MACHINE LEARNING FOR INCREASING LOCATION MEASUREMENT SAMPLING FREQUENCY AND ACCURACY

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- THE IORL PROJECT

CONTENTS

THE CONTEXT

INTERNET OF RADIO LIGHT 5G NETWORK

- ## Overview

  Enabling an indoor 5G network by utilising both mm-Wave and Visible Light Communications (VLC) for high throughput, low latency transmission from a Distributed Antenna System (DAS) situated in ceiling lights.

- ## Primary targets
  - Target 10GBps
  - Sub 1ms latency
  - Full coverage and reduced transmission occlusion from optimal ceiling positions in every room
  - An Indoor Positioning System (IPS) with sub 10cm accuracy

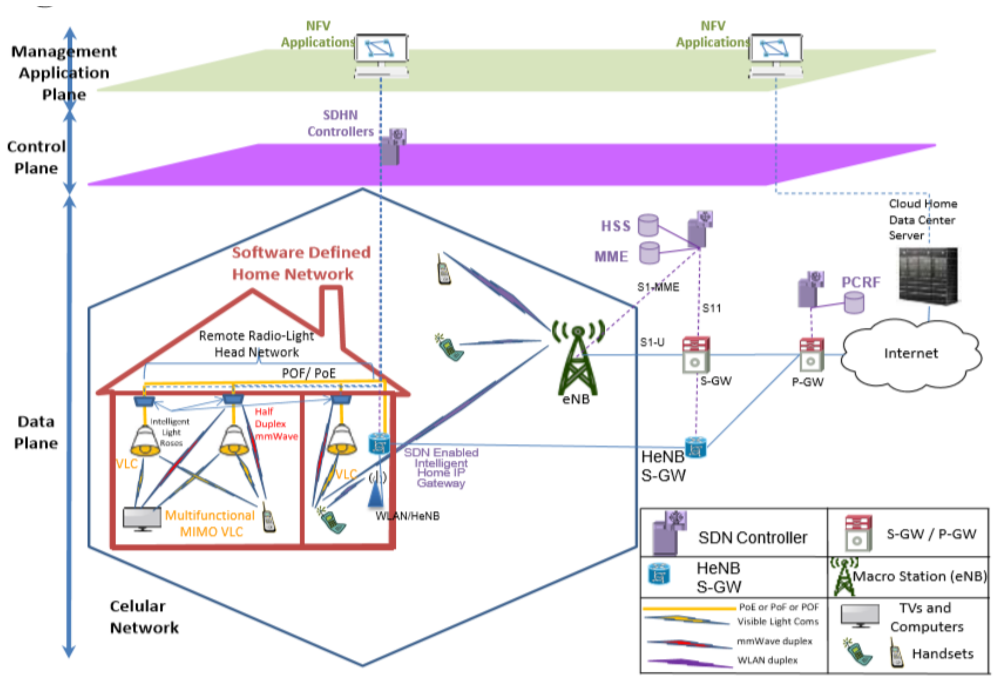


Figure 1 – IoRL Architecture

LOCALISATION

- Attention to tracking in wireless systems for such applications:
  - Health care and safety [20] [18]
  - Navigation and tours [51]
  - Object tracking in smart factories
- Focusing on tracking
  - Precision
  - Latency
  - accuracy

VIRTUAL REALITY AND 5G

VR is one of the most data intensive media systems, expected to benefit greatly from 5G

- Data consumption
- Multiplayer accessibility.
- Performance increase from edge computing

Exploiting the IoRL IPS for VR tracking proposes new prospects

- Enabling tracking of various devices (Phones, PC's)
- Multiple users in shared environments
- Tether-less connectivity
- Full coverage for extended play spaces

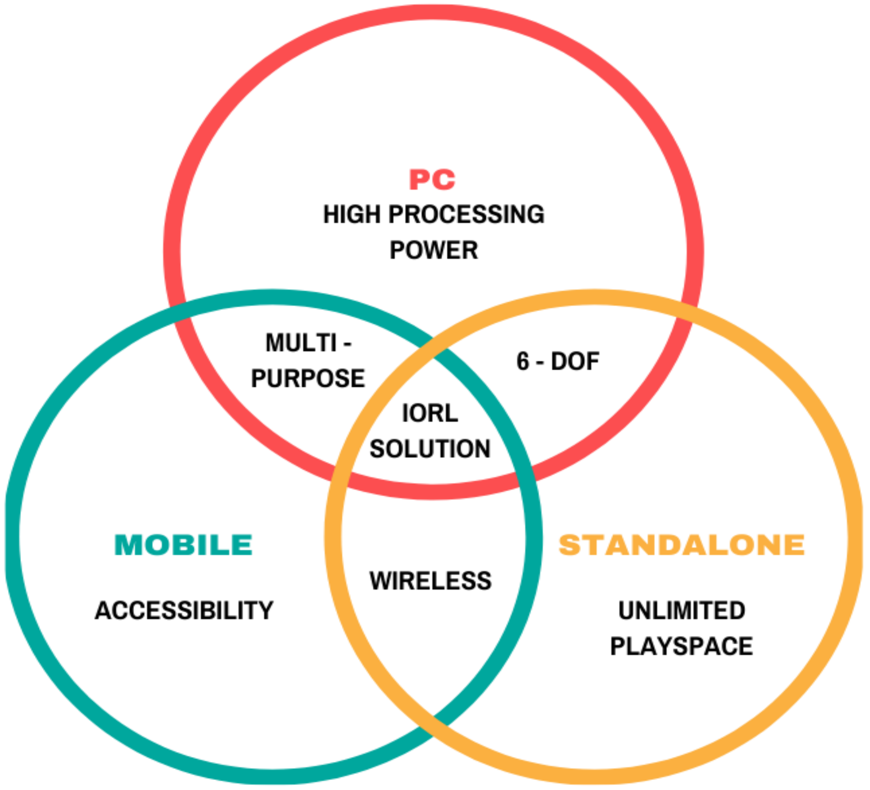


Figure 2 – Comparison of the main VR platforms

THE FOCUS ON IORL VR - TRACKING

Successful tracking is pivotal to exploiting the benefits of extended coverage and tether-less VR.

