Latency Compensation Method for VR Displays

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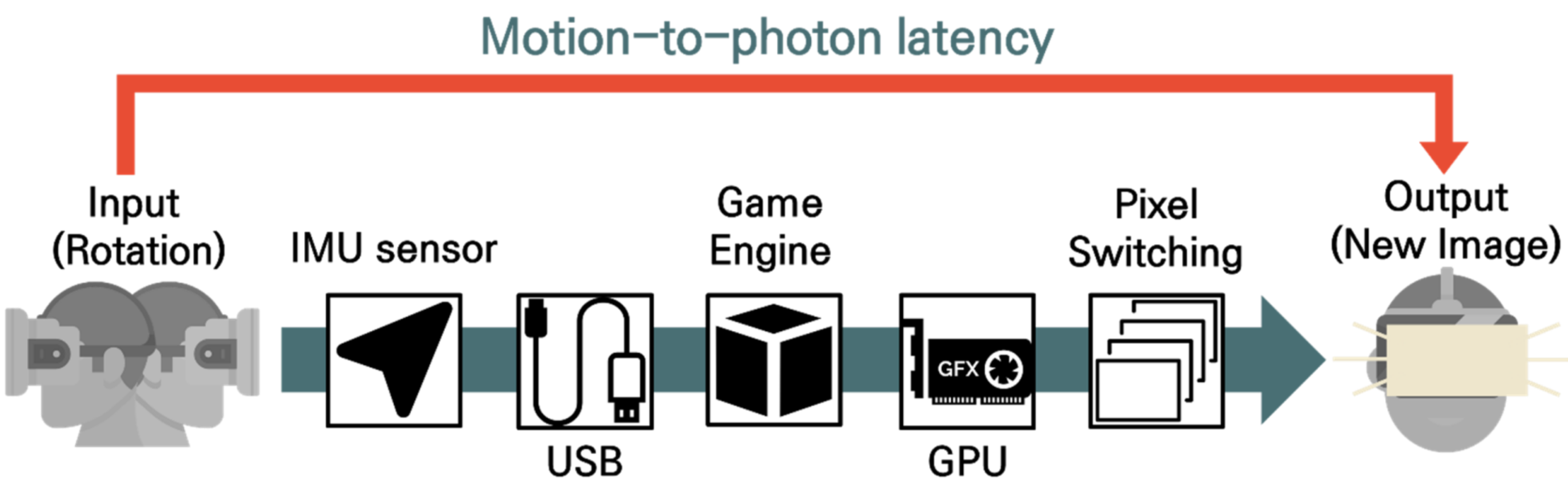
Outline

- ✓ Introduction
- ✓ Motion-to-Photon Latency Compensation Method
  - Motion Prediction Process
  - Sensor Fusion Algorithm
  - Various Prediction Method
- ✓ Experimental Result
- ✓ Conclusion

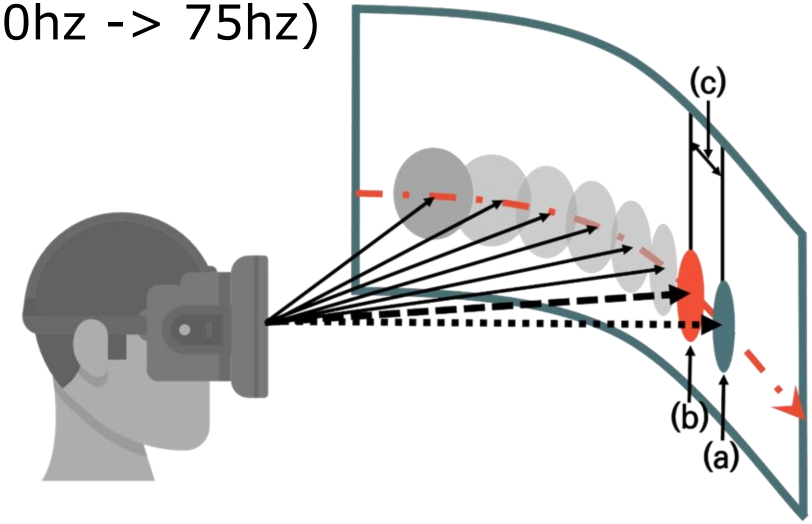
Introduction

✓ Motion-to-photon latency
  - Time delay which takes between the head motion to new orientation and the correct image arriving on a display of the device
  - Overall process of the image rendering in HMDs



