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The European Event for Electronic System Design & Test

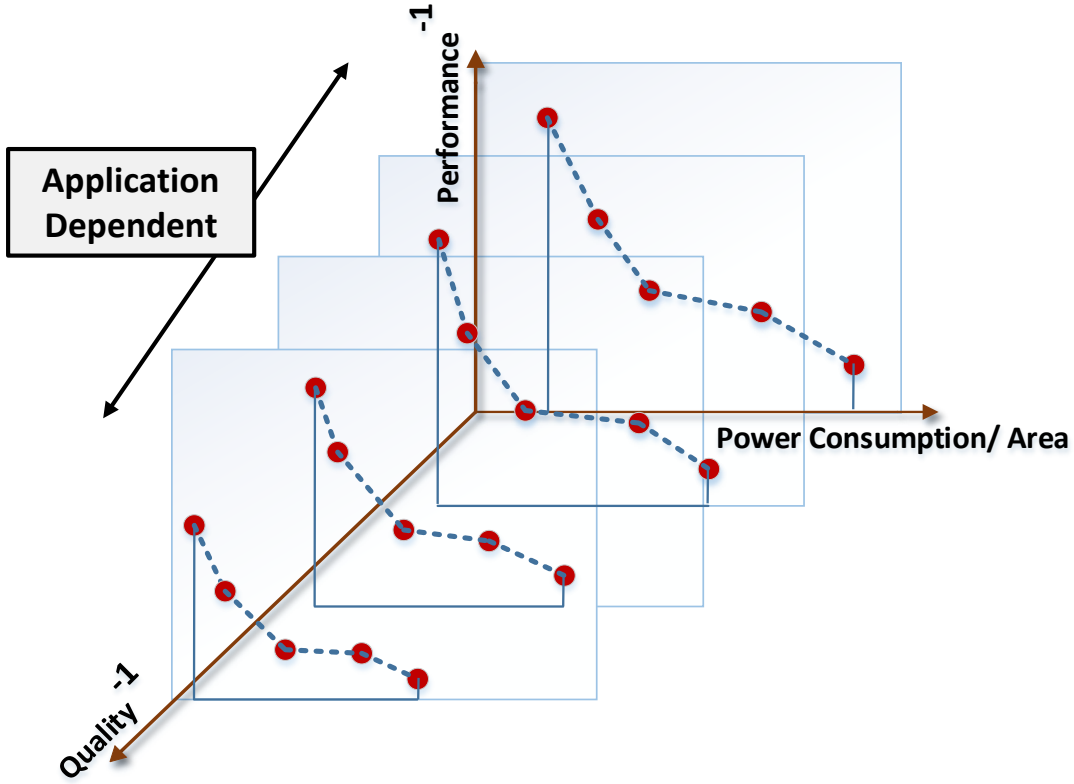
ES ELECTRONIC SYSTEMS
TU/e

Approximation Trade Offs in an Image-Based Control System

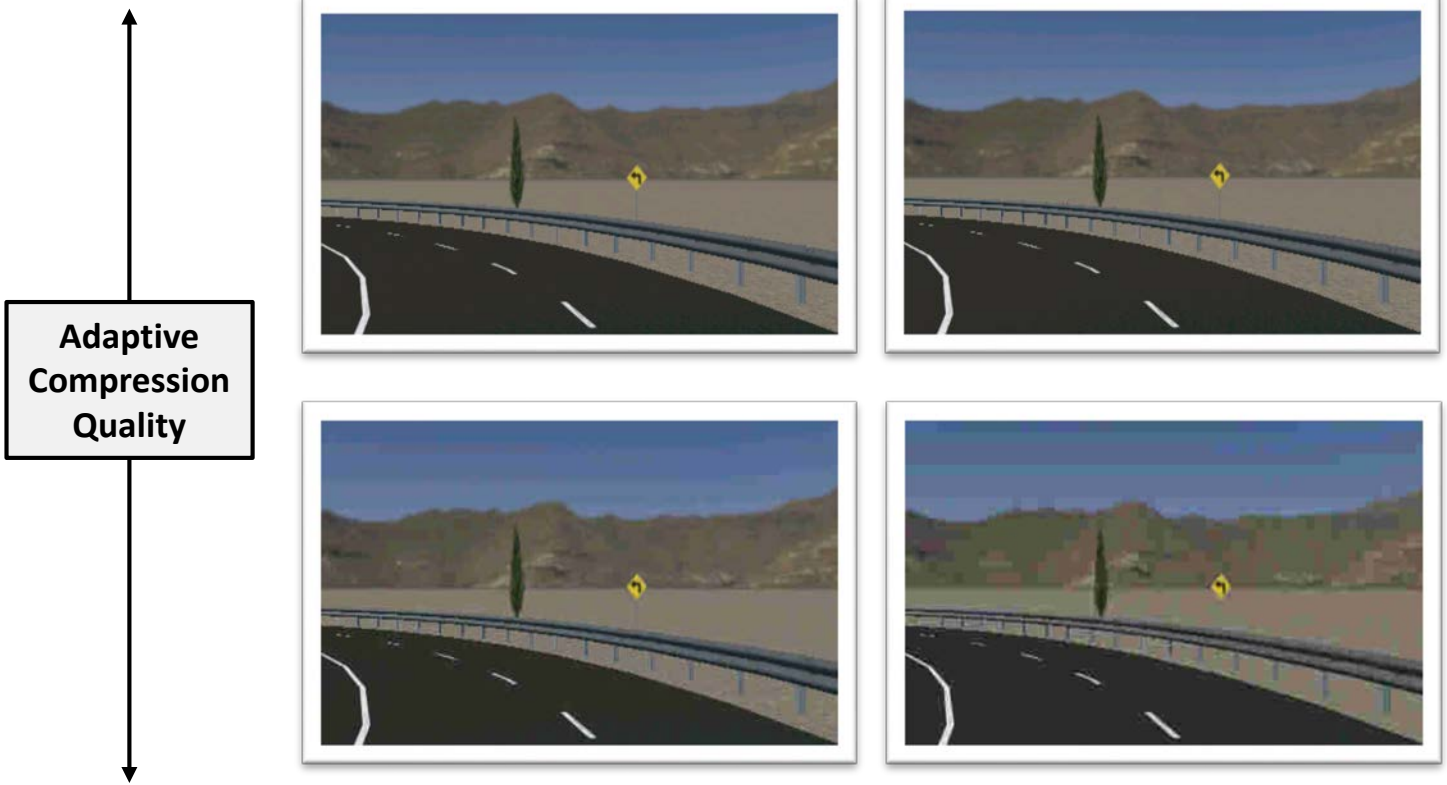
Sayandip De, Sajid Mohamed, Konstantinos Bimpisidis, Dip Goswami, Twan Basten, Henk Corporaal

