Enhancing Inertial Odometry with WiFi

A new approach to using WiFi as a velocity sensor to accurately track distance moved by humans and robots in indoor environments

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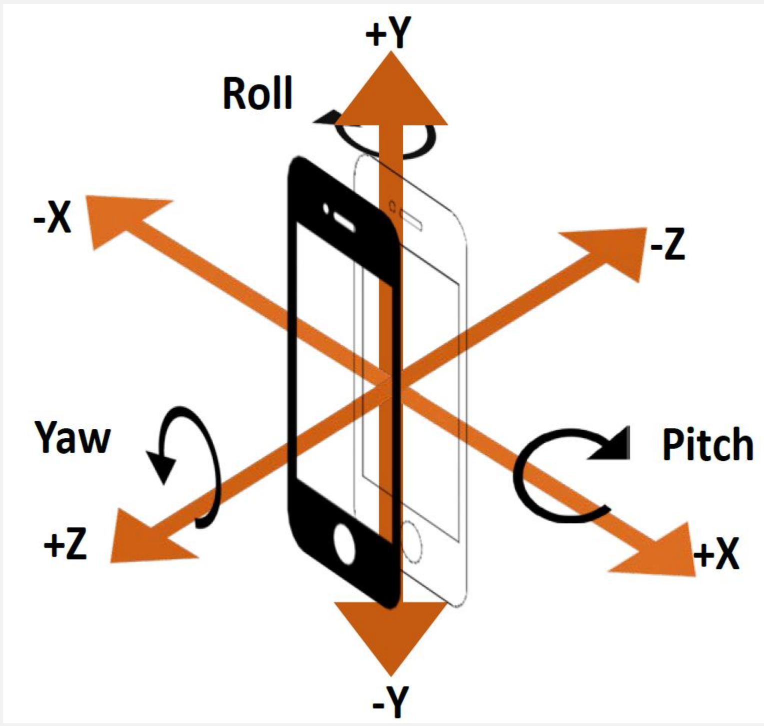
INTRODUCTION

Inertial Navigation is a viable alternative to GPS in indoor environments



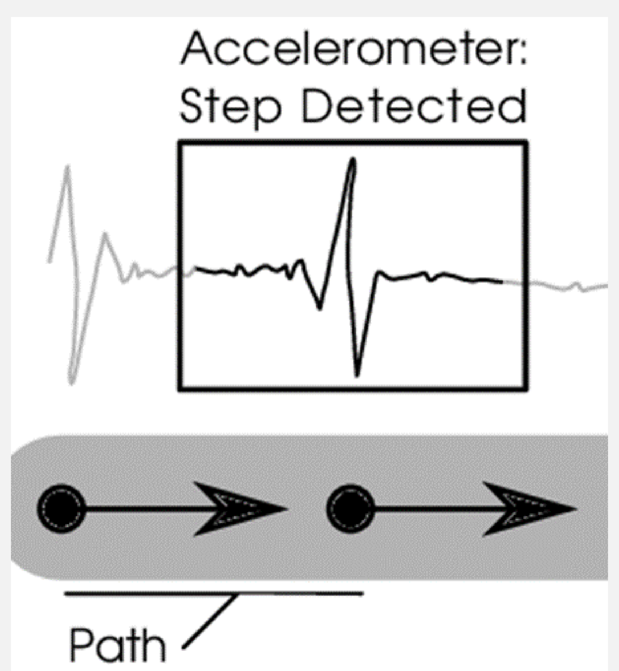
Inertial Measurement Units(IMUs) are low cost (~$2) and ubiquitous.

Measure linear and rotational acceleration using accelerometer and a gyroscope.

Double integral of acceleration gives linear and rotational speed.