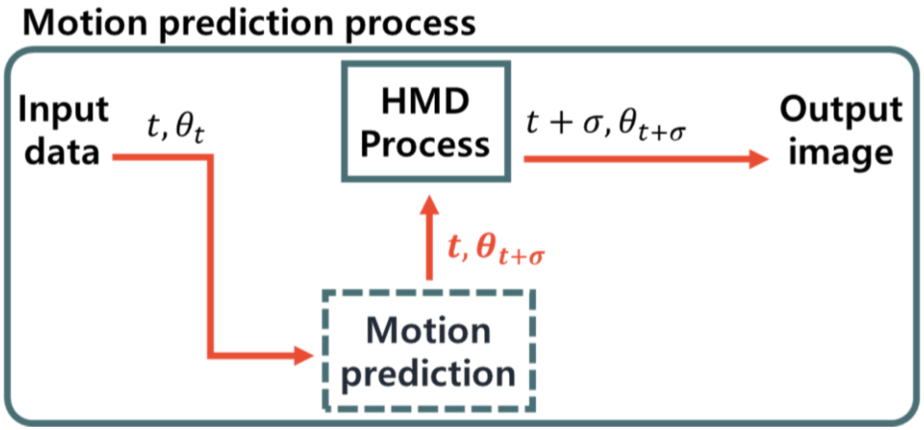
Introduction

- ✓ Motion-to-photon latency
  - Due to the latency, the HMD outputs a delayed image different from the image at an ideal time point
- ✓ The motion-to-photon latency is an important problem in the HMD, and various solutions have been proposed
  - Foveated rendering
  - Increasing display frame rate (60hz -> 75hz)
  - Pre-warping technique
  - Asynchronous time-warp
- ✓ Limitation of conventional methods
  - Hardware dependency
  - High complexity



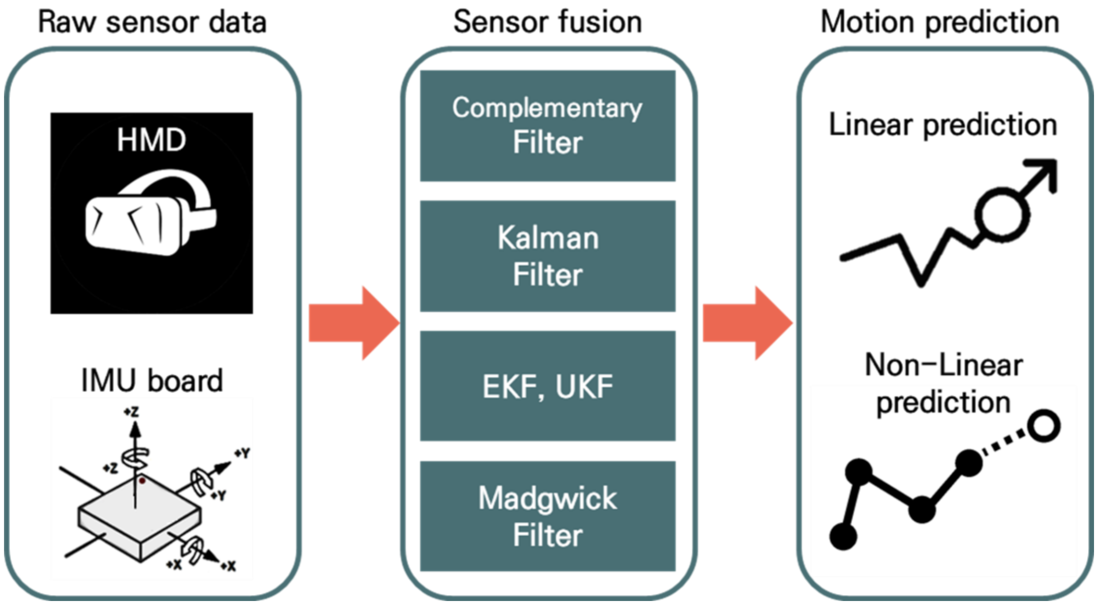
Latency Compensation Method

✓ Motion prediction process
  - The motion prediction process predicts the latency σ and outputs an image quickly
  - It outputs an image of angles that match the current time
  - As a result, discrepancies between the current angle and the represented angle are compensated
  - Concept of latency reduction model using prediction method