Poses the ultimate challenge for a tracking

- Accuracy – Correct tracking response in the order of a $1/10^{th}$ of a mm
- Precision – Sub millimeter
- Latency –Real time, Motion to Photon (MTP) latency of approximately 12ms

Initial proposed IoRL tracking:

- MmWave TDOA in the uplink channel
- VLC RSS in the downlink channel
- Kalman filter for prediction and sensor fusion

THE IORL INDOOR POSITIONING SYSTEM

THE IORL IPS FRAMEWORK

- Zadoff Chu sequences transmitted in the uplink channel to each Remote Radio Light Head (RRLH) transceiver. The raw TOA data is collected by the IoRL RAN and stored in the Location Database (LD)
- Positioning Reference Signals (PRS) are transmitted by each RRLH for VLC communication. The raw RSS data is again stored in the Location Database
- The Location database stores the known antenna locations, both measurement data sets and estimated user positions
- The Location server performs the location estimation and Kalman filtering to output the estimated user position

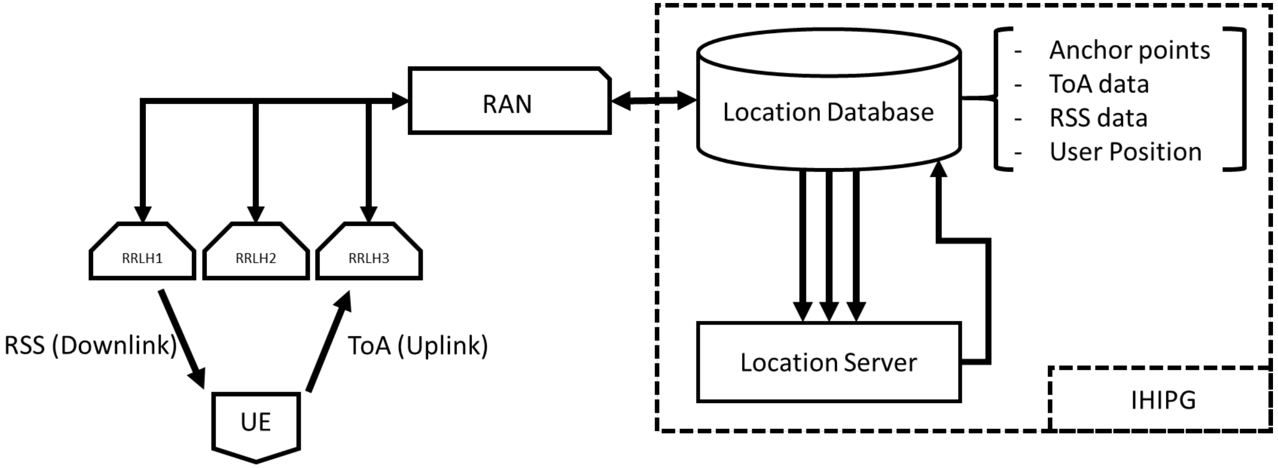


Figure 3 – IoRL IPS framework

LOCATION DATABASE AND LOCATION SERVER

Location Database – Comprised of four tables

- Anchor points
- ToA data
- RSS data
- User Position

Location server – Performs the algorithms

- Collects Anchor data
- Collects both measurement data sets
- Estimates TDOA position and RSS position
- Performs Kalman Filtering
- Outputs estimated position

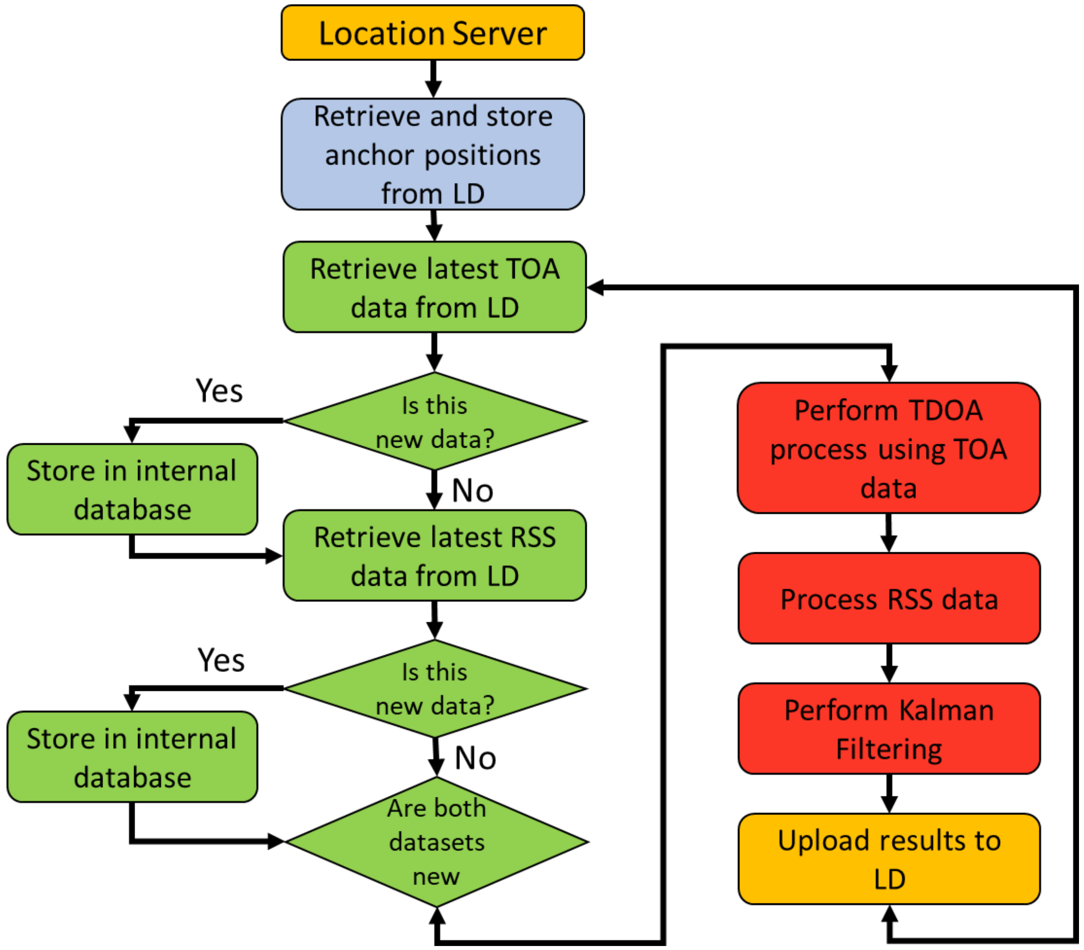
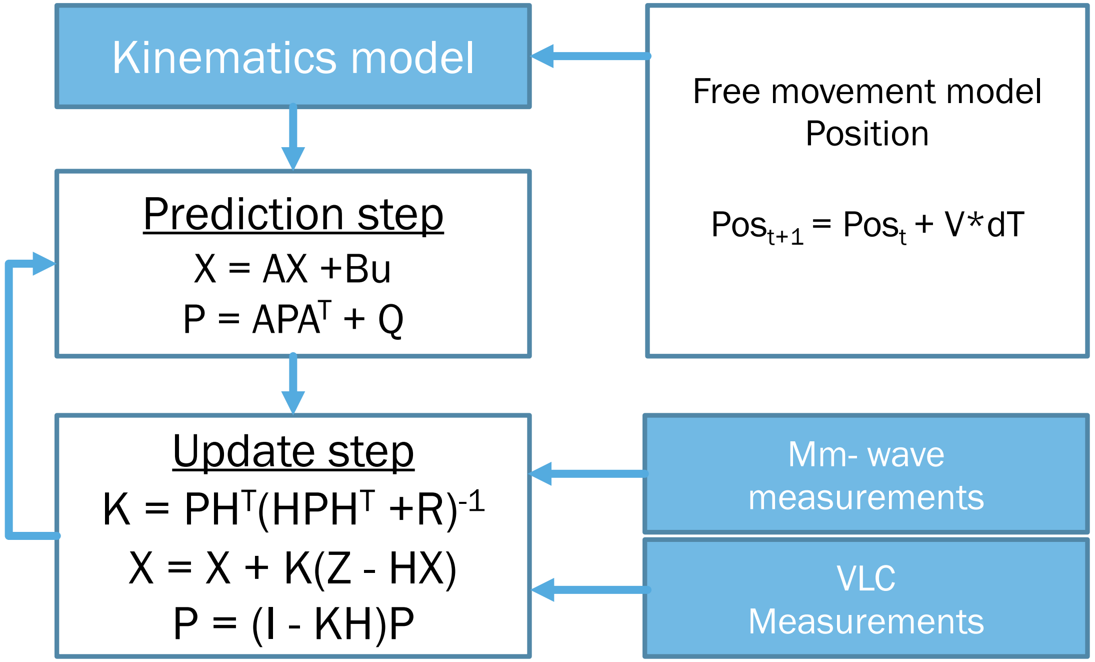