Eindhoven University of Technology, The Netherlands

Preliminaries: Approximate Computing



Example: Lossy Compression



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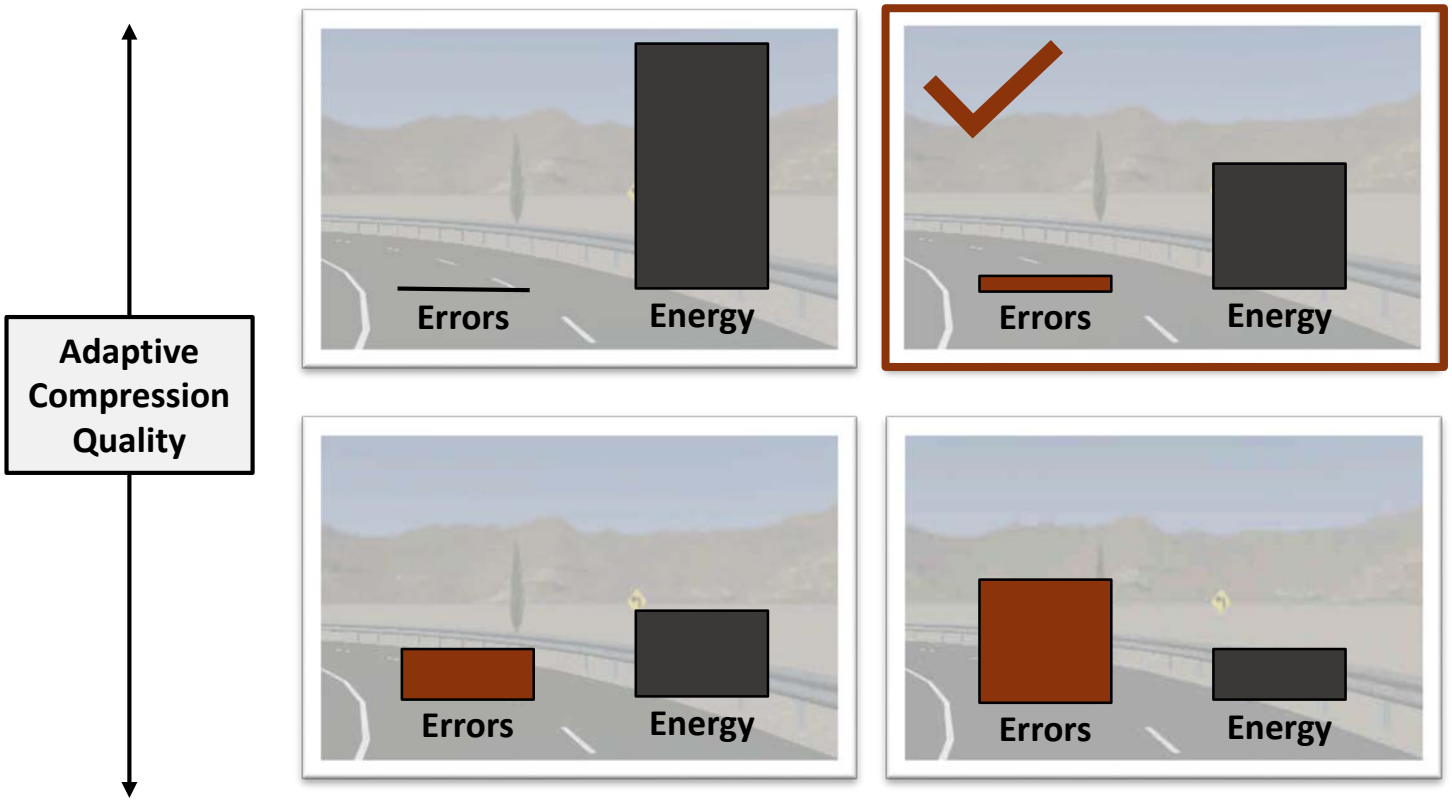


Existing Literature

Image Processing benefits from Approximate Computing!

IEEE TRANSACTIONS ON VERY LARGE SCALE INTEGRATION (VLSI) SYSTEMS

Approximating Beyond the Processor: Exploring Full-System Energy-Accuracy Tradeoffs in a Smart Camera System

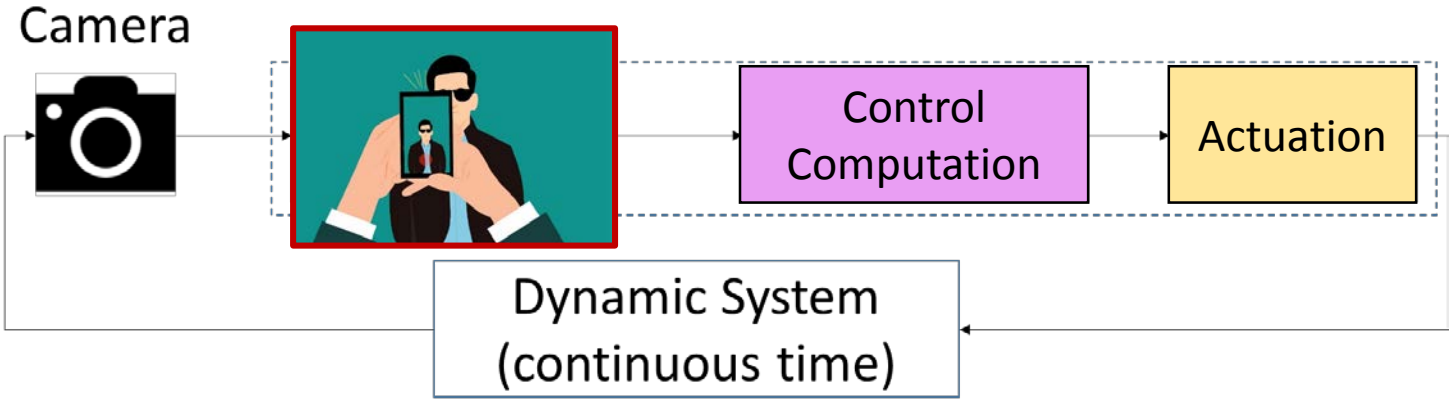
Arnab Raha, *Member, IEEE*, and Vijay Raghunathan, *Member, IEEE*

Optimal Design of JPEG Hardware Under the Approximate Computing Paradigm

Farhana Sharmin Snigdha[1], Deepashree Sengupta[1], Jiang Hu[2] and Sachin S. Sapatnekar[1],
[1]Department of ECE, University of Minnesota
[2]Department of ECE, Texas A&M University
{sharm304,sengu026,sachin}@umn.edu, jianghu@ece.tamu.edu

But . . .

