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RF Free Ultrasonic Positioning

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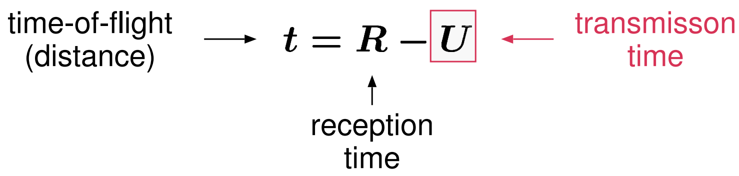
Background

- ultrasonic positioning systems use RF as a synchronisation mechanism to determine transmission times, necessary for time-of-flight calculations



AT&T Bat System

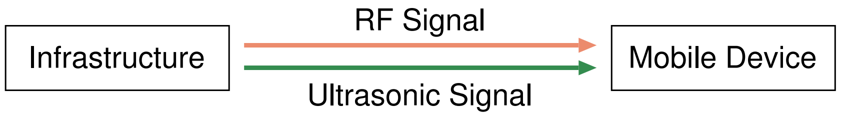
- infrastructure uses RF to activate a single mobile device

Intersense Constellation System

- mobile device uses RF to activate a single transmitter

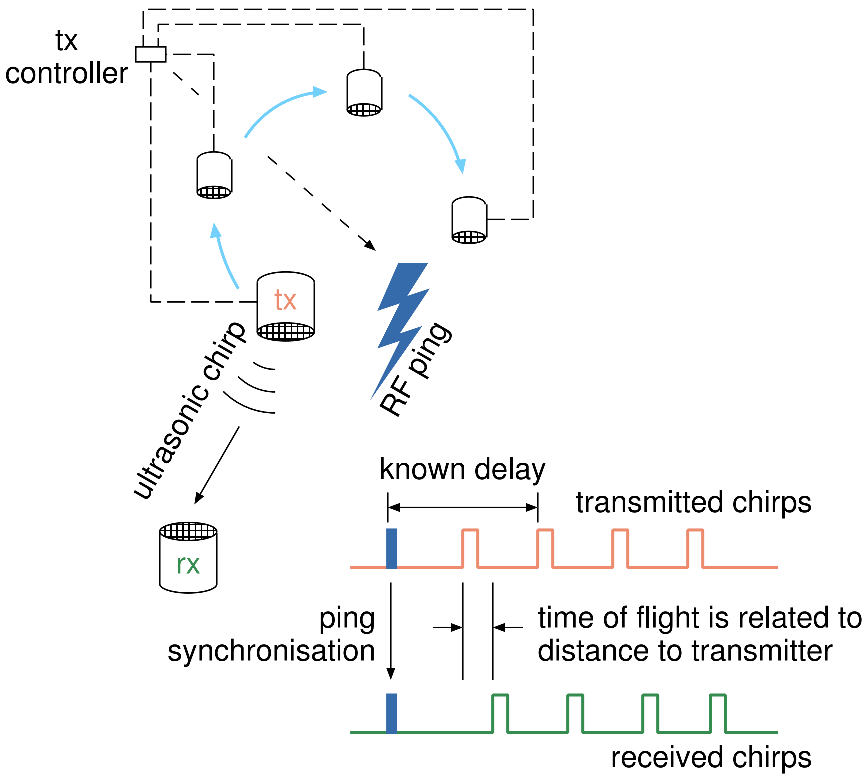
Bristol Low Cost System

- infrastructure sends one RF signal followed by timed ultrasonic signals



Work at Bristol

The Low Cost System



Operation

- RF signal (ping) followed by four or more equally spaced ultrasonic signals (chirps)
- receiver calculates time-of-flight (distance) using time from ping and known delay
- known transmitter locations allows receiver to trilaterate its position

Advantages

- **private**: position is known only to the receiver
- **scalable**: multiple receivers can use the infrastructure without increasing the load on the system (passive, read-only like GPS)