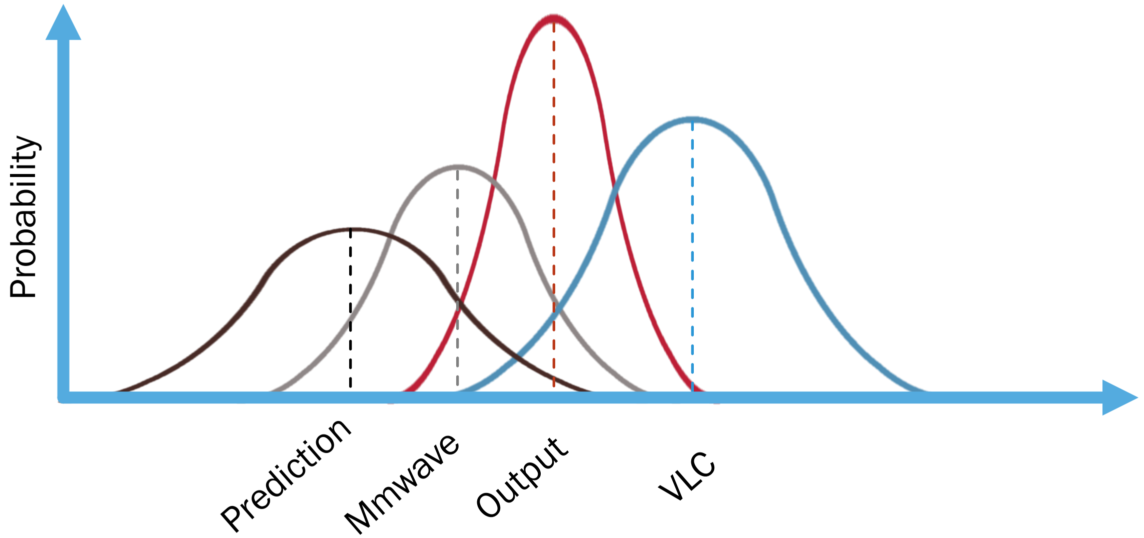
Figure 4 – The Location Server Process

SENSOR FUSION – KALMAN FILTERING

- Kalman filtering has proven to be a robust tracking filter
  - Enabling prediction of user movements with no data
  - Considering weightings of uncertainty's in noisy measurements
  - Responsive and non computationally intensive

- A recursive filter consisting of two stages
  - Prediction stage - use a physical model to suggest position
  - Update – compare prediction and measurements to evaluate the output





THE PRIMARY METHOD

In order to realise the positioning system capabilities we model the various components.

- Firstly, we collect a real VR users position data (x_{pos}) from a HTC Vive system
- Apply AWGN $z_{i} \sim N(0, \sigma)$ to the position data (x_{pos}) to generate our mmWave and VLC measurement data

$$x_{mm/vlc} = x_{pos} + z_i$$

- σ_{VLC} = 0.17, based on data collected from ISEP partners
- σ_{mmwave} for simplicity is varied between 0.05 & 0.1
- Data transfers within the IoRL system are as shown in Figure 5

