Object Tracking using Kalman Filter

Jaikrishna
Neelkamal
Rangeesh
Riya

TEXAS A&M UNIVERSITY

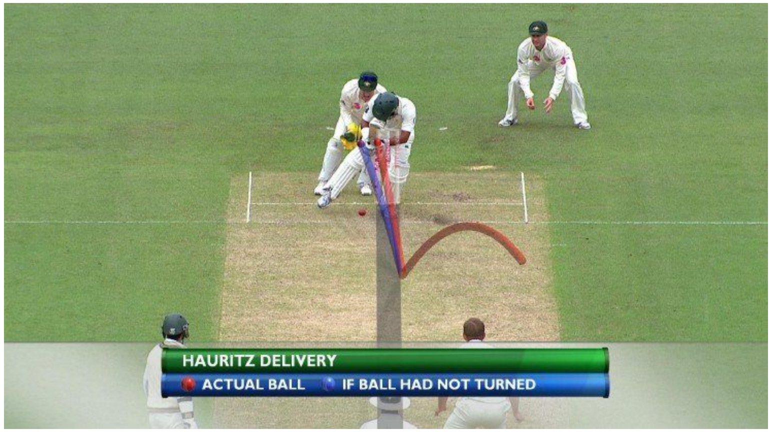
Motivation

Motivation | Hawk-eye

Crucial Decisions in Sports

Ball Tracking

Future Path Prediction

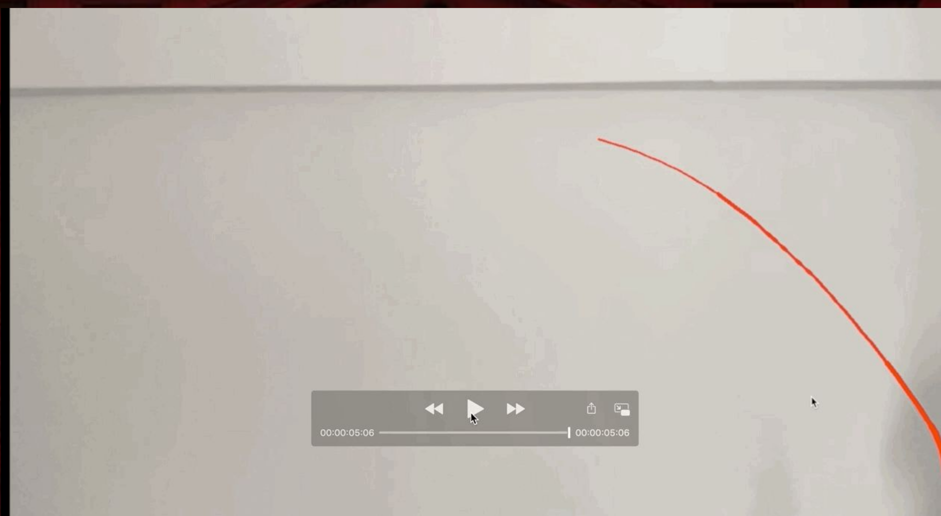


Path Deviation Prediction

Motivation | Hawk-eye

- Multiple cameras
    - Camera calibration
- Image Processing
    - Ball Recognition
    - Ball Characteristics
- Filtering
    - State Model
    - Measurement Model
    - UKF parameters
    - LSE
- Results