But they are always part of bigger systems.



Focus of this presentation

Image-approximation in-the-loop

Image-based Control (IBC) System

- **Video**
  - **Source: https://vimeo.com/192179726**

Image-based Control (IBC) System

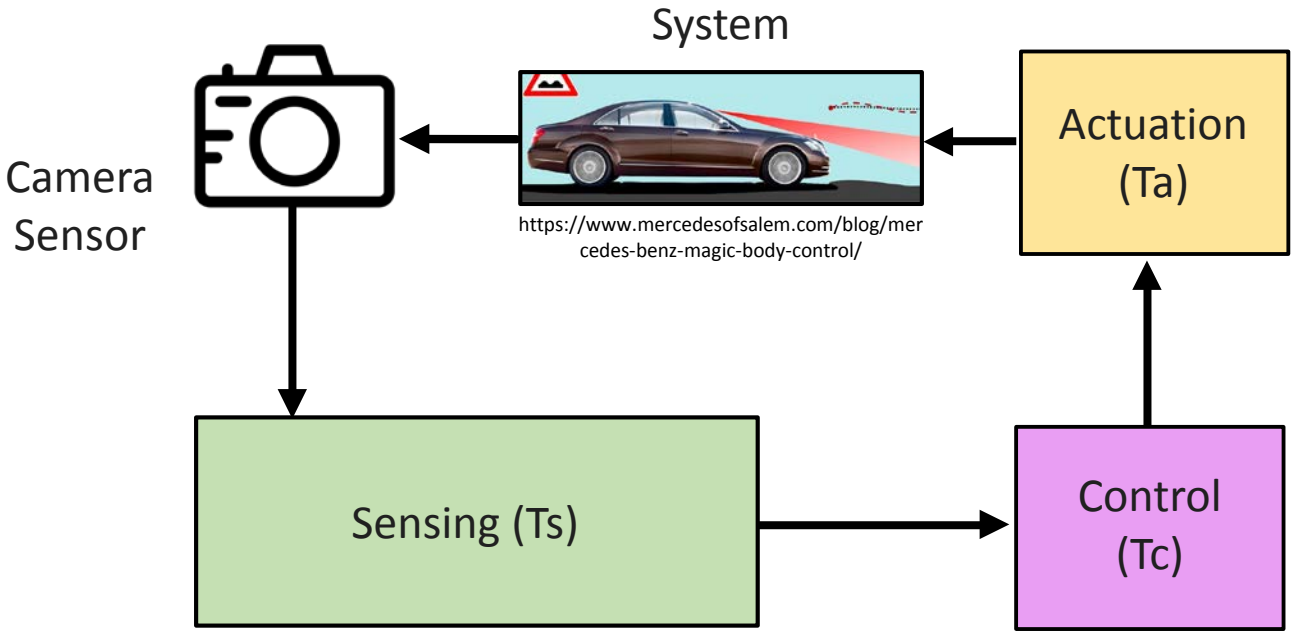


Image-based Control (IBC) System

Lane keeping assist system (LKAS)