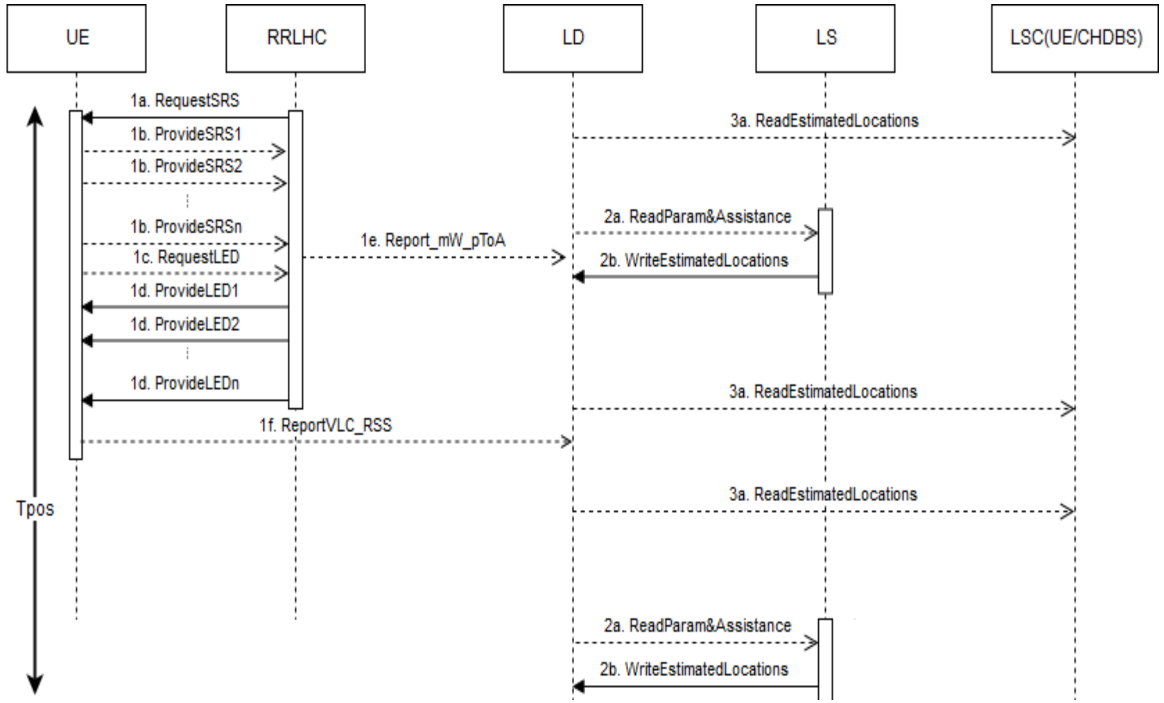


Figure 5 – The IPS data exchanges

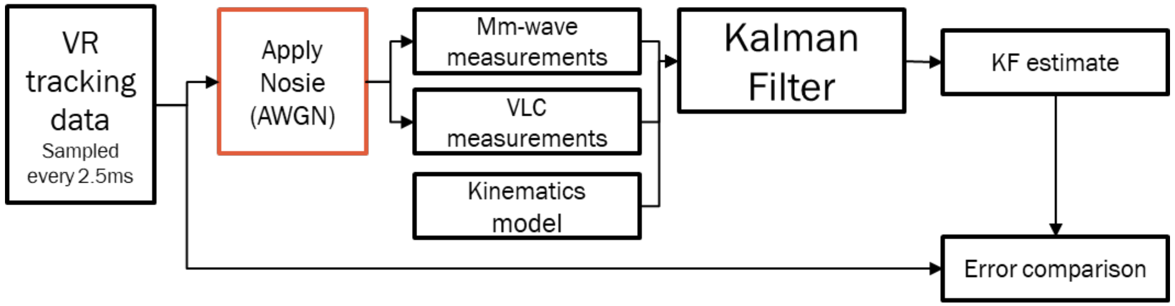


Figure 6 – The model structure

MODELLING MEASUREMENT ERROR

- Relates to three areas of estimation error
  - Attenuation/path errors – Multipath, occlusion
  - Measurement/detection error – Bandwidth, method
  - Estimation error – linearization, initial estimates, etc
- Model assumptions
  - Assumes LOS detection only
  - Uniform omnidirectional antennas
  - Error is uniformly distributed throughout the tracking area
    - soon to be adjusted to reflect more realistic results
- Initial possible result improvements
  - KF kinematics model
  - KF parameters
  - Filter choice
- Results
  - While the trend is non linear between mmWave SD and RMSE
  - Approximate 4x increase in RMSE from a mmWave SD of 0.01 to 0.1m

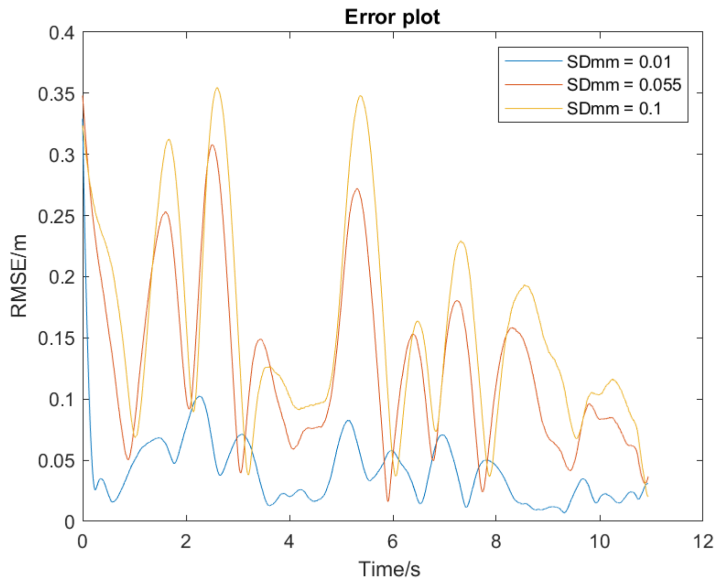


Figure 7 – comparison of RMSE with varied mmWave measurement error

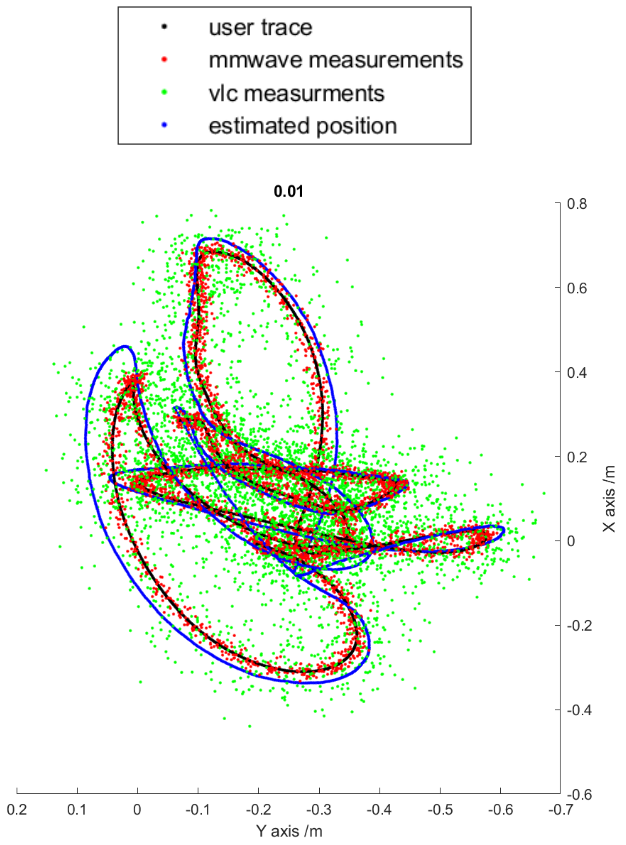
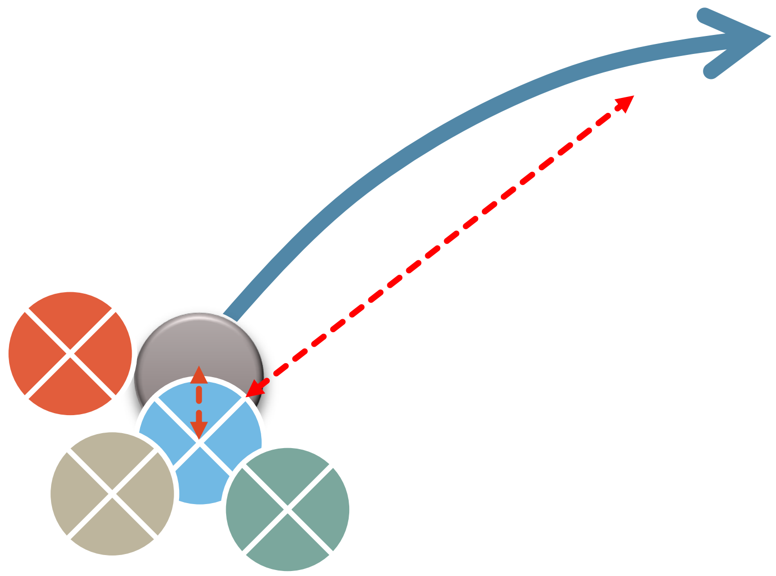


Figure 8 – Example (Birdseye view) of tracking and measurement plots



INTRODUCING LATENCY

INCREASED ERROR FROM LATENCY

EFFECTS OF LATENCY
- PROCESSING LATENCY (MTP)

Current model fails to account for latency in measurements

- Proposed IoRL framework suggests new measurement data every 2.5ms
- Updating the data transaction diagram and applying measurements of processing delays we approximate.
  - LS is able to process a new measurement every *7.5ms = dT*
  - This measurement is made visible to the user in approximately ***18.2ms. = MTP latency***
- These latencies are applied to our model and the error is again calculated.