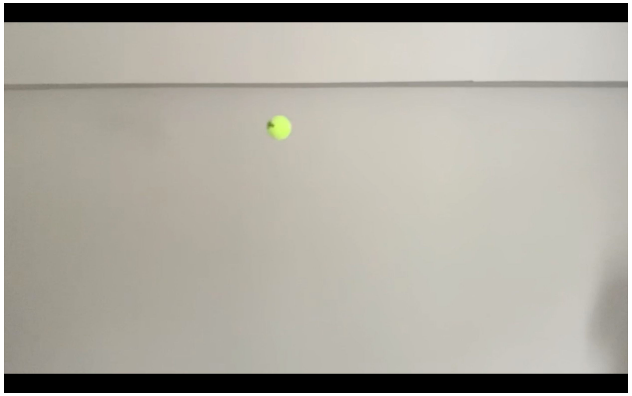
Computer Vision



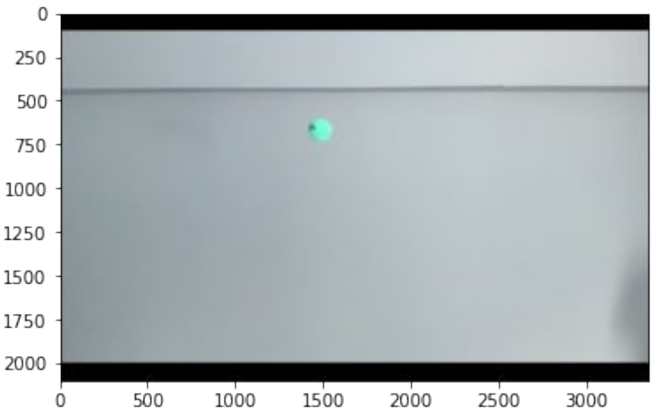
TEXAS A&M UNIVERSITY

Image Processing | Ball Recognition

- Single camera
  - Camera calibration
- **Image Processing**
  - **Ball Recognition**
  - Ball Characteristics
- Filtering
  - State Model
  - Measurement Model
  - UKF parameters
  - LSE
- Results



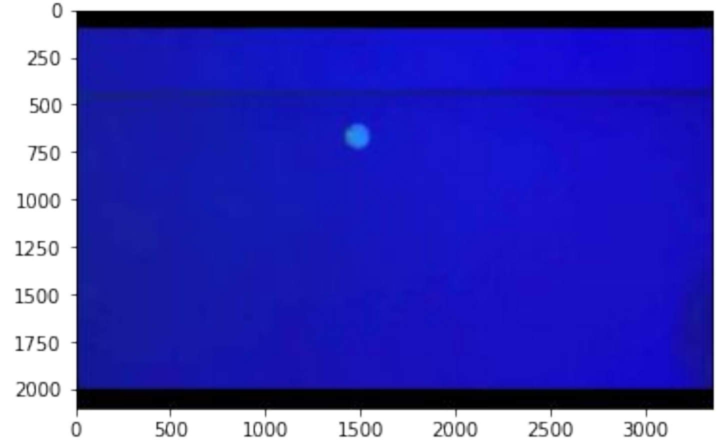
Imported Picture



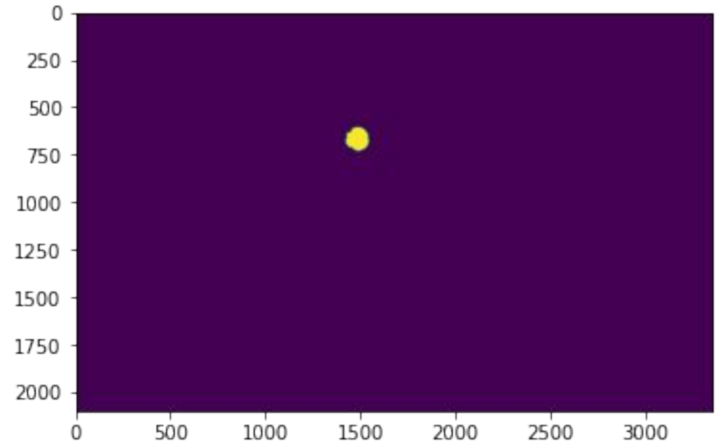
Smoothened Image after Gaussian Blur Filtering

Image Processing | Ball Recognition

- Single camera
  - Camera calibration
- **Image Processing**
  - **Ball Recognition**
  - Ball Characteristics
- Filtering
  - State Model
  - Measurement Model
  - UKF parameters
  - LSE
- Results