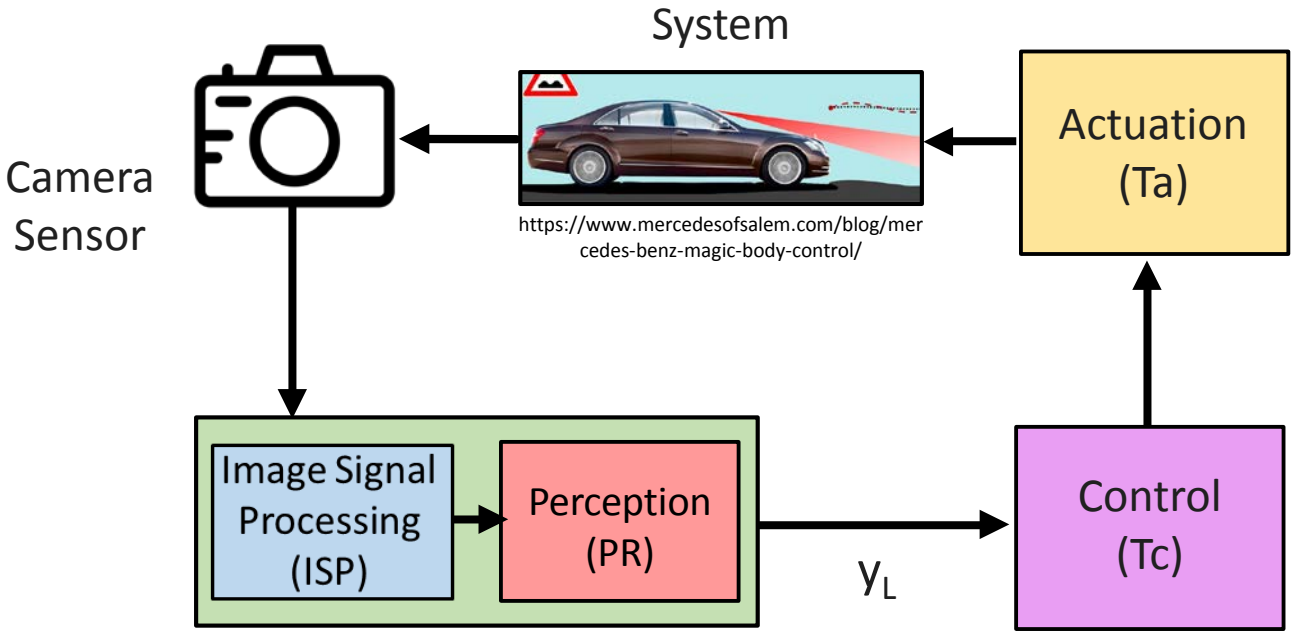


Image-based Control (IBC) System

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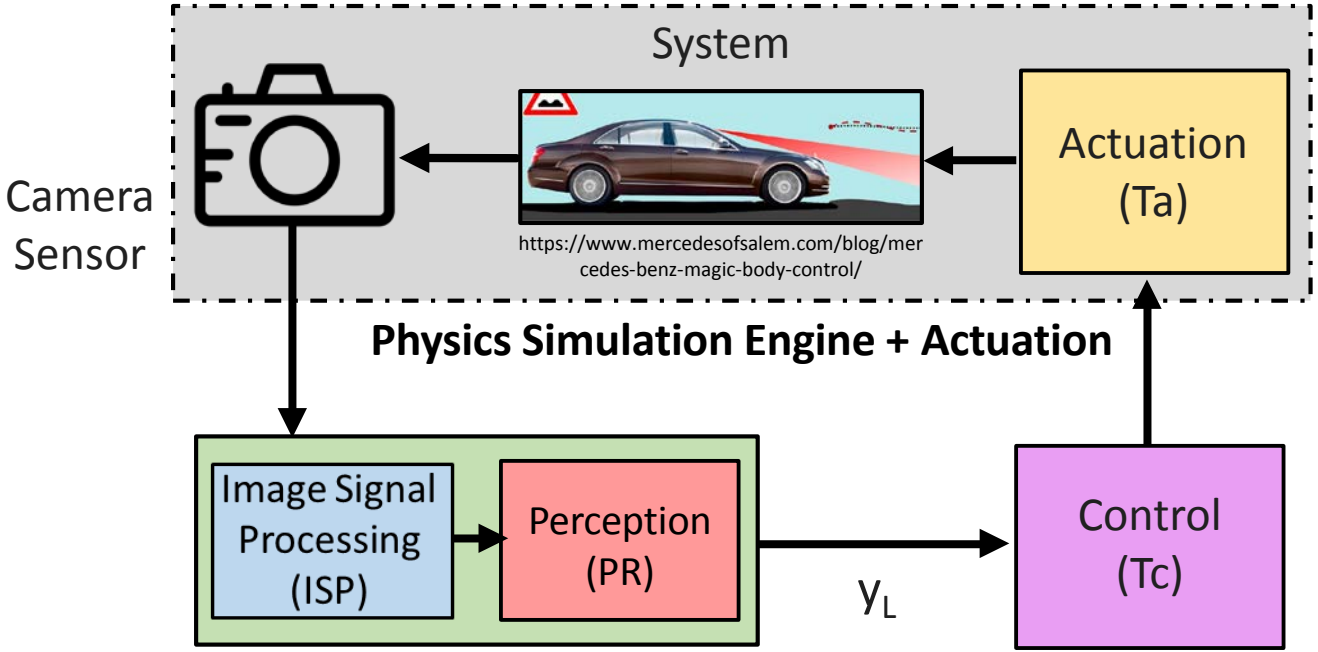

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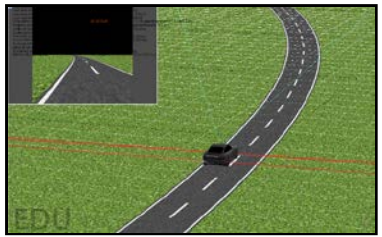


Camera Sensor

System

https://www.mercedesofsalem.com/blog/mercedes-benz-magic-body-control/

Actuation (Ta)

v-rep

Physics Simulation Engine + Actuation

Image Signal Processing (ISP)

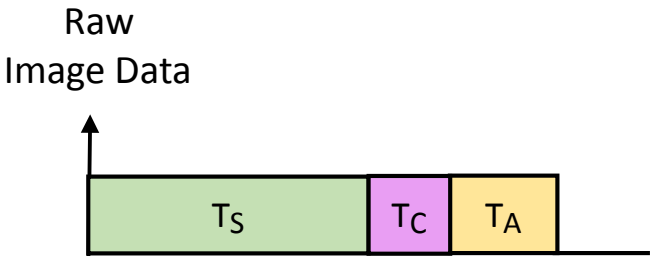
Perception (PR)

y_L

Control (Tc)

E. Rohmer et al., "V-REP: a versatile and scalable robot simulation framework," in IROS, 2013

Image-based Control (IBC) System



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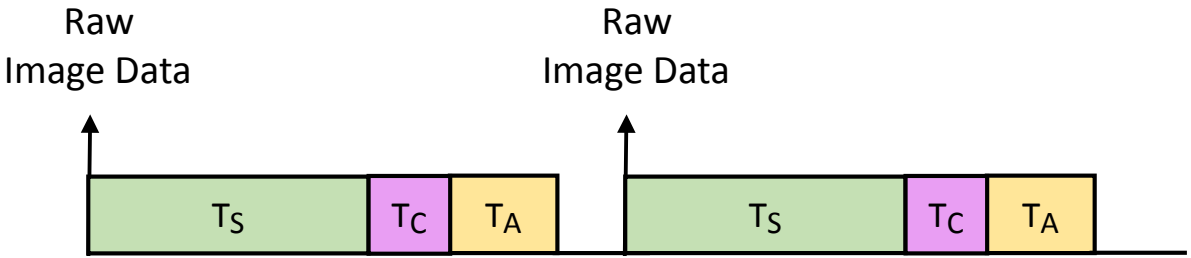

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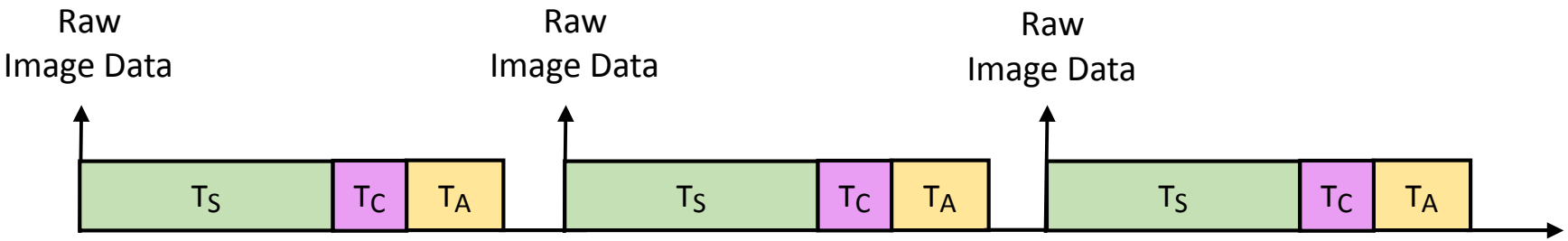