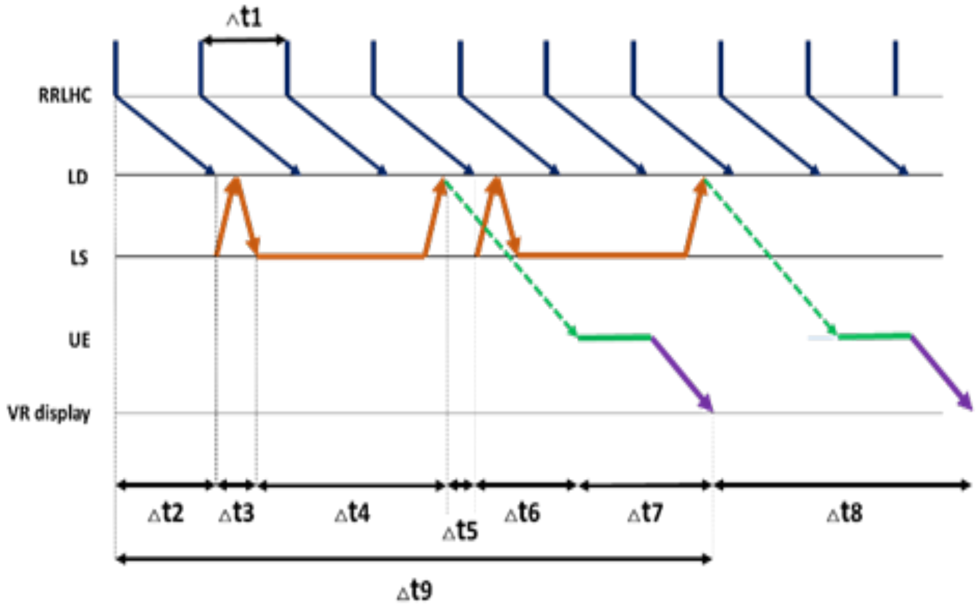


Figure 9 – IPS Data exchanges with time

Latency (Δtn)	Average measurement (ms)
Δt_1	2.5
Δt_2	2.8
Δt_3	1.2
Δt_4	5.4
Δt_5	0.9
$\Delta t_5 + \Delta t_6$	3.9
Δt_7	5.0
Δt_8	7.5
Δt_9	18.3

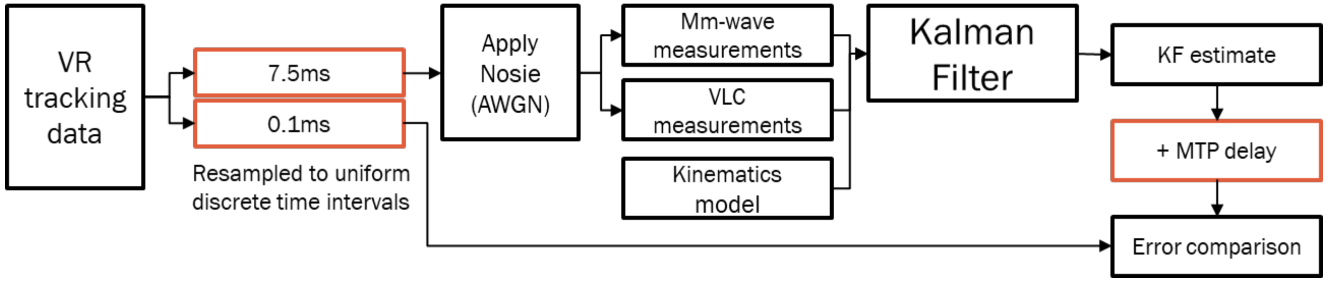


Figure 10 – The model structure

EFFECTS OF LATENCY
- PROCESSING LATENCY (MTP)

Parameters

- Setting our mmWave SD to 0.03m
- Receiving measurements every 7.5ms
- Adjusting solely the MTP latency

Observations

- As expected tracking performance greatly decreases with less frequent and delayed results.
- Initial results show a RMSE increase of 0.5mm per additional ms of MTP latency
- Our expected system latency shows an 8% increase in average RSME

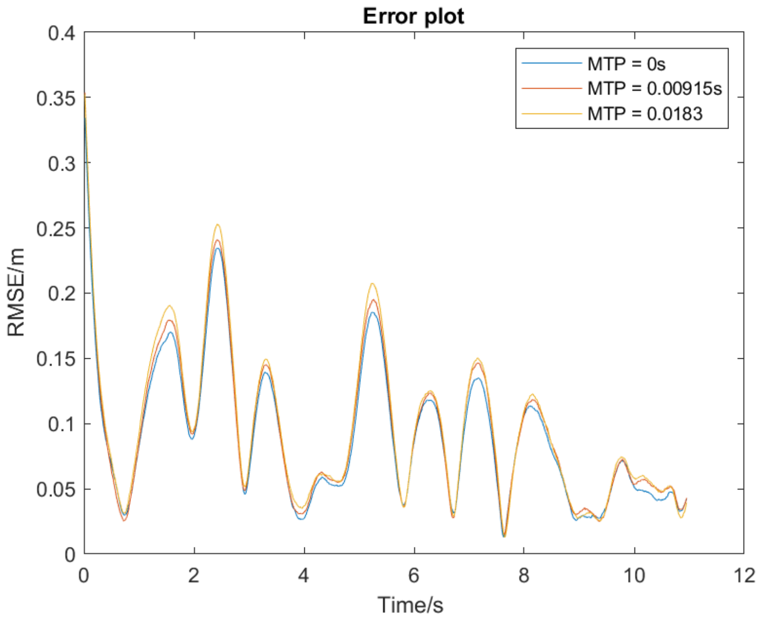


Figure 11 – Error of various MTP latencies

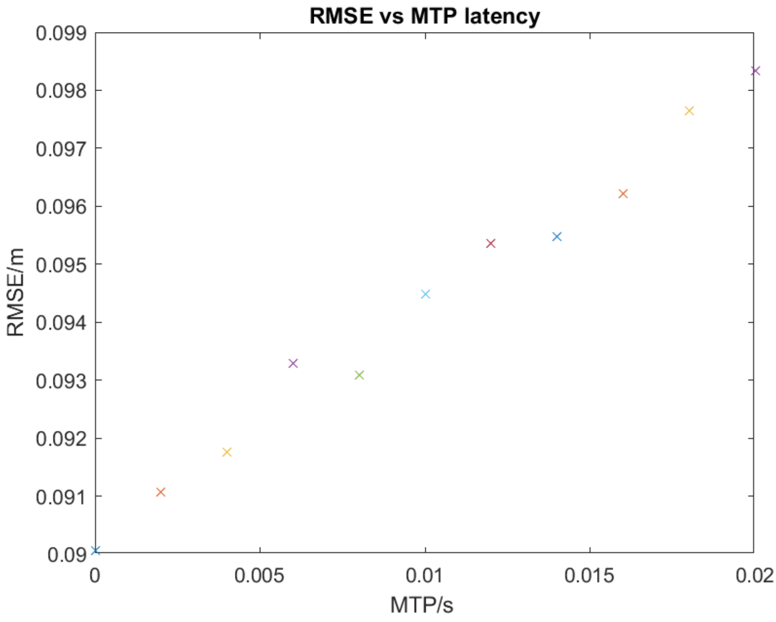


Figure 12 – Average RMSE with various MTP

EFFECTS OF LATENCY
- VARIED ESTIMATION DELAY

- In reality, TDOA estimations arrive every 40-50ms (much less frequent that MTP latency required of VR systems)
- Adjusted for by more frequent VLC measurements
- Implement a filter prior to the KF to check for available mmWave measurements
- This will cause minor delays as mmWave measurements may arrive earlier than the VLC update and thus will have additional delays to being processed