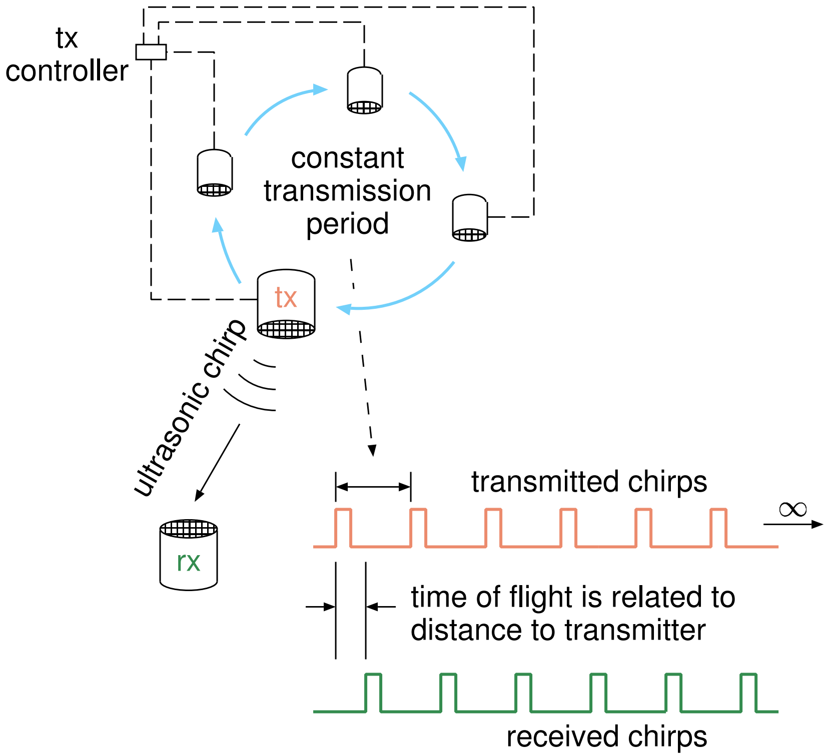
Motivation

Why eliminate RF?

- **no clock drift** and time-of-flight/ranging bias
  - drift between transmitter and receiver clocks means that there is an increasing ranging bias for chirps late in the sequence
- **no RF signal processing** which gives a latency, although small
- fewer components:
  - **smaller form factor** - easier to integrate into a wearable system
  - **less power**
  - **cheaper** - low cost narrow-band ultrasonic components

RF Free System

No More Synchronisation



Operation

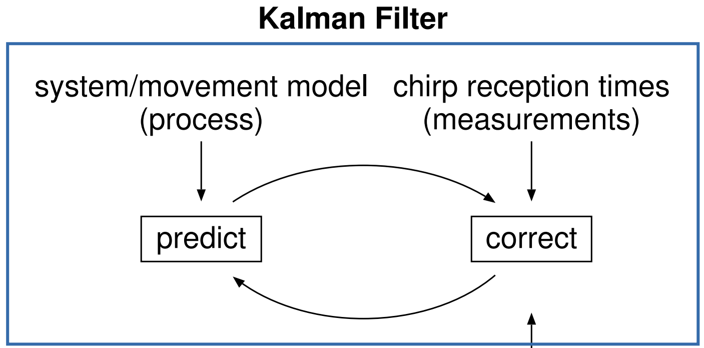
- cyclical transmission pattern
- constant transmission period 20-25Hz
- no RF synchronisation trigger to determine transmission times
- infrastructure only sends ultrasonic signals

- so receivers must use chirp reception times **ONLY**, *Yikes!*

RF Free Positioning (1)

How do we do it?

- use state space model (Kalman filter) to relate position and transmission times to chirp reception times
- transmission time for each chirp is found by exploiting constant transmission period



$$t = R - U \iff R = \boxed{U} + t$$

$$R_k = \boxed{U_0 + k \cdot P} + \sqrt{(x - X_{k\%n})^2 + (y - Y_{k\%n})^2 + (z - Z_{k\%n})^2} / v_s$$

R_k: reception time; U_0: transmission time of first chirp; k: chirp counter; P: transmission period; X, Y, Z: transmitter position; x, y, z: receiver position; v_s: speed of sound

Measurement Sensitivity Equation

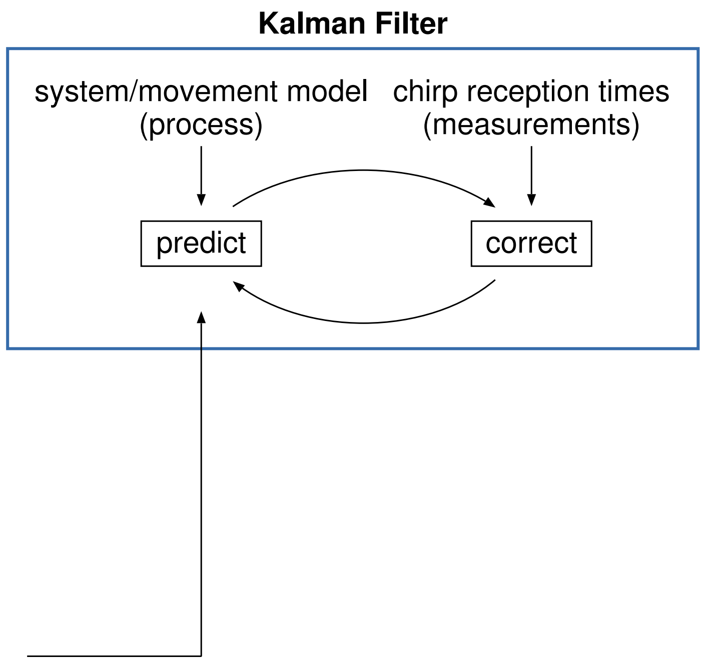
RF Free Positioning (2)