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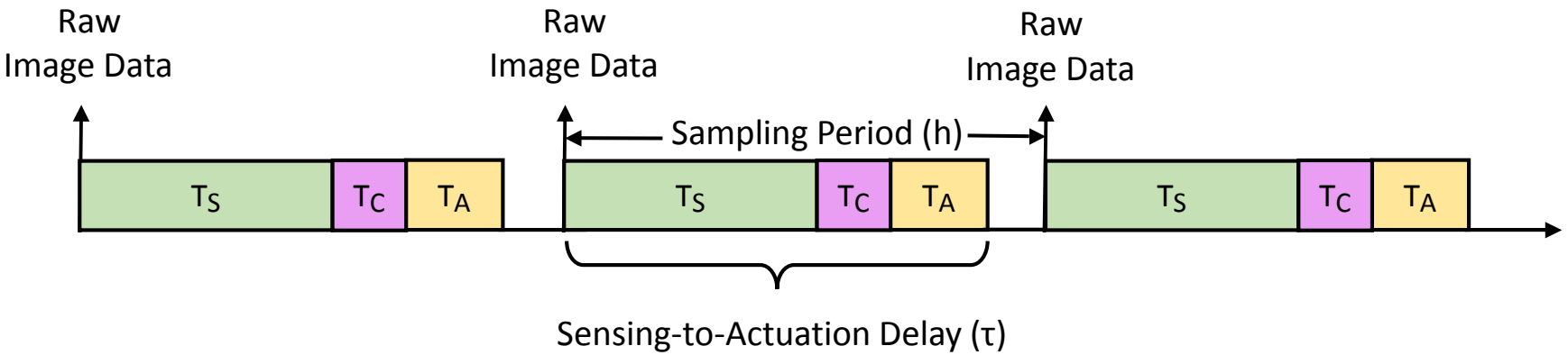

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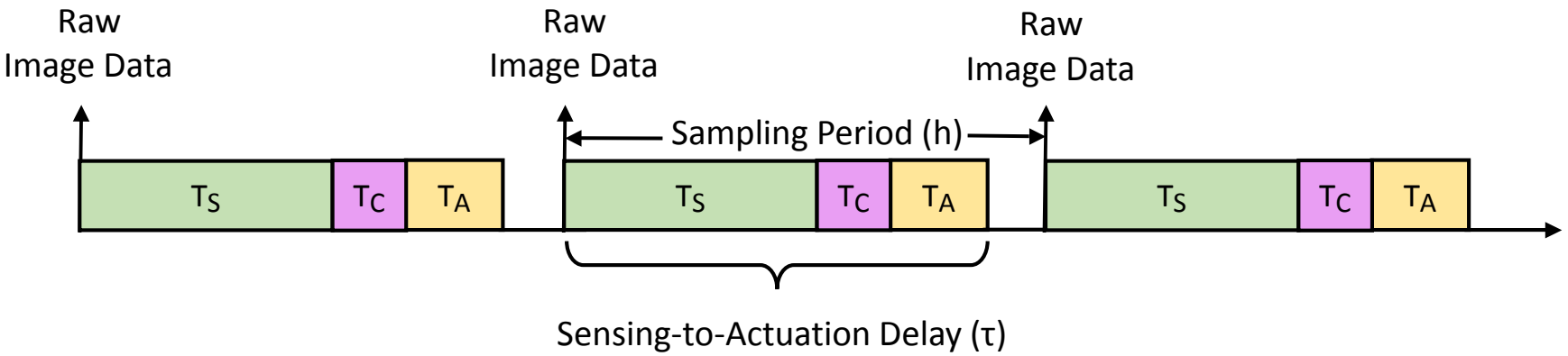
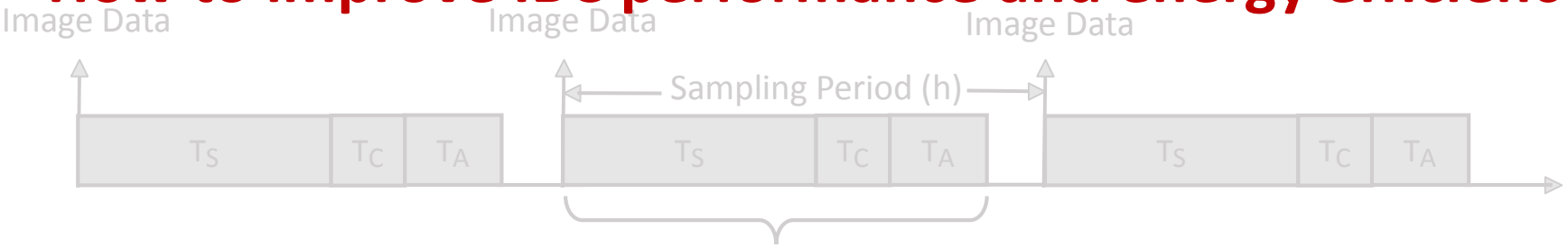


Impacts the control performance of IBC systems

Image-based Control (IBC) System

How to improve IBC performance and energy efficiency?



Sensing-to-Actuation Delay (τ)

Impacts the control performance of IBC systems

Image-based Control (IBC) System

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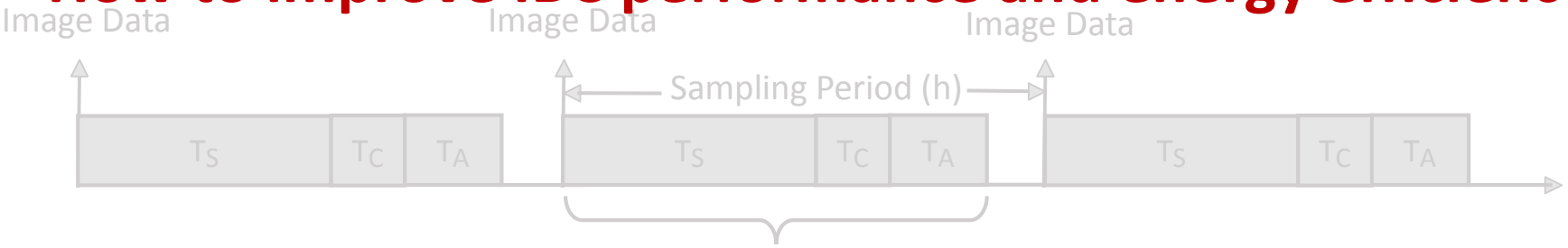
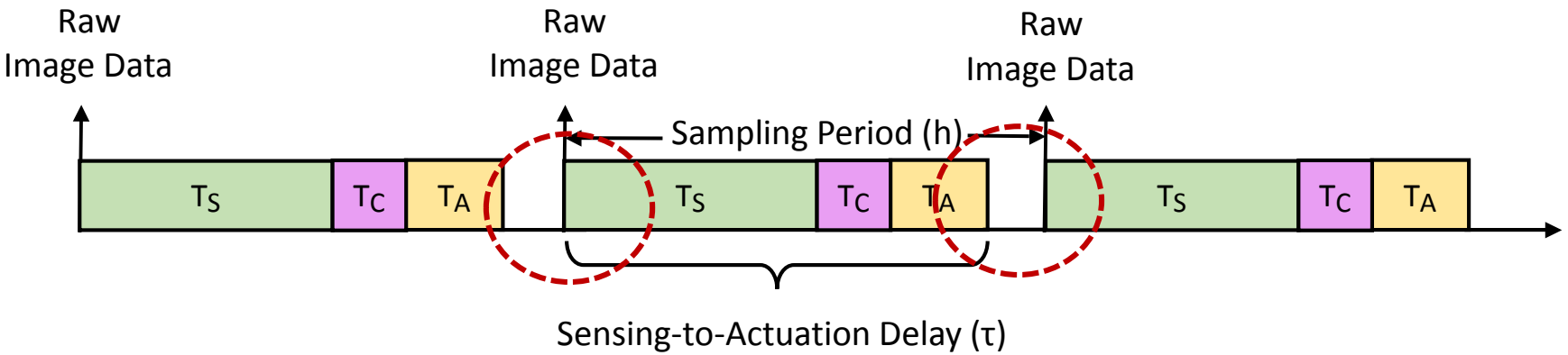