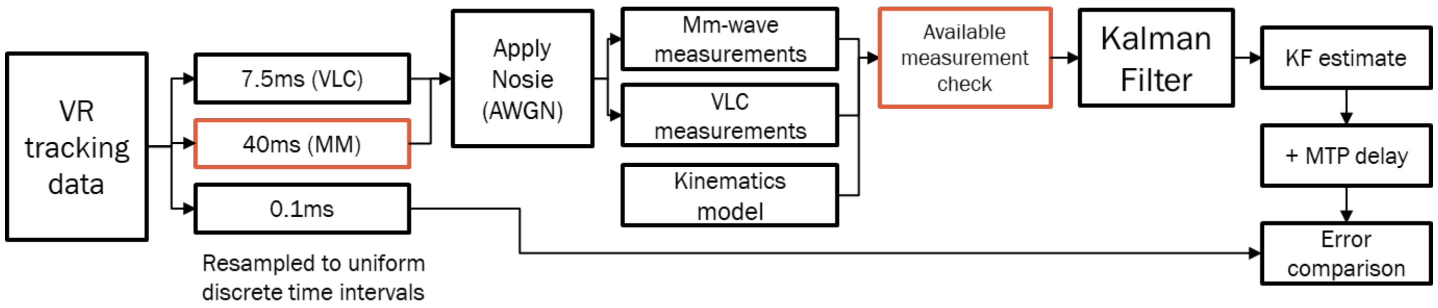


Figure 13 – The model structure

EFFECTS OF LATENCY
- VARIED ESTIMATION DELAY

Parameters

- Maintaining regular intervals of 7.5ms between VLC readings
- Increasing the delay of mmWave results to 40ms intervals

Observations

- Results in drastically larger RMSE
- **mmWave measurement data intervals from 7.5ms to 40ms intervals in increases RMSE by 150%**
- Interesting observation of harsh variations in the output as a result of increased mmWave intervals

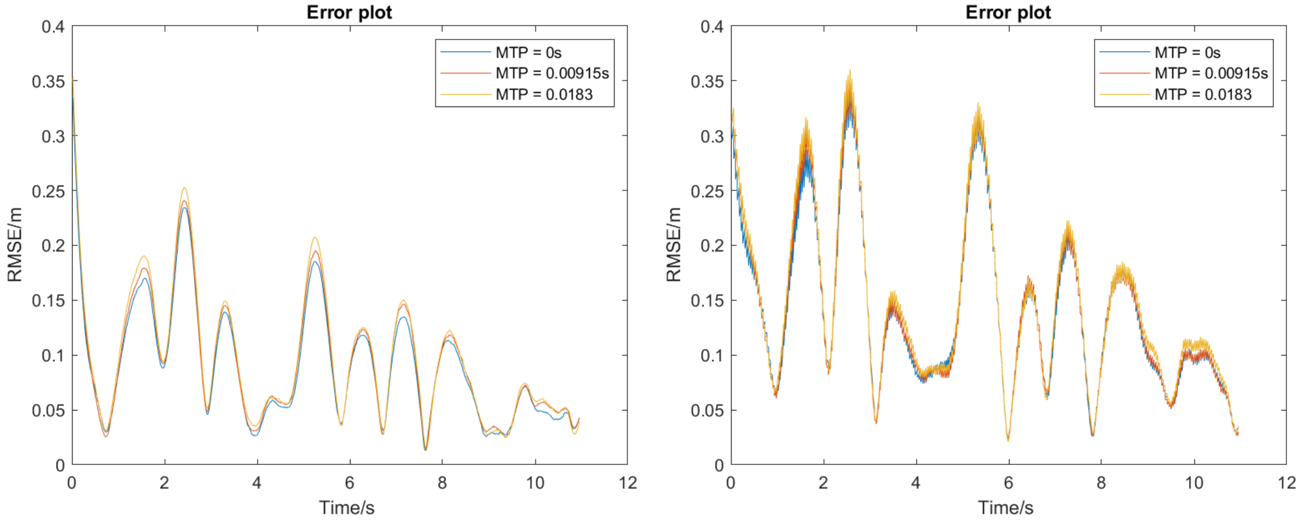


Figure 14 – Comparison of Errors With (left) and without (right) 40ms mmWave measurement delay

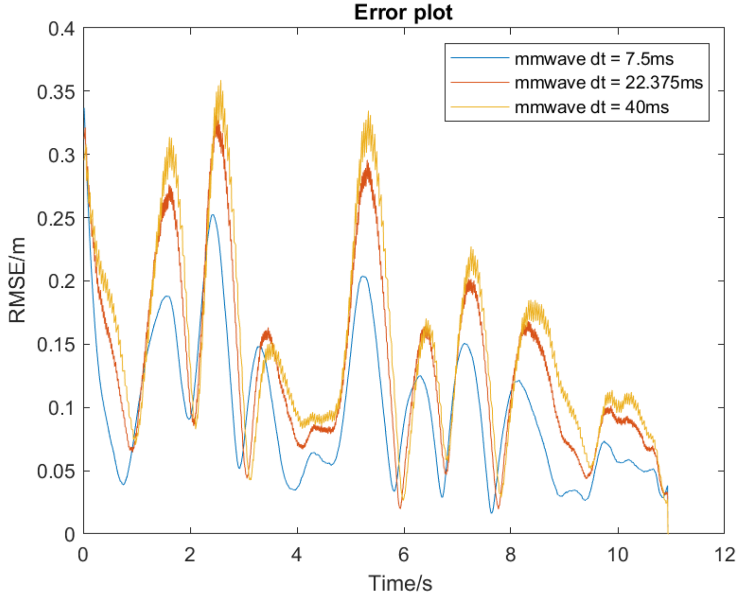
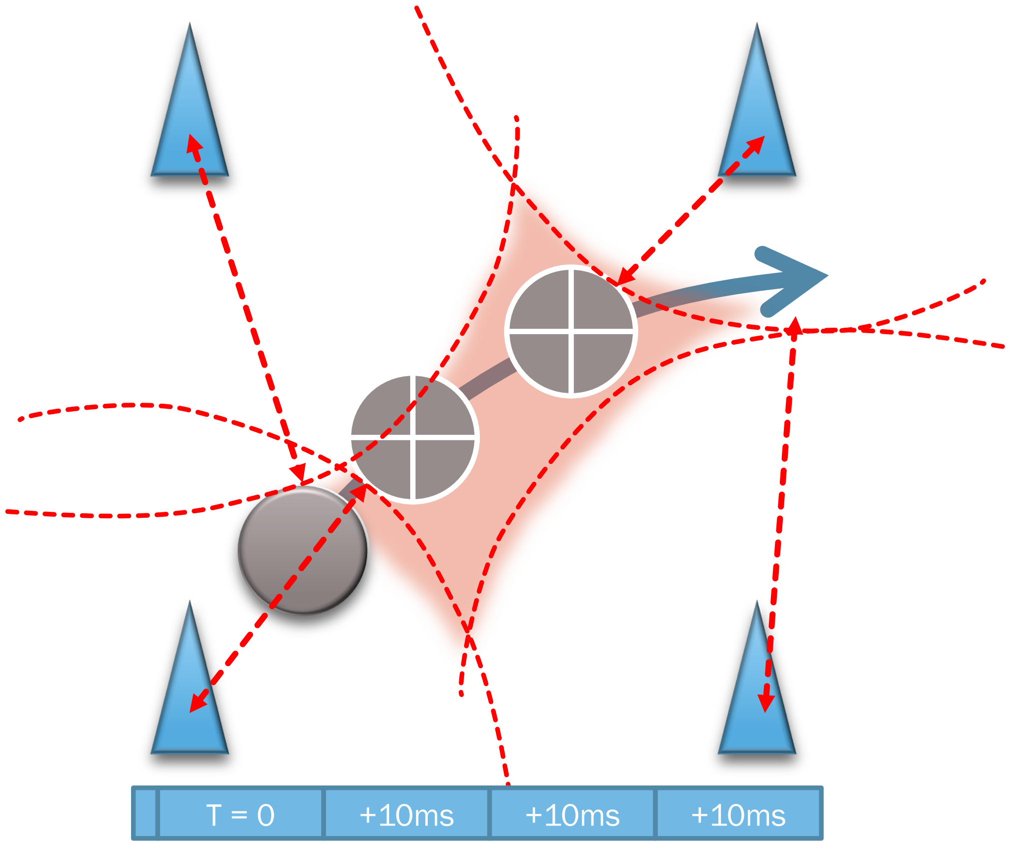