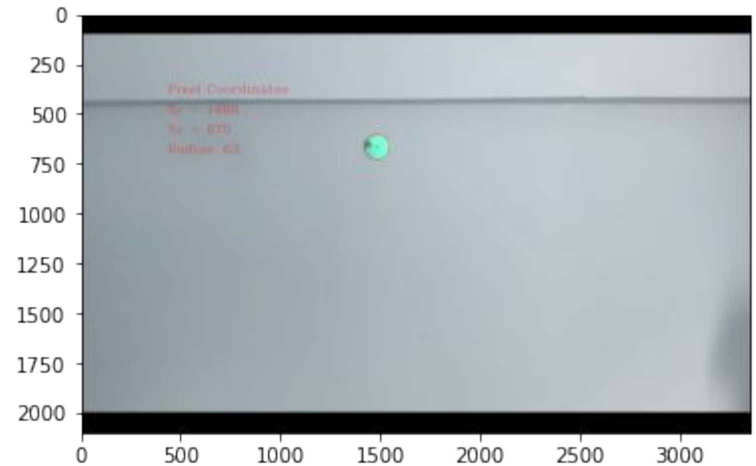
Masked Image



White Noise Cancellation

Image Processing | Ball Characteristics

- Single camera
    - Camera calibration
- **Image Processing**
    - Ball Recognition
    - **Ball Characteristics**
- Filtering
    - State Model
    - Measurement Model
    - UKF parameters
    - LSE
- Results



Coordinates and Radius of the Ball

Object Tracking - Real Time

Camera | Calibration

- **Single camera**
  - **Camera calibration**
- Image Processing
  - Ball Recognition
  - Ball Characteristics
- Filtering
  - State Model
  - Measurement Model
  - UKF parameters
  - LSE
- Results

Camera Options

- Phone Camera
  - Real-Time & Offline
- **Laptop Camera**
  - **Real-Time & Offline**
- DSLR
  - Offline
- USB Cam
  - Real-Time & Offline

Camera | Calibration

Origin Determination and Focal Length Calibration

- **Single camera**
  - **Camera calibration**
- Image Processing
  - Ball Recognition
  - Ball Characteristics
- Filtering
  - State Model
  - Measurement Model
  - UKF parameters
  - LSE
- Results

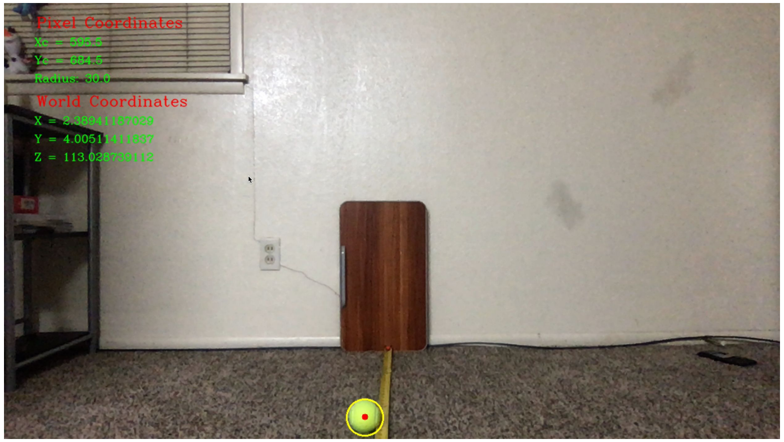


Image Processing | Real-time Ball Tracking

- Single camera
  - Camera calibration
- **Image Processing**
  - Ball Recognition
  - Ball Characteristics
- Filtering
  - State Model
  - Measurement Model
  - UKF parameters
  - LSE
- Results

Filtering

Filtering | State Model

- Single camera
    - Camera calibration
- Image Processing
    - Ball Recognition
    - Ball Characteristics
- **Filtering**
    - State Model
    - Measurement Model
    - UKF parameters
    - LSE
- Results

Input to Model

2D Projectile motion

Filtering | State Model

- Single camera
  - Camera calibration
- Image Processing
  - Ball Recognition
  - Ball Characteristics
- **Filtering**
  - **State Model**
  - Measurement Model
  - UKF parameters
  - LSE
- Results

State : (x, y, z)
Ball coordinates in world frame

State Equations

$$x_{k+1} = x_k + \frac{(x_k - x_0)}{\Delta t} dt$$

$$y_{k+1} = y_k + V_{yo} dt - g * \Delta t * dt$$

$$z_{k+1} = z_k + \frac{(z_k - z_0)}{\Delta t} dt$$

Filtering | Measurement Model

- Single camera
  - Camera calibration
- Image Processing
  - Identify the ball
  - Calculate characteristics of ball
- **Filtering**
  - State Model
  - **Measurement Model**
  - UKF parameters
  - LSE
- Results