Impacts the control performance of IBC systems

1 **Reduce Sampling Period (h)**

Image-based Control (IBC) System



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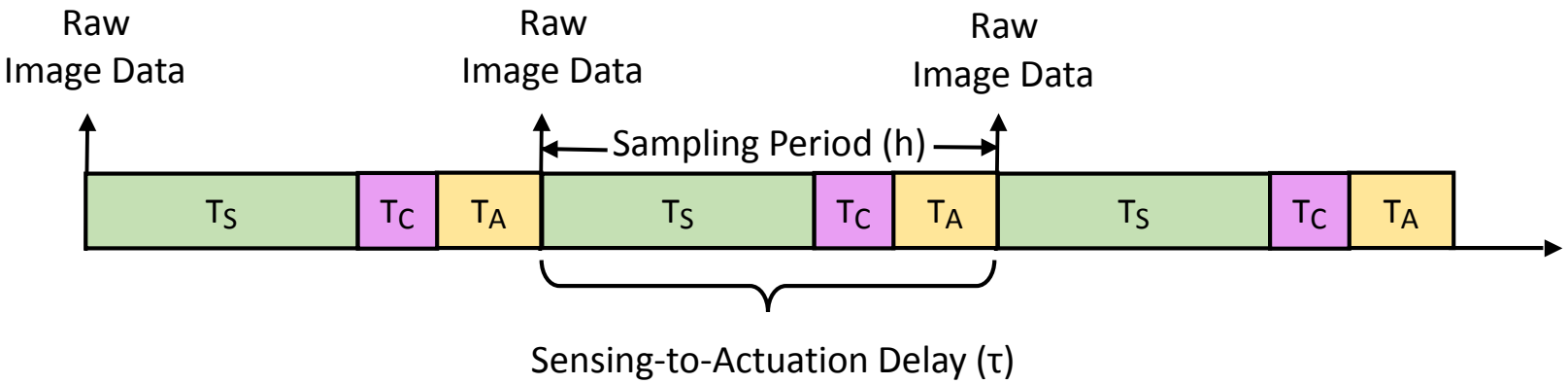
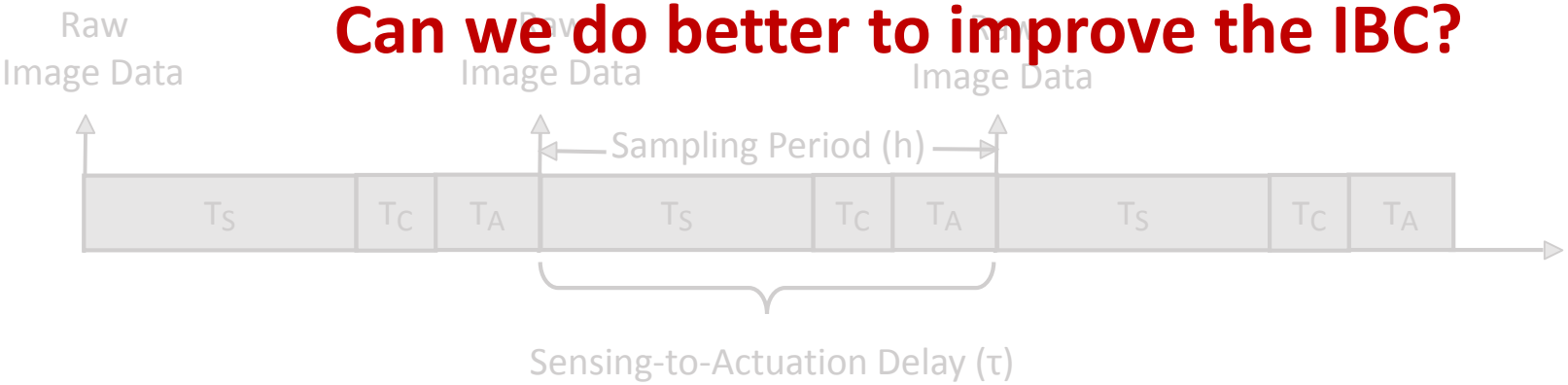


1 **Reduce Sampling Period (h)**

Image-based Control (IBC) System

Can we do better to improve the IBC?



