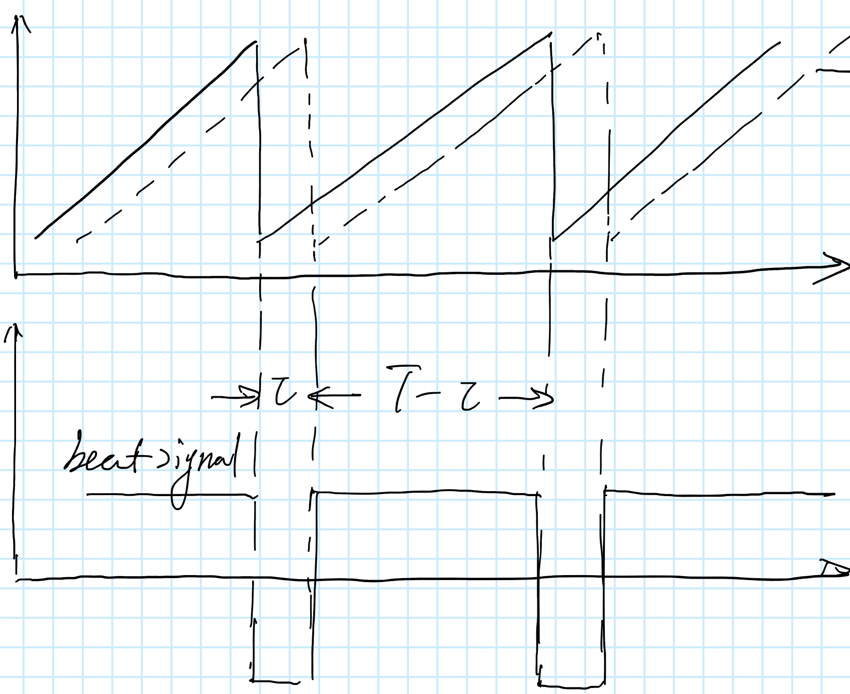
$$\tilde{S}_{Rx}(t) = \sum_{n-\infty}^{\infty} S_{Tx}(t-nT)$$

mixer : $S_{Tx}(t)\cdot S_{Rx}(t)$

$$= \text{rect}\left(\frac{t}{T}\right)\text{rect}\left(\frac{t-\tau}{T}\right)\cos\left(2\pi\left(f_c\tau + a\tau t - \frac{1}{2}at^2\right)\right)$$

$$= r(t)\cos\left(2\pi\left(f_c\tau + a\tau t - \frac{1}{2}a\tau^2\right)\right)$$



