Wireless Lensing for Human Activity: A Survey
Lin et al. IEEE C&I 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

\[
\begin{align*}
\theta_k &= \frac{d}{\lambda} = \frac{df}{c} \\
TX &= X \in \mathbb{C} \\
RX &= X \frac{P_t}{P_r} e^{i(\frac{df}{c})} \text{(Euler's identity)} \\
&= X \frac{P_r}{P_t} (\cos(\frac{df}{c}) + i\sin(\frac{df}{c}))
\end{align*}
\]

reflection path
Reflection path

\[ d_1 \quad t_1 \quad P_{R_1} \quad O_{R_1} \quad RX \]

\[ d_2 \quad t_2 \quad P_{R_2} \quad O_{R_2} \quad RX \]

Application: Human activities detection
- Behavior analysis
- Authentication
- Physiological monitoring
- Emotion detection
- Localization & tracking

Measurements and techniques:
- Wireless sensing
- Radar sensors
  - Monostatic continuous-wave (CW) radar
  - Synthesizer, divider, PA

Derived metrics associated with human movements:
- Signal strength variations
- Channel condition variations
- Frequency shift associated with human body depth
- Frequency shift associated with human body moving speed

Signal pre-processing:
- Feature extraction
- Prediction via machine learning & model-based methods

Applications:
- Intrusion detection
- Room occupancy monitoring
- Daily activity recognition
- Gesture recognition
- Vital signs monitoring
- User identification
- Indoor localization & tracking
mixer: center frequency $f_c$

$TX = \cos(2\pi f_c t)$

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

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

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

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

$\tac\left(\frac{1}{G}\right) = \frac{2\pi}{\lambda}(2x(t) + d)$

can only detect relative change in distance since phase wraps around

ii. monostatic frequency modulated CW (FMCW) radar

$BW = \frac{f_c - f_0}{T_s}$

$\frac{BW}{T_s} = \alpha$

sweep rate

$mixer: (f(t), \phi(t))$

$TX$: instantaneous frequency is the derivative of
\[ TX: \text{instantaneous frequency is the derivative of} \]
\[ f_tX = \frac{1}{2\pi} \frac{d\phi_tX}{dt} = f_c + at \]
\[ \phi_tX = f_c t + \frac{1}{2} at^2 \]

only one
\[ S_{TX}(t) = \text{rect} \left( \frac{t}{T} \right) \cos \left( 2\pi \phi_tX \right) \]

\[ S_{TX}(t) = \sum_{n=-\infty}^{\infty} S_{TX}(t-nT) \]

\[ RX: S_{RX}(t) = S_{TX}(t-\tau), \tau = -\frac{2d(t)}{c} \]

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

\[ S_{RX}(t) = \text{rect} \left( \frac{t}{T} \right) \cos \left( 2\pi \phi_{RX} \right) \]

\[ S_{RX}(t) = \sum_{n=-\infty}^{\infty} S_{TX}(t-nT) \]

\[ \text{mixing: } S_{TX}(t) \cdot S_{RX}(t) \]

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

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

$\text{TX} = \cos(2\pi f_c t)$

$\text{RX} = \cos(2\pi f_c t + \phi_f) + \frac{2\pi d}{\lambda}$

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

faidel et al., 2015
Q&A:

What's the principle of wireless sensing?

What system support wireless sensing?

What can CW FMCW and doppler radar detect?