PROBLEM

Distance tracking using accelerometers suffers from drift errors



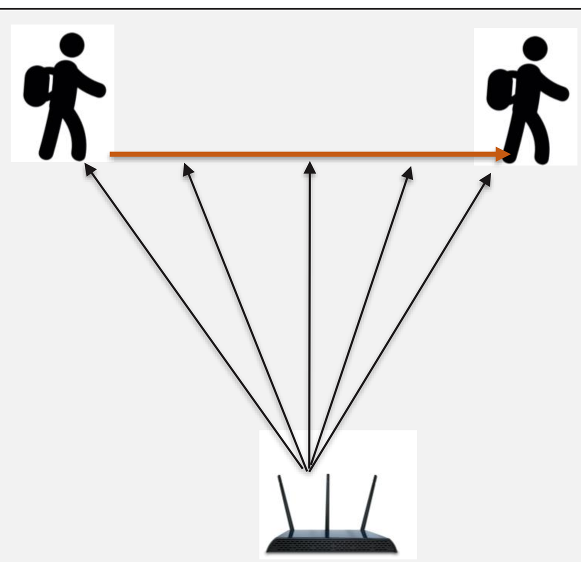
Error after double integration grows cubically in time

Current solutions use external sensors to correct drift through sensor fusion.

Outdoors : GPS Measurements
Indoors : No ubiquitous sensor
Limited to step counts

RESEARCH QUESTION

Can we use ubiquitous WiFi signals to achieve accurate inertial distance tracking i.e odometry?



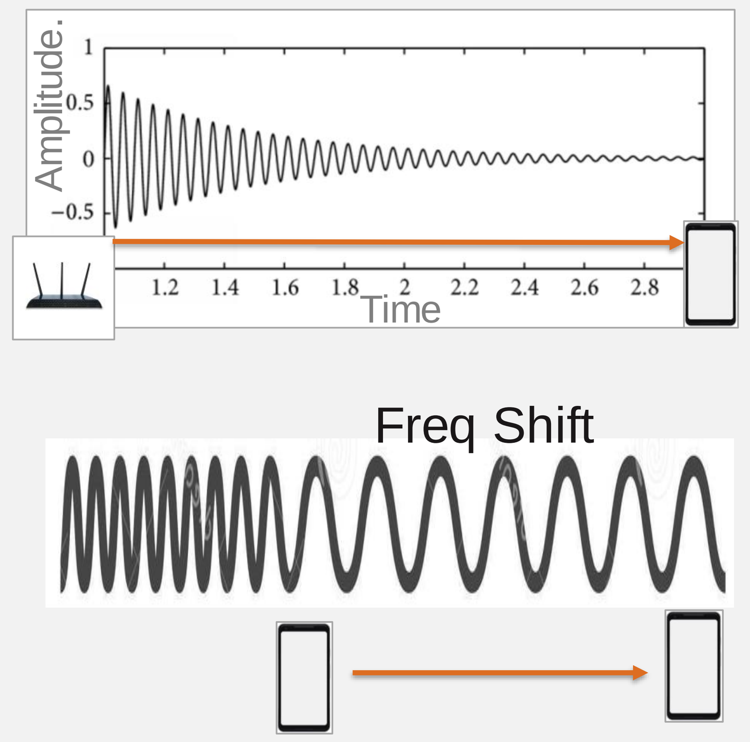
WiFi is becoming ubiquitous.

Smartphones already have IMUs and WiFi chipsets.

Can we make them sense distance instead of just steps?

METHOD

Use Doppler Shift from WiFi Channel State Information (CSI) as an external velocity sensor for Sensor Fusion.