Latency Compensation Method

- ✓ Motion prediction process
  - Overall procedure of the proposed latency reduction
  - The motion prediction process consists of three steps: raw sensor data acquisition, sensor fusion, motion prediction

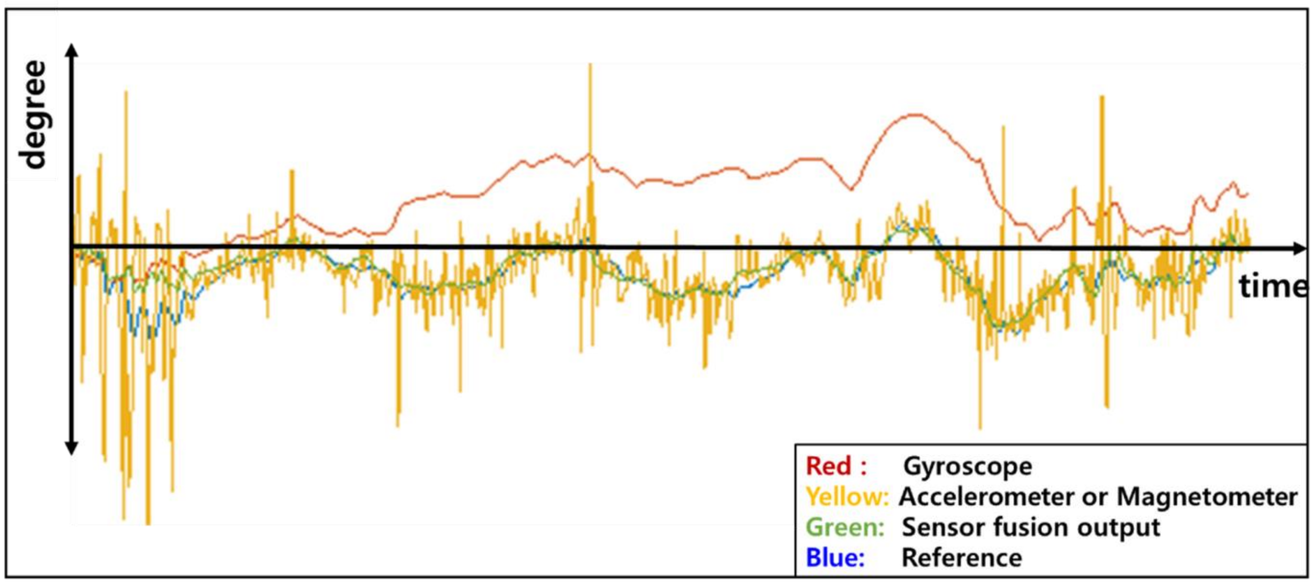


Latency Compensation Method

- ✓ Raw sensor data
  - The Inertial Measurement Unit (IMU) consists of a gyroscope, an accelerometer, and a magnetometer
  - Usually, the IMU outputs raw data with motion information at regular intervals
- ✓ Optimal sensor fusion algorithm
  - It is needed to compensate for distortion of raw data such as drift, diffusion, and bias
  - Candidate filters with high accuracy and low computation
    - 1st complimentary filter
    - Linear Kalman filter (LKF)
    - Extended Kalman Filter (EKF)
    - Unscented Kalman Filter (UKF)
    - Madgwick filter