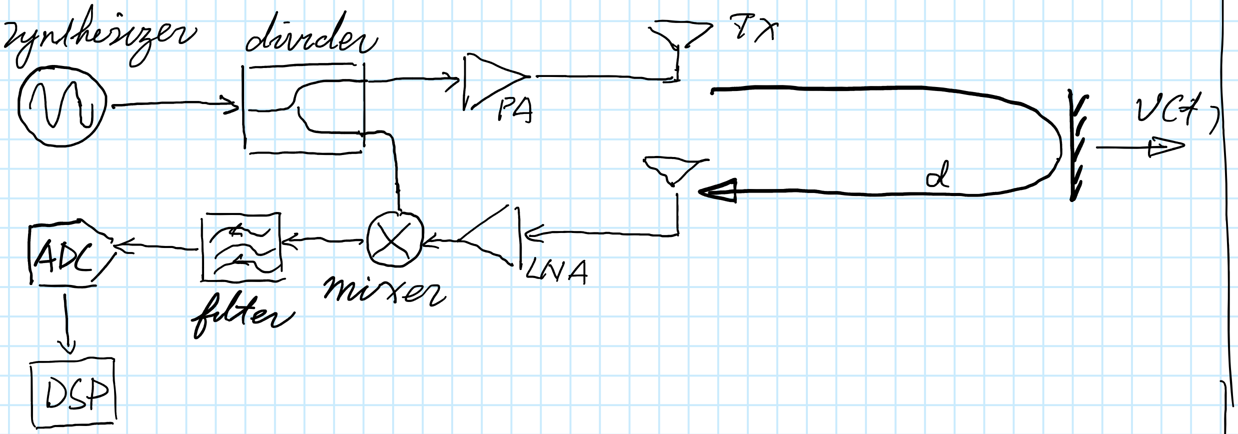


the duration of τ gives range information

iii Doppler radar

synthesizer divider $\rightarrow$ Tx

Doppler radar



mixer: center frequency f_c

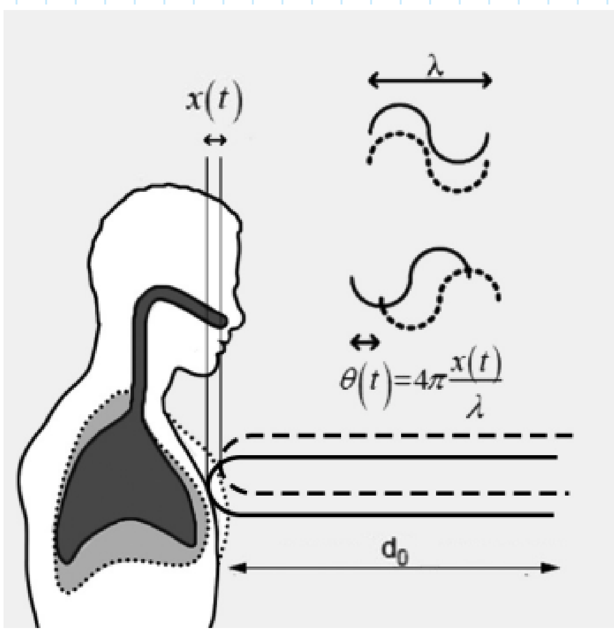
TX: $\cos(2\pi f_c t)$ RX: $\cos(2\pi(f_c+\Delta f) + \frac{2\pi d}{\lambda})$

beat frequency $\Delta f = 2v(t)\frac{f_c}{c-v(t)}$

$$\therefore f_c + \Delta f = f_c\left(\frac{c+v(t)}{c-v(t)}\right)$$

application:

(i) CW radar: breathing detection, heart beat detection

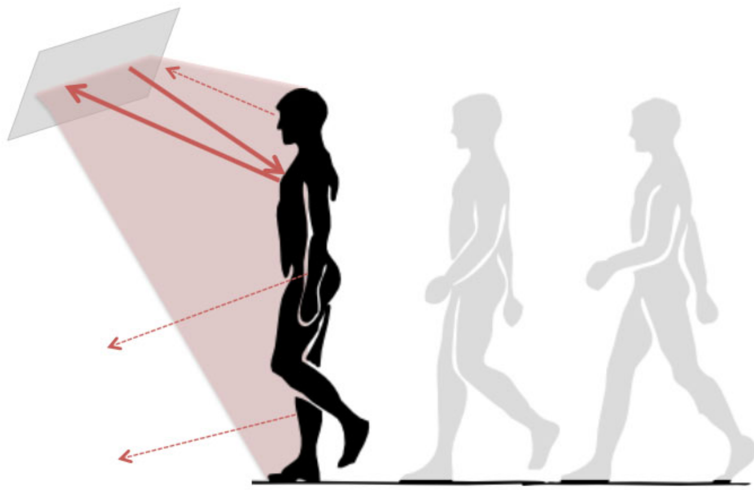


Zheng et al. 2021

(ii) FMCW radar: imaging (MIMO), gait detection

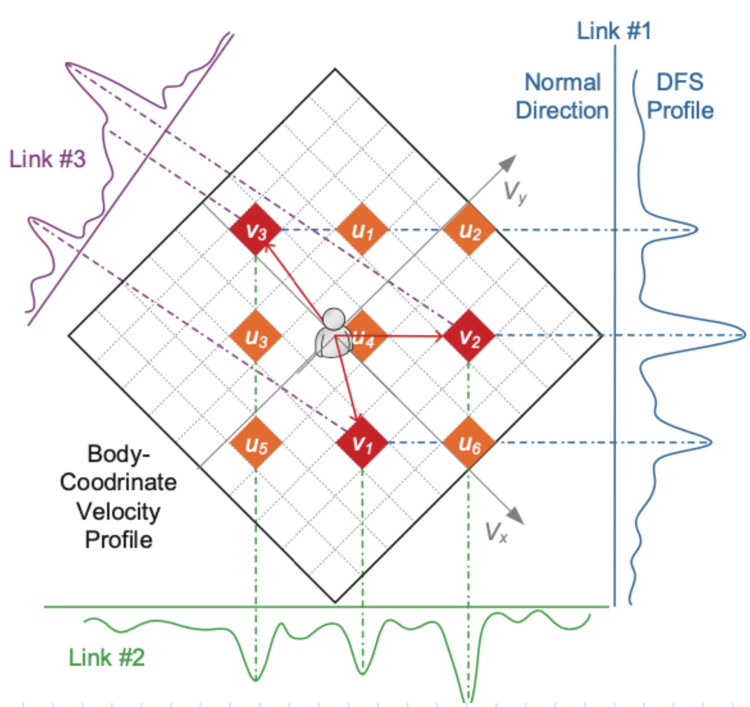
Fadel et al. 2015

Fadel et al. 2015



(iii) doppler radar : motion detection

Zheng et al. 2019



Q&A:
what's the principle of wireless sensing?
what system support wireless sensing?
what can CW FMCW and doppler radar detect?