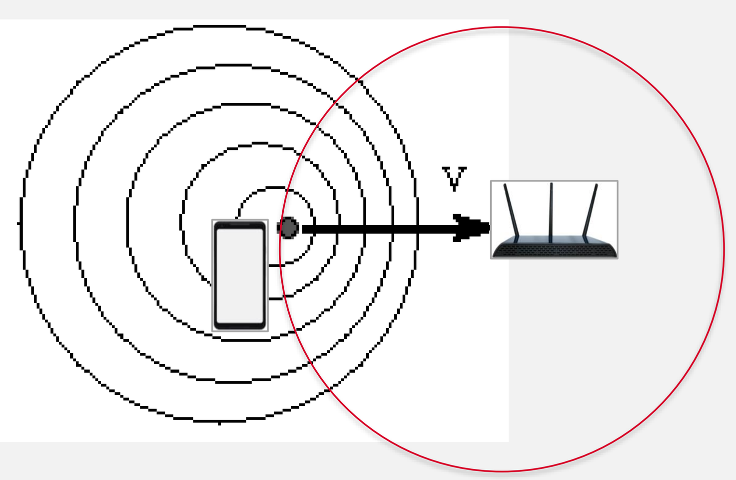
CSI: Change in the amplitude and phase of the transmitted signal.

802.11n/ac WiFi chipsets must measure CSI to decode packets.

Receiver's motion causes an apparent change of frequency in the transmitted signal (Doppler Shift), observable in CSI as a sinusoid.

KEY CHALLENGE

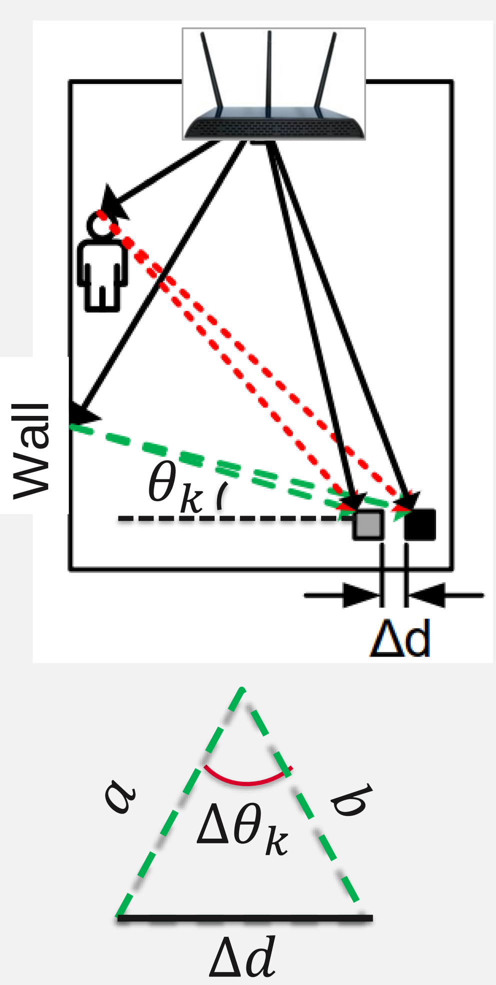
Doppler Shift only measures radial velocity, not the actual velocity.



Doppler Shift ∝ cos(direction of motion)
How can the receiver measure its actual velocity and not its radial velocity?

Key Innovations:

1) Exploit Doppler shift from multiple reflectors in the environment!
2) Select reflection most parallel to direction of motion