Figure 15 – Error plot with various mmWave measurement delays

EFFECTS OF LATENCY
- NON-SIMULTANEOUS TOA MEASUREMENTS

- Conventional TDOA involves emitting a signal at one time instant and comparing the various TOA from the receiver(s)
- Further complications arise when TOA signals are not emitted simultaneously but in sequence
- Within the demo setup the delay between each TOA measurement is expected to be 10ms
- To highlight the variety in error from increased latency between individual TOA measurements we have developed a simple TDOA model.



EFFECTS OF LATENCY
- NON-SIMULTANEOUS TOA MEASUREMENTS

parameters

- 5 RRLHs, one at each corner of a 10m cube room and one in the centre.
- User travelling at constant velocity of 1m/s
- Zero measurement error
- No latencies between measurements and outputs

Observations

- The greater the delay between TOA measurements the greater the positioning error
- 10x average error increase from 1ms intervals to 10ms

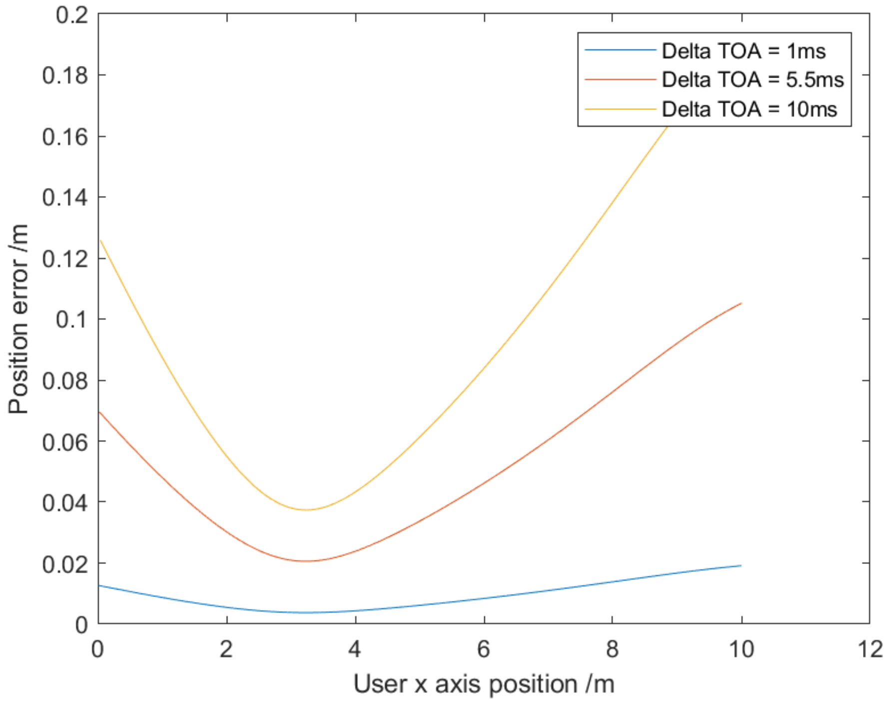
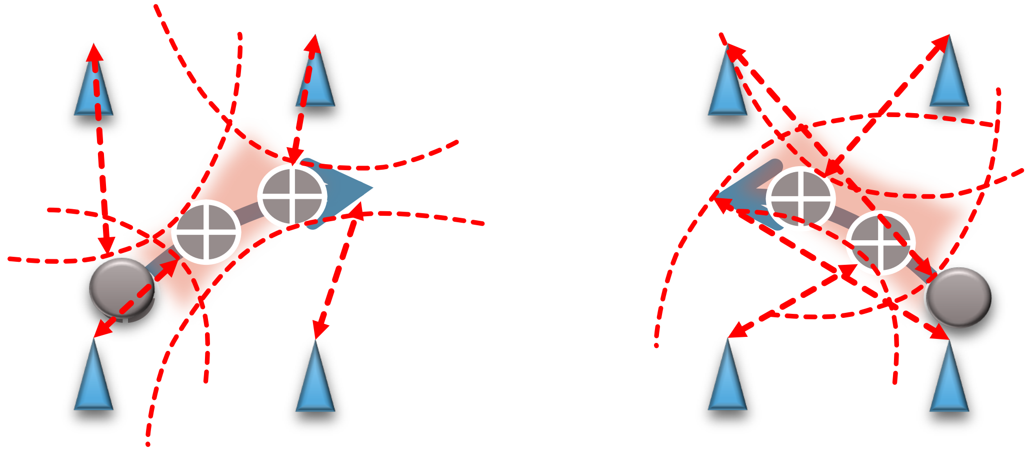


Figure 16 – Positioning error with various delays between TOA measurements

EFFECTS OF LATENCY
- NON-SIMULTANEOUS TOA MEASUREMENTS

- As the user travels in varied directions the TOA data used to calculate the final estimate is skewed
- Change in error profile is dependant on the direction of travel and the constant measurement sequence of RRLHs

We can expect to see similar effects as the user changes direction and velocity between measurements