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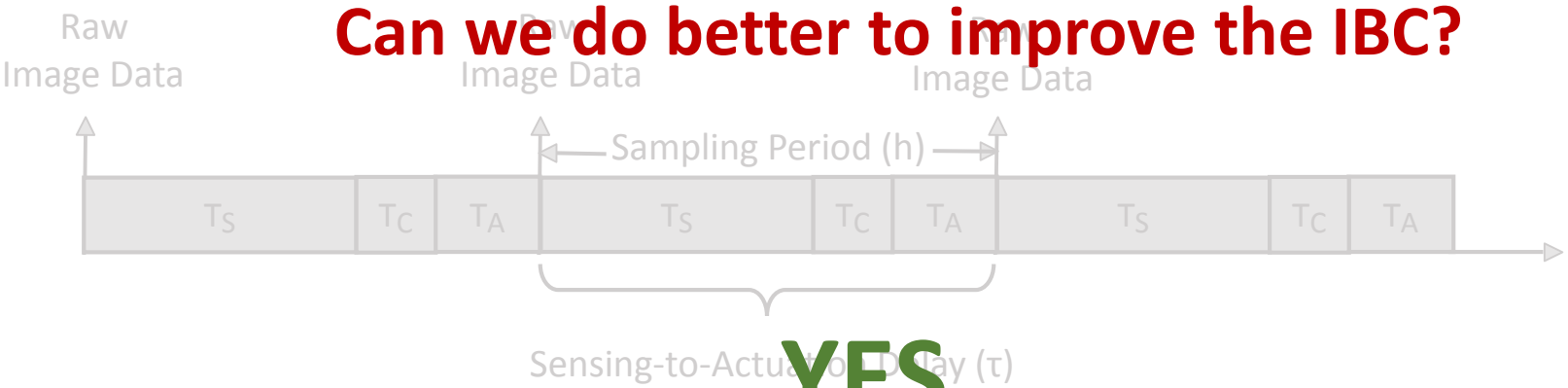
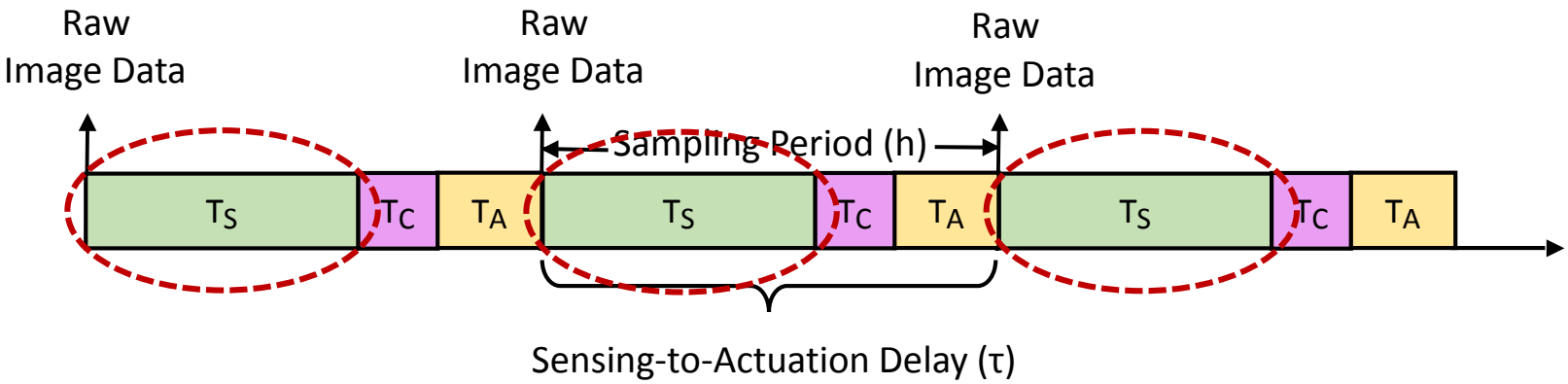


Can we do better to improve the IBC?

YES

2 Apply **Approximations** to reduce the Sensor to Actuation Delay (τ)

Image-based Control (IBC) System



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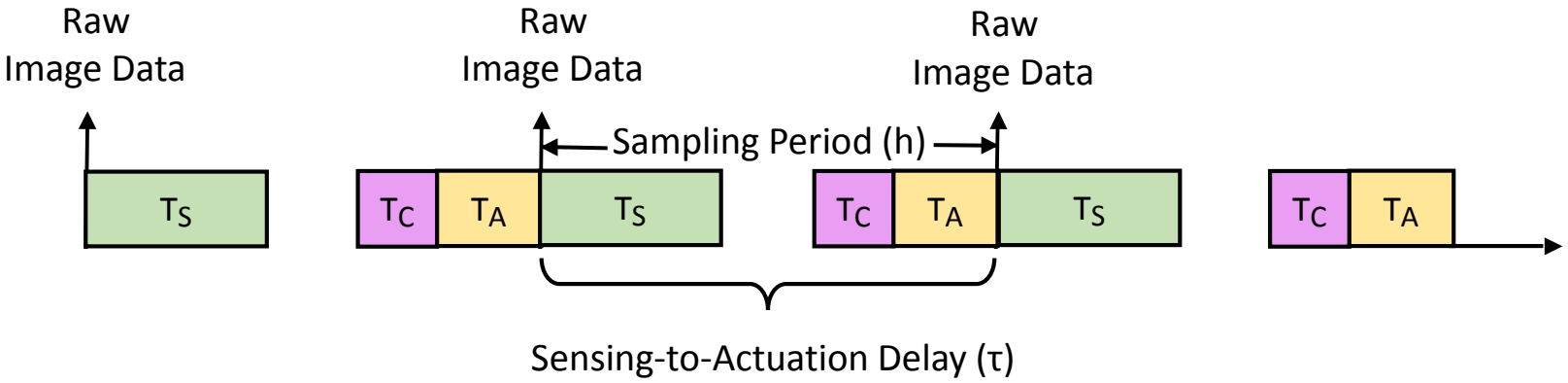

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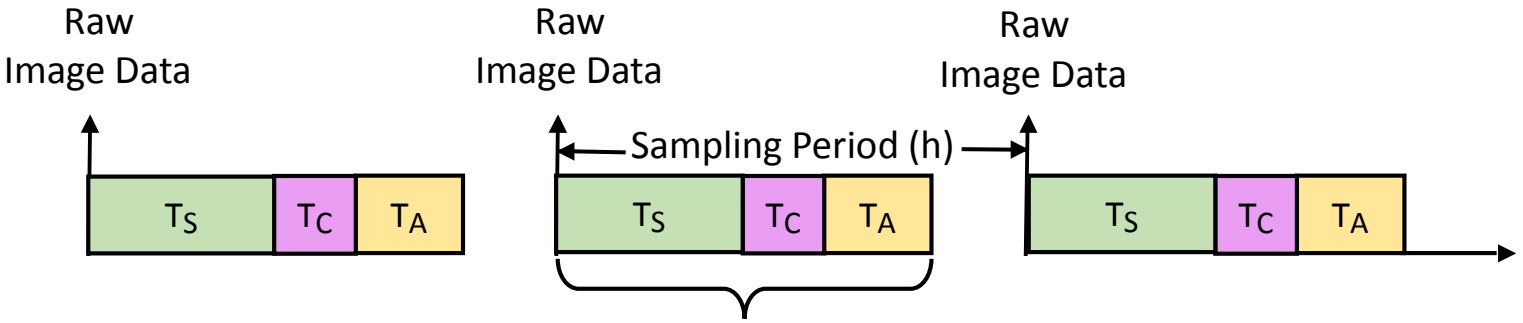


Reduced Sensing-to-Actuation Delay (τ)

2 **Apply Approximations to reduce the Sensor to Actuation Delay (τ)**

Image-based Control (IBC) System

Can we improve further?