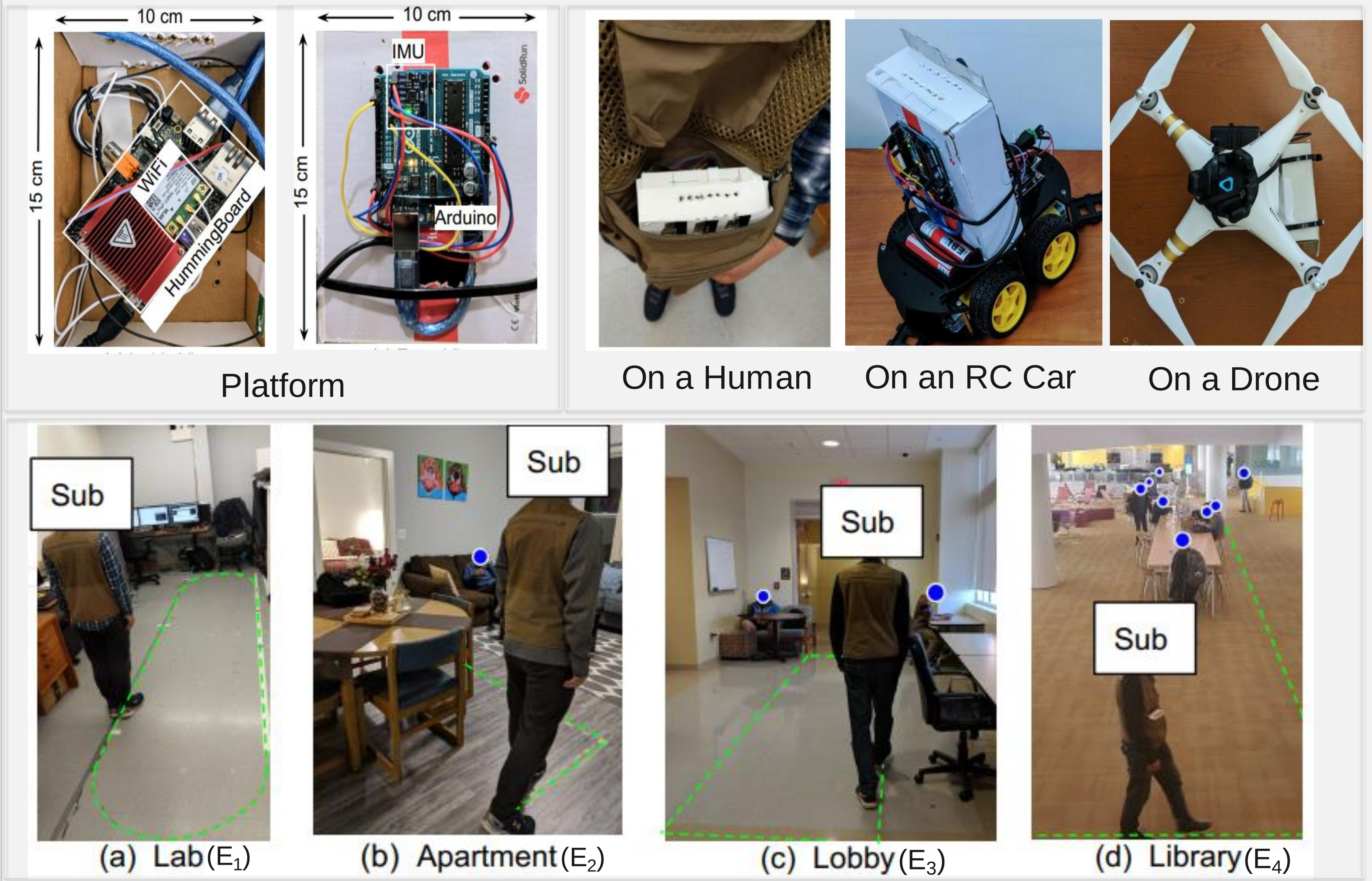


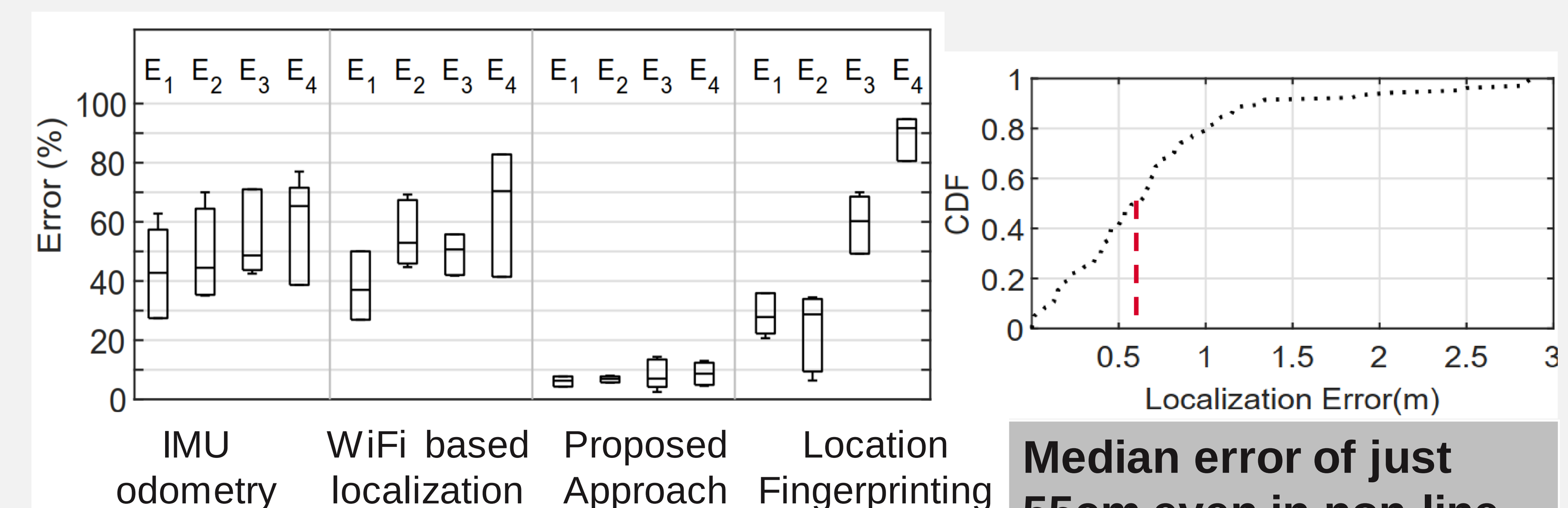
Doppler Velocity from reflector k:
$\left(\sqrt{\Delta d^2 + 2ab(\boldsymbol{cos}(\boldsymbol{\Delta\theta_k}) - 1)}\right)/t$

⇒ Minimizing $\boldsymbol{\theta_k}$ yields smaller $\Delta\theta_k$, and thus, larger shift.
⇒ Conversely, sinusoid with highest frequency ($\boldsymbol{F_k}$) approximates actual velocity: $\boldsymbol{v \approx F_k\,\lambda}$
(λ = just 5.2cm at 5.8 Ghz!)

EVALUATION