Measurements : (u, v, r)
Ball coordinates in image frame and Ball Radius

Measurement Equations

$$u = 617 - \frac{fx}{z}$$

$$v = 360 - \frac{f}{z}(y + \frac{z}{20} - 18 * 2.54)$$

$$r = \frac{fR}{z}$$

Filtering | UKF Parameters

- Single camera
  - Camera calibration
- Image Processing
  - Identify the ball
  - Calculate characteristics of ball
- **Filtering**
  - State Model
  - Measurement Model
  - **UKF parameters**
  - LSE
- Results

$$Q := \begin{bmatrix} 0.1 & 0 & 0 \\ 0 & 0.1 & 0 \\ 0 & 0 & 0.1 \end{bmatrix} \quad R := \begin{bmatrix} 10 & 0 & 0 \\ 0 & 3 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Noise Q and R matrix

- The states x,y,z are uncorrelated. So the Q matrix is diagonal.
- Tennis ball is dense enough for its projectile to be assumed perfect. Hence we picked low process variance.
- The measurements u,v,r are uncorrelated. So the R matrix is diagonal.
- The state y in the model heavily depends on the initial conditions. So measurement v was entrusted with higher confidence (low variance)
- Variation in r is much smaller as distance from the screen is fixed. Low Variance.

Filtering | UKF Parameters

- Single camera
  - Camera calibration
- Image Processing
  - Identify the ball
  - Calculate characteristics of ball
- **Filtering**
  - State Model
  - Measurement Model
  - **UKF Parameters**
  - LSE
- Results

Unscented Transform

$$\lambda = \alpha^2(n+\kappa) - n$$

$$\begin{cases} \mathcal{X}_0 = \mu \\ \mathcal{X}_i = \mu + \left[\sqrt{(n+\lambda)\Sigma}\right]_i, & for\, i = 1..n \\ \mathcal{X}_i = \mu - \left[\sqrt{(n+\lambda)\Sigma}\right]_{i-n} & for\, i = (n+1)..2n \end{cases}$$

$$W_0^m = \frac{\lambda}{n+\lambda}$$

$$W_0^c = \frac{\lambda}{n+\lambda} + 1 - \alpha^2 + \beta$$

$$W_i^m = W_i^c = \frac{1}{2(n+\lambda)} \quad i = 1..2n$$

- α, β and κ are the parameters to be chosen
- Larger α spreads the sigma points further
- $\alpha = 0.1$ was a good choice (trial and error)
- $\beta = 2$ is advisable for gaussian problems
- κ = 3-n is advisable in general

Filtering | LSE

- Multiple cameras
  - Camera calibration
- Image Processing
  - Ball Recognition
  - Ball Characteristics
- **Filtering**
  - State Model
  - Measurement Model
  - UKF Parameters
  - **LSE**
- Results

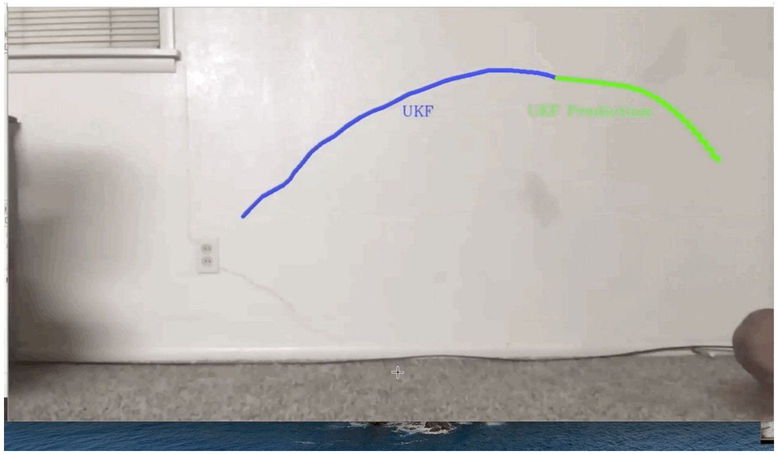
- The general trajectory of a projectile with velocity components along x and y as parameters was curve fit onto the measurements using least squares approach.
- Assumption: 2D projectile
- Susceptible to errors due to outliers but reasonable approach in the absence of extreme outliers.