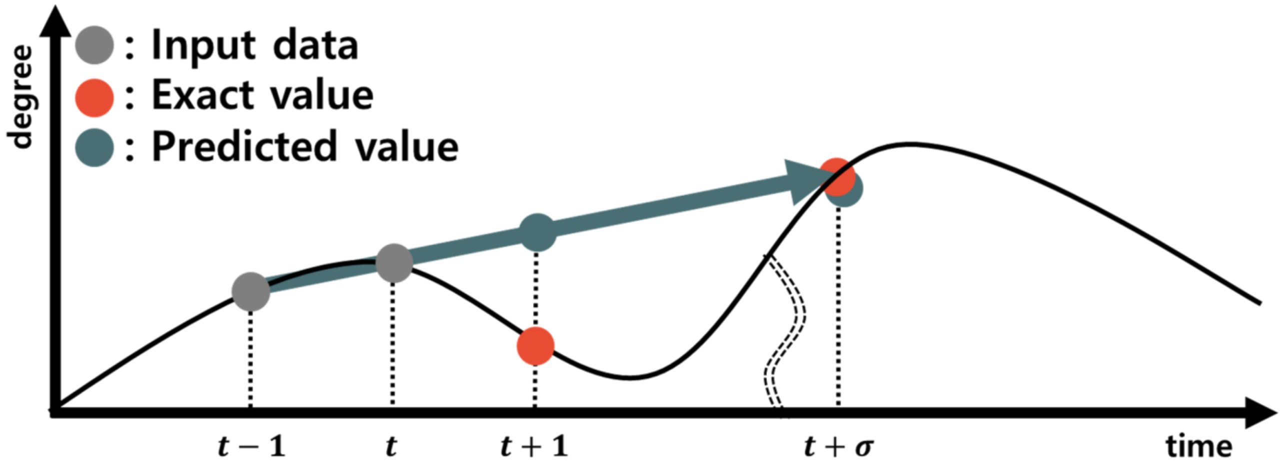
Latency Compensation Method

- ✓ Optimal sensor fusion algorithm
  - Raw data output: red(gyroscope),yellow(accelerometer or magnetometer)
  - Sensor fusion output: green(1st complimentary filter)



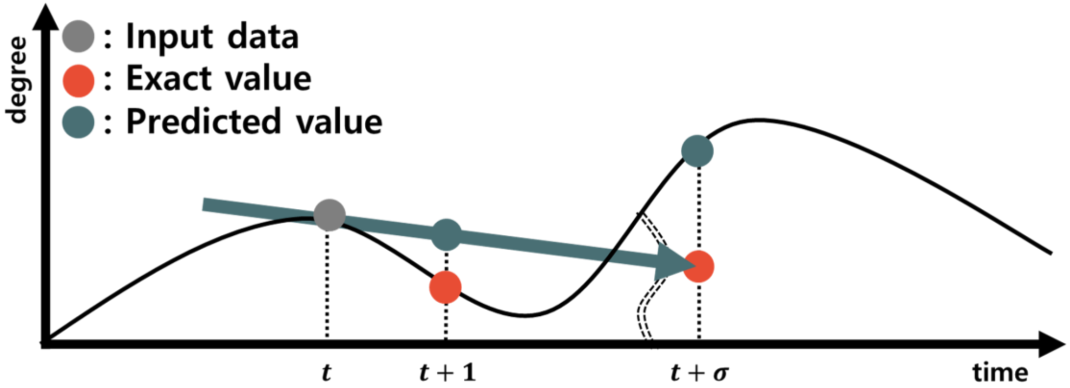
Latency Compensation Method

- ✓ Various prediction method
- ✓ Linear extrapolation
  - $\boldsymbol{\theta_{t+\sigma} \cong (\theta_t - \theta_{t-T}) \times \sigma + \theta_t}$
  - Although a linear extrapolation is a simple formula, it has a good result in the high sampling rate and it is suitable for low computing power devices