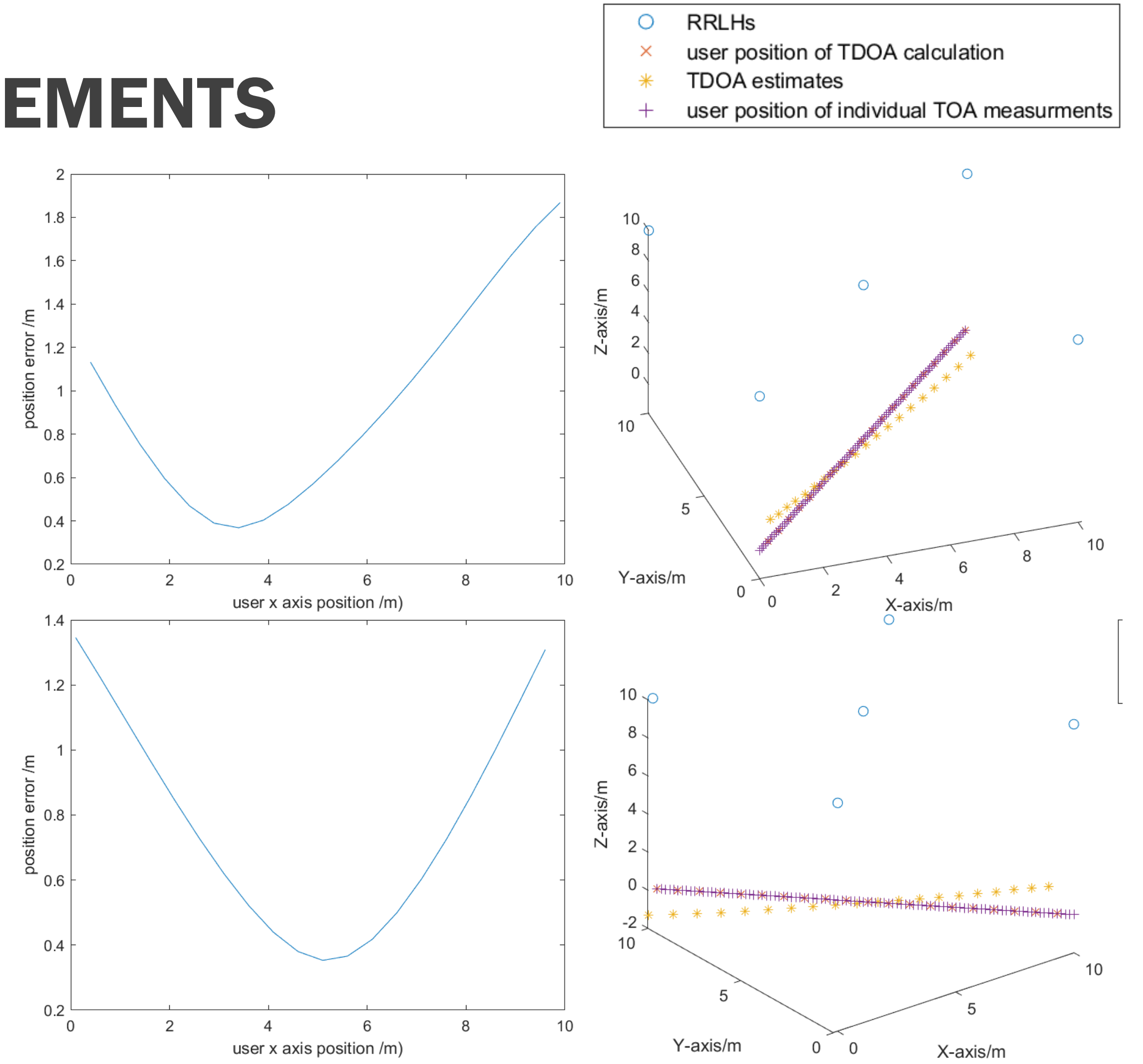
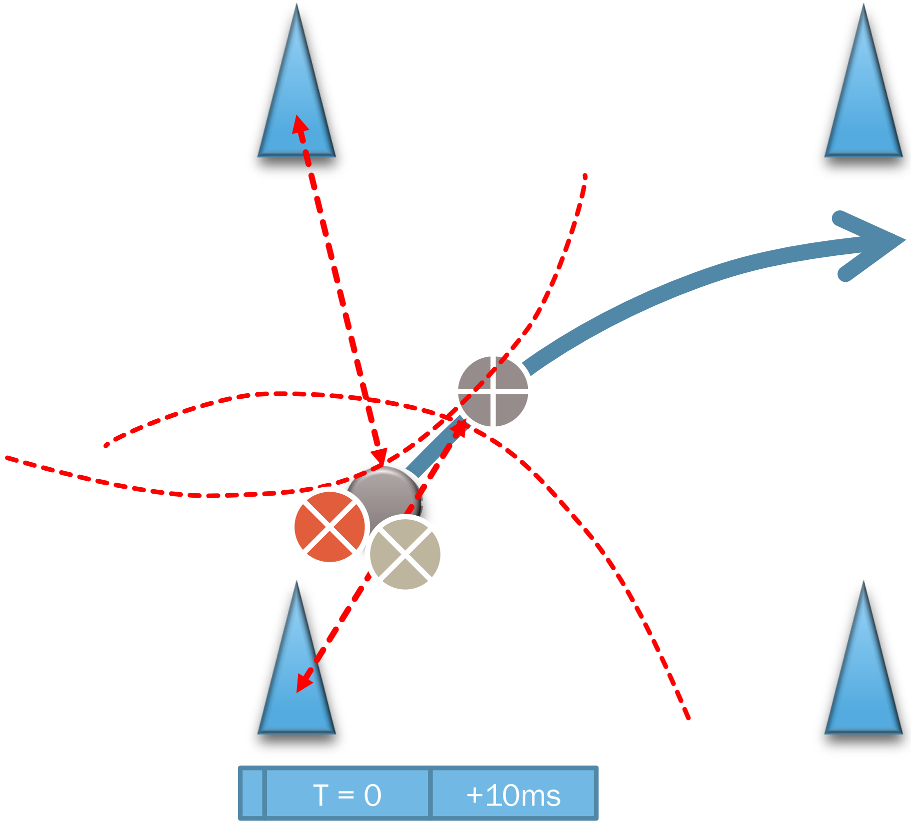


Figure 17 – Error profile effect from user travelling perpendicular directions across the room (top – left to right) (bottom – Right to left)

POSSIBLE PROPOSED SOLUTIONS

- Use a single TOA measurement every 10ms from an individual RRLH alongside the Kalman Filter prediction estimate and VLC measurement to correct the output
- Apply dynamic Kalman filtering by adjusting the measurement uncertainties given approximated user location



FURTHER WORK

- Use the mini – model to assess:
  - The effects under measurement error
  - Addition of expected latencies
  - Effects of user speed changes in velocity
- Apply more realistic noise to the measurement data
- Analyse the results of delay in TOA measurements applied to full Kalman model with VR trace data
- Develop and test the proposed solution

THANK YOU