Cost Function

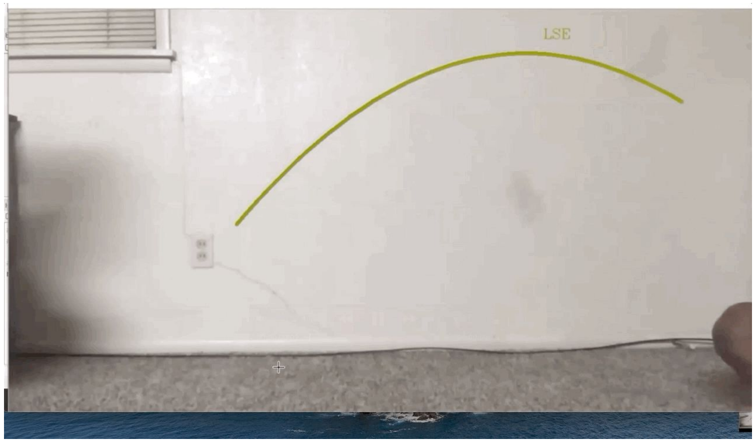
$$\sum_{i=1}^{N}\left[y-\frac{V_{yi}(x-x_o)}{V_{xi}}-y_o+\frac{g}{2}\left(\frac{x-x_o}{V_{xi}}\right)^2\right]^2$$

Filtering | Results

- Single camera
    - Camera calibration
- Image Processing
    - Identify the ball
    - Calculate characteristics of ball
- Filtering
    - State Model
    - Measurement Model
    - UKF Parameters
    - LSE
- **Results**