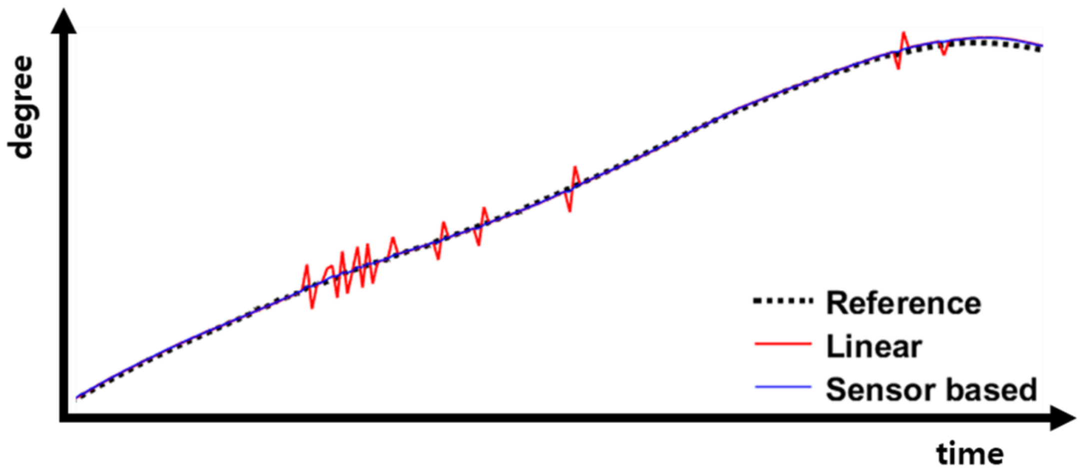
Latency Compensation Method

- ✓ Sensor-based extrapolation
  - $$\begin{bmatrix}\phi' \\ \theta' \\ \psi'\end{bmatrix} = \begin{bmatrix}1 & sin\phi tan\theta & cos\phi tan\theta \\ 0 & cos\phi & -sin\phi \\ 0 & sin\phi sec\theta & cos\phi sec\phi\end{bmatrix} \times \begin{bmatrix}p \\ q \\ r\end{bmatrix}$$
  - $\theta_{t+\sigma} \cong \theta'_t \times \sigma + \theta_t$
  - The sensor-based extrapolation uses the current angular velocity measured by the gyroscope of the IMU to predict the Euler angle



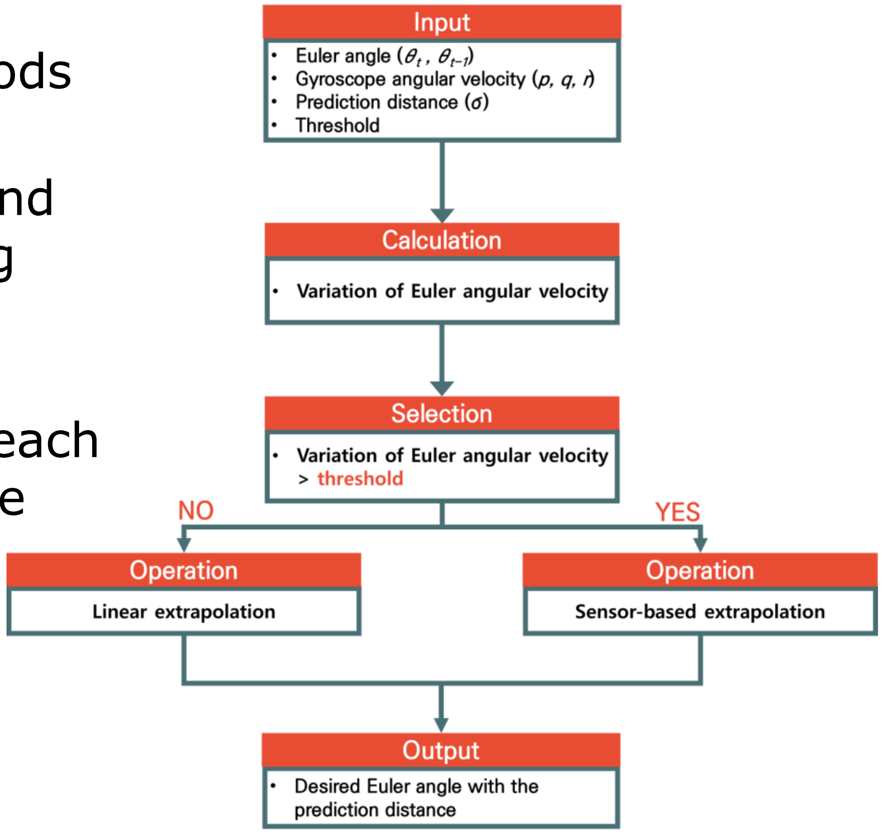
Latency Compensation Method

- ✓ Sensor-based extrapolation
  - Comparison of the reference and conventional methods
  - In certain areas, the linear extrapolation has a vibration
  - The estimation performance of the sensor based method is more accurate than the linear method