Average distance estimation error of 6.28% for human and robot subjects across 4 Environments

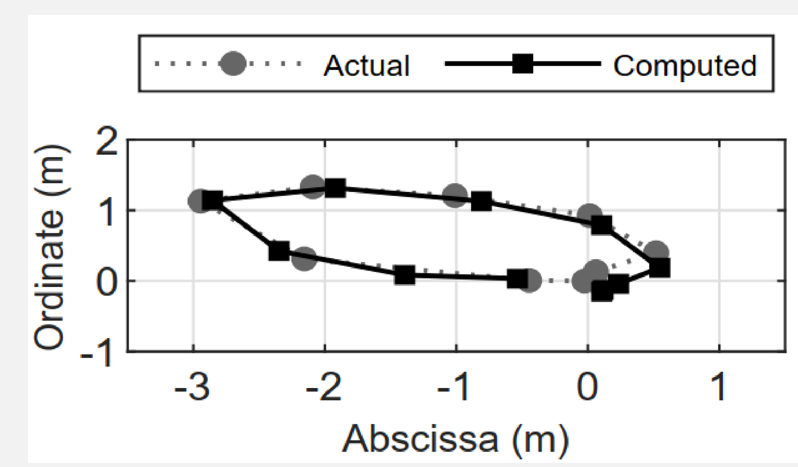




Median error of just 55cm even in non-line of sight environments!

KEY TAKEAWAY

Used Doppler Shift from WiFi CSI to accurately measure distance and location of a moving object.



Applications :

- Virtual Reality
- Indoor Fitness Tracking
- Drone Tracking for Warehouses

(This work is available at ACM UbiComp/IMWUT Vol3 Issue 2 June 2019 https://imwut.acm.org/)