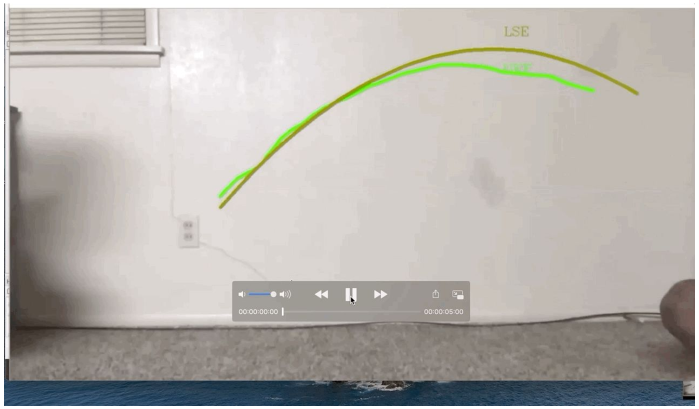


UKF

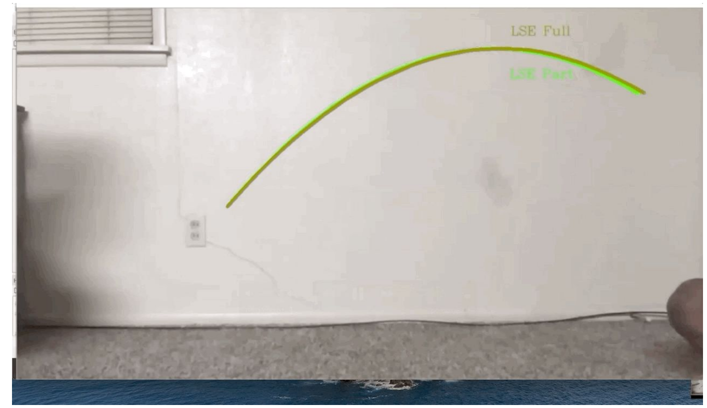


LSE

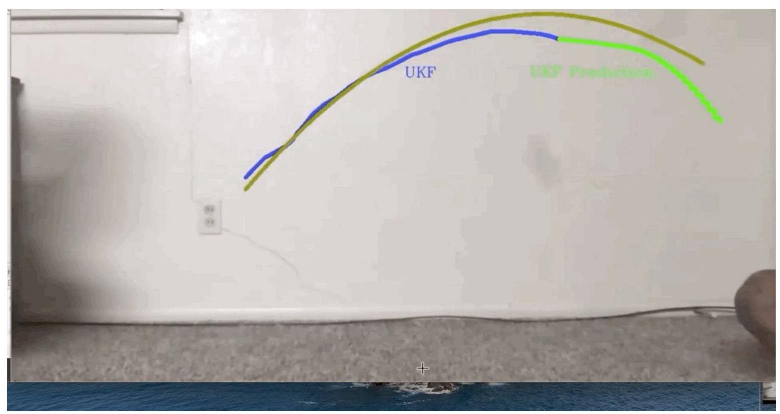
Filtering | Results - Comparison



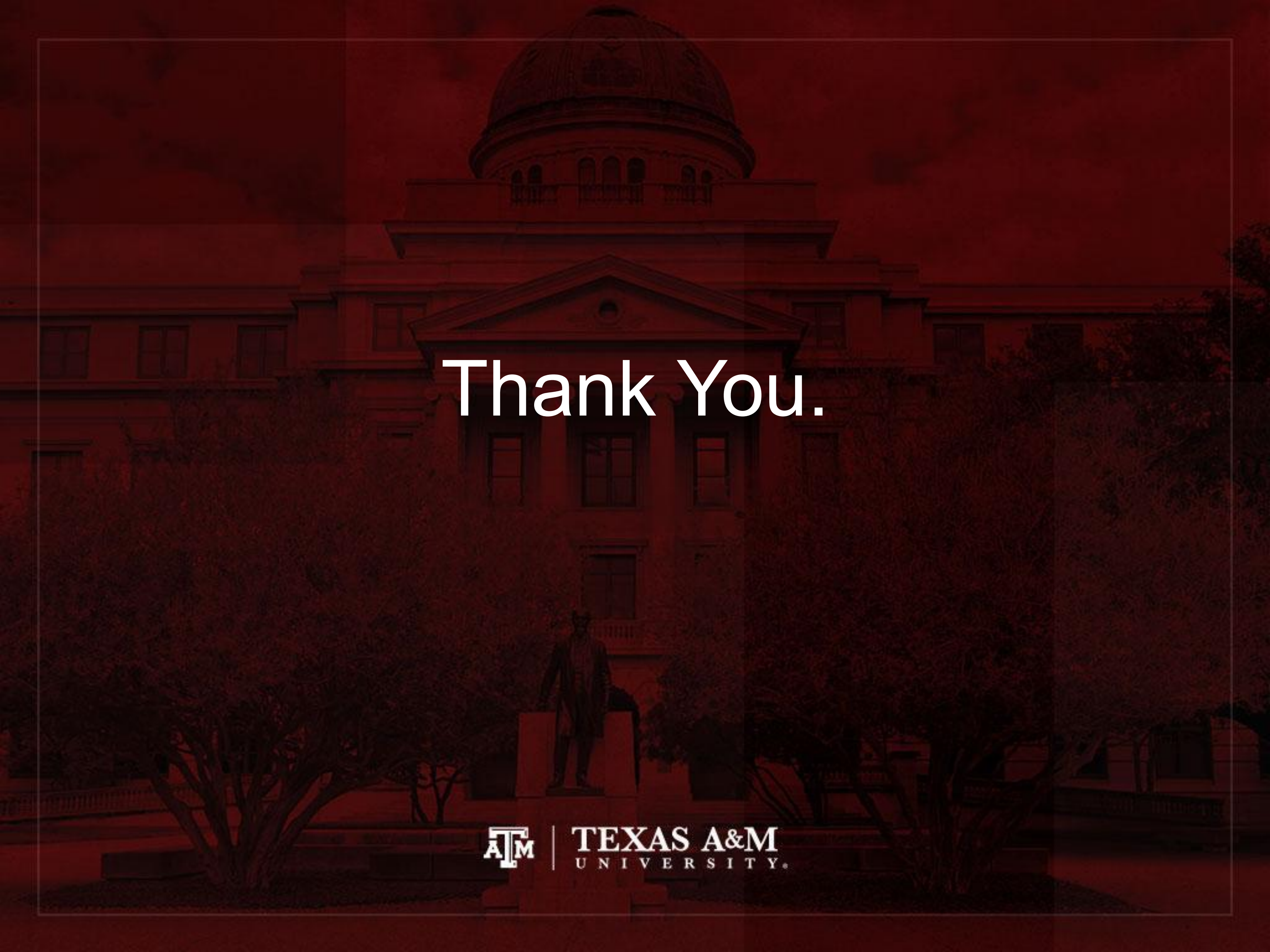
LSE vs UKF Full



LSE Part vs LSE Full



UKF Part vs LSE


Thank You.
TEXAS A&M
UNIVERSITY