Latency Compensation Method

- ✓ Proposed prediction method
  - Hybrid combination of two conventional prediction methods for compensating latency
  - This improves the precision and computation time by selecting both prediction methods in suitable cases
  - It is possible to complement each disadvantage and to maximize the advantage



Experimental Result

- ✓ Optimal sensor fusion method for HMD
  - This experiment used a data set with the motion of the HMD for a certain period of time
  - Experiments to verify optimized sensor fusion filters in terms of low computational complexity
  - EKF and Madgwick filter show good performance

Sensor fusion filter	Root Mean Square (degree)				Computation time (sec)
	Yaw	Pitch	Roll	Mean	
1^{st} complementary filter	3.180	1.713	2.366	2.420	1.723
LKF	2.283	0.408	0.382	1.562	1.769
EKF	0.963	0.363	0.423	0.583	1.800
UKF	0.967	0.363	0.423	0.585	3.357
Madgwick filter	0.848	1.516	0.901	1.088	1.730

Experimental Result

- ✓ Optimal prediction method for HMD
  - This experiment used a data set with the motion of the HMD for a certain period of time
  - The results are compared with the precision and the computation time according to the prediction method
  - The proposed prediction method has good performance

Prediction Data VS. Reference Data (prediction distance 40ms)					
Prediction	Root Mean Square (degree)				Computation time (sec)
	Yaw	Pitch	Roll	Mean	
Linear	0.218	0.301	0.141	0.220	0.229
Sensor based	0.195	0.282	0.132	0.203	0.369
Proposed	0.199	0.288	0.135	0.207	0.289

Experimental Result

- ✓ Performance comparison between the integration of the sensor fusions and the prediction filters
  - This experiment used a data set with the motion of the HMD for a certain period of time
  - The performance of the proposed prediction method and EKF are good

Sensor fusion filter	Prediction method	Root Mean Square (degree) Yaw	Pitch	Roll	Mean	Computation time (sec)
1st complementary filter	Linear extrapolation	4.046	1.707	2.012	2.588	1.798
	Sensor-based extrapolation	4.054	1.404	1.932	2.464	1.932
	Proposed method	4.046	1.420	1.966	2.477	1.864
LKF	Linear extrapolation	1.799	0.392	0.329	0.840	1.828
	Sensor-based extrapolation	1.795	0.393	0.331	0.840	1.957
	Proposed method	1.797	0.392	0.329	0.839	1.894

Prediction Data VS. Reference Data (prediction distance 40ms)

Sensor fusion filter	Prediction method	Root Mean Square (degree) Yaw	Pitch	Roll	Mean	Computation time (sec)
EKF	Linear extrapolation	0.620	0.374	0.453	0.483	1.850
	Sensor-based extrapolation	0.617	0.373	0.453	0.481	1.977
	Proposed method	0.620	0.373	0.453	0.482	1.915
UKF	Linear extrapolation	0.625	0.375	0.454	0.484	3.219
	Sensor-based extrapolation	0.622	0.374	0.453	0.483	3.356
	Proposed method	0.625	0.374	0.453	0.484	3.286
Madgwick filter	Linear extrapolation	1.024	1.057	1.075	1.052	1.810
	Sensor-based extrapolation	1.024	1.060	1.078	1.054	1.944
	Proposed method	1.024	1.057	1.075	1.052	1.875

Prediction Data VS. Reference Data (prediction distance 40ms)

Conclusion

- ✓ We proposed a low computational complexity-based a prediction method that can effectively remove the motion-to-photon latency in a HMD
  - We compared various sensor fusion methods to calculate the head position of a user because there was no sensor fusion comparison for the HMD
  - The experimental results showed that the proposed prediction method with the sensor fusion method has the highest accuracy and low computation time