The Kalman Filter

- extended Kalman filter
- single-constraint-at-a-time (SCAAT) measurement input (UNC)
- state variables:
  - transmission period P (constant)
  - transmission of first chirp U_0 (constant)
  - position (x, y, z)
- stationary process model, aka Position Model

$$\vec{x}_k = \vec{x}_{k-1}$$

Process Equation

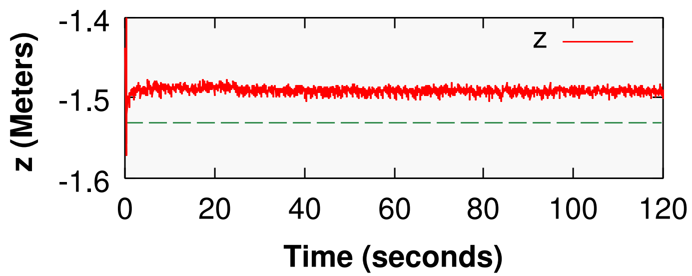


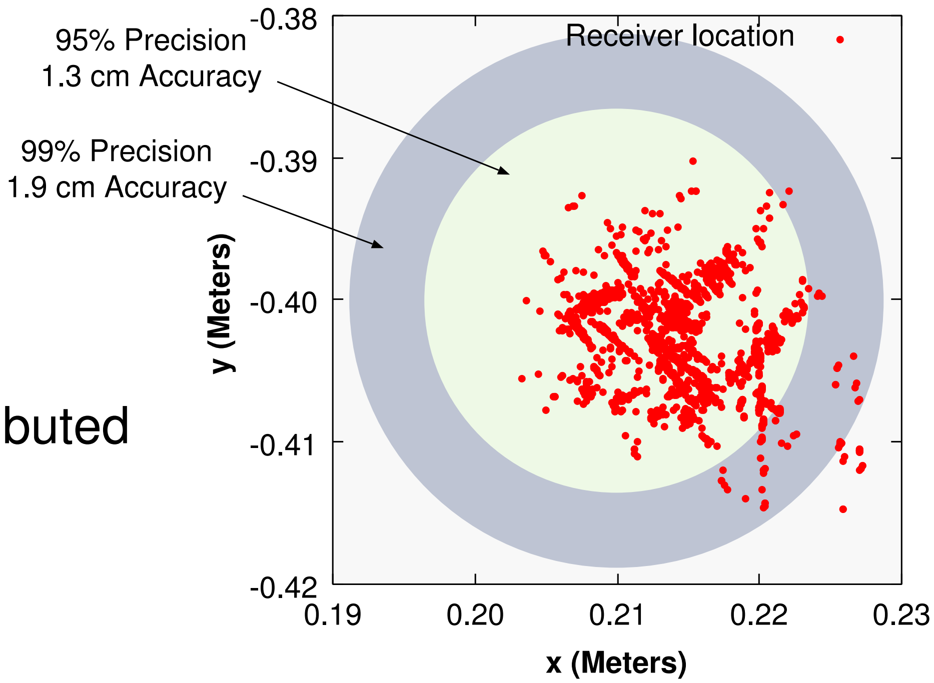
Stationary Results

- two minute trial with receiver stationary
- six transmitters in the infrastructure

		Precision	
		95%	99%
Accuracy	2D	1.3 cm	1.9 cm
	3D	4.7 cm	5.0 cm

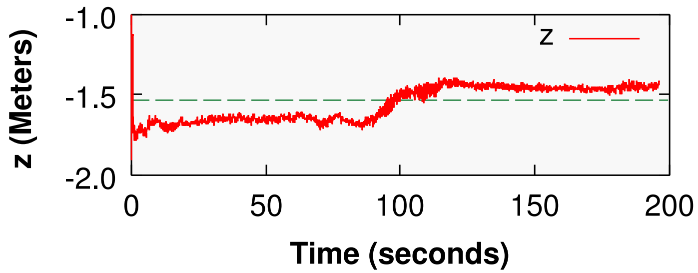
- poorer performance along z axis attributed to dilution of precision (DOP)