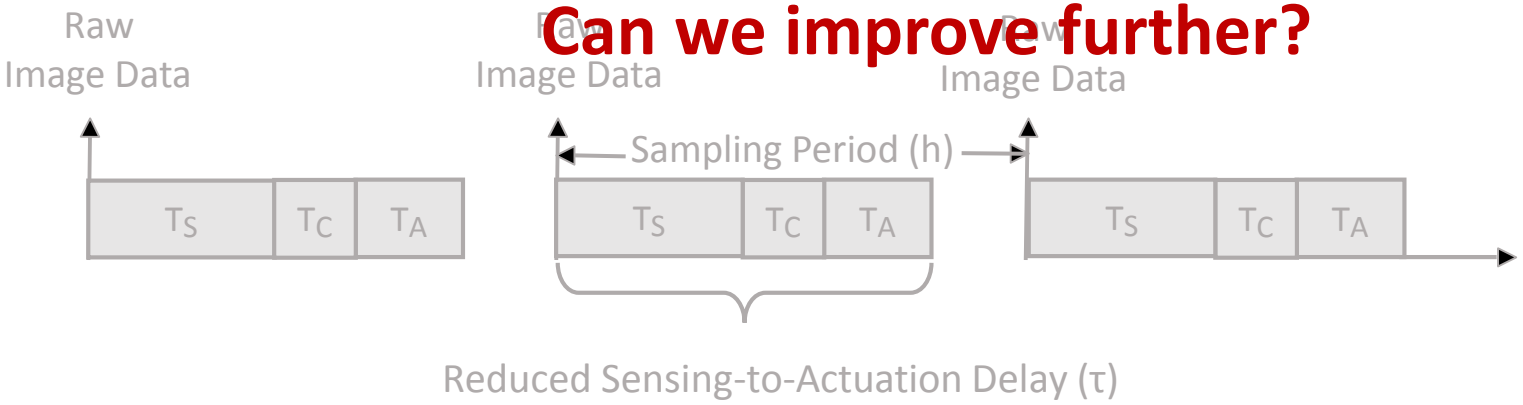
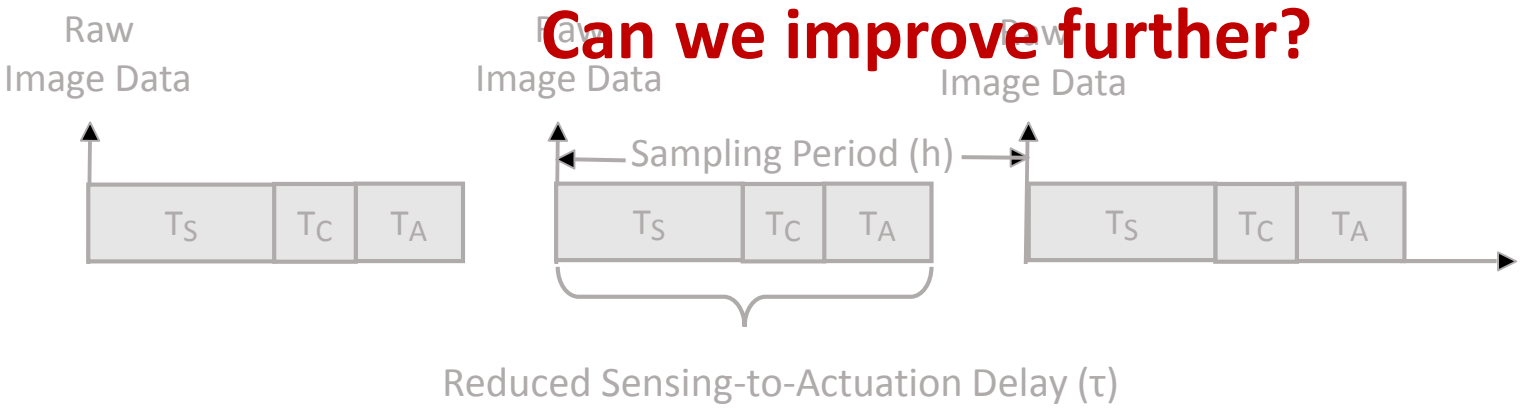
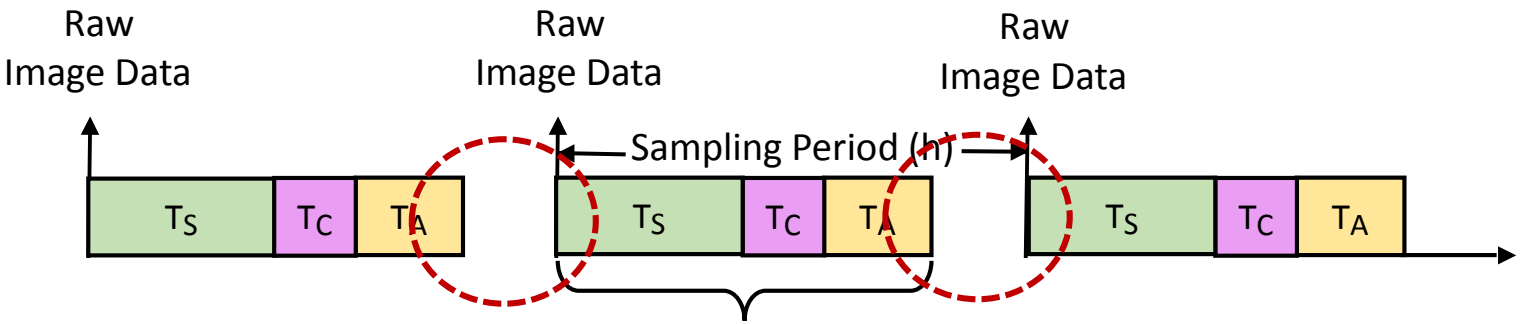


Image-based Control (IBC) System



3 **Apply Approximations + Reduce Sampling Period(h)**

Image-based Control (IBC) System



Reduced Sensing-to-Actuation Delay (τ)

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