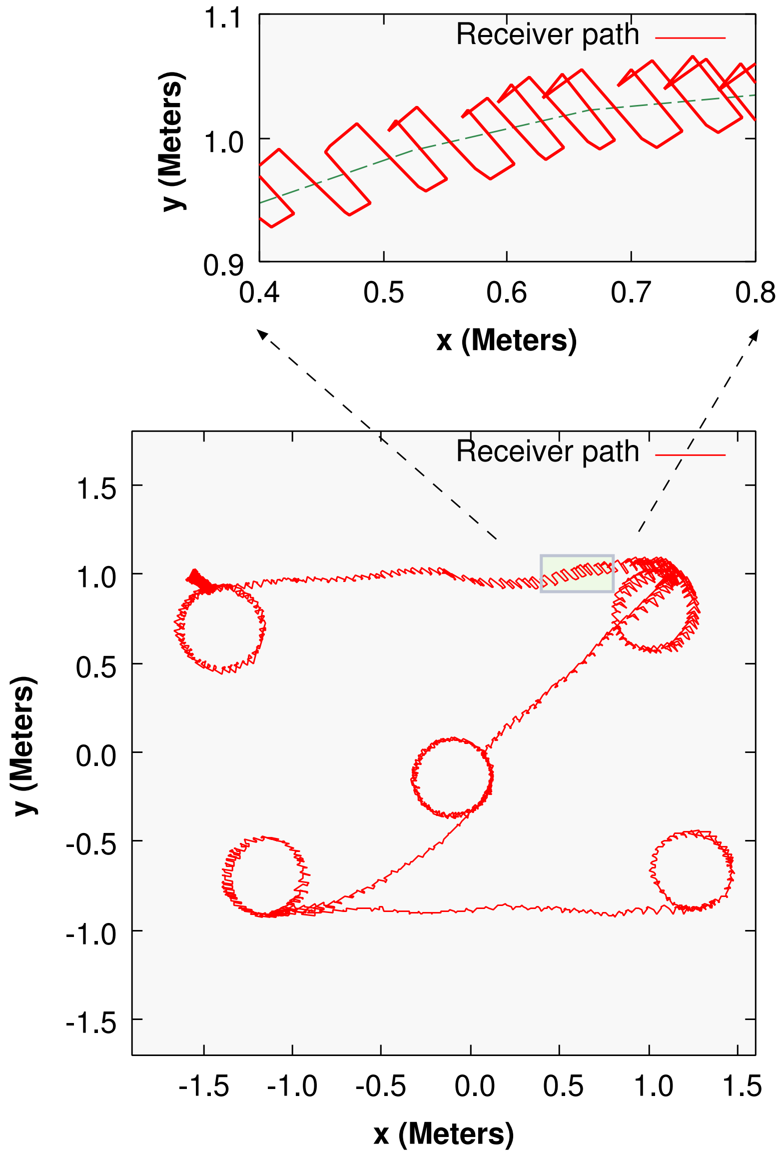


Dynamic Results

- three minute trial
- six transmitters in the infrastructure
- receiver on the back of a swivel chair
- Projected Standard Deviation (x, y) ~ **5 cm**
- error along z axis: 15 cm, 95%; 21 cm, 99% (DOP again)



- easily achieved in real-time by 200MHz StrongARM wearable PC



Advantages

- fewer components means **lower power** consumption, **smaller** receiver circuit, and **lower cost**
- use of SCAAT provides **low latency** since position is updated with every chirp instead of waiting for four or more
- **improved accuracy** (3D: 5cm) since clock drift problems are eliminated
- no **privacy** issues: passive, read-only positioning system where position is known only to the receiver
- **scalable**: can add receivers without increasing the load on system
- Kalman filter residual analysis allows us to discard poor measurements from in-band noise, occlusions to improve **reliability** (future work)

Future Work

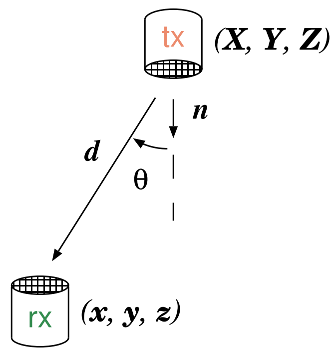
- evaluate performance against various environmental disturbances such as in-band noise and occlusions

- add velocity to the process model to reduce deviations

$$\vec{x}_k = \vec{x}_{k-1} + \delta t \cdot \vec{v}_{k-1}$$

- evaluate performance with different receiver velocities and accelerations

- improve measurement model by incorporating errors related to angle (θ) and distance *(d)* from the transmitters



- optimisation and miniaturisation

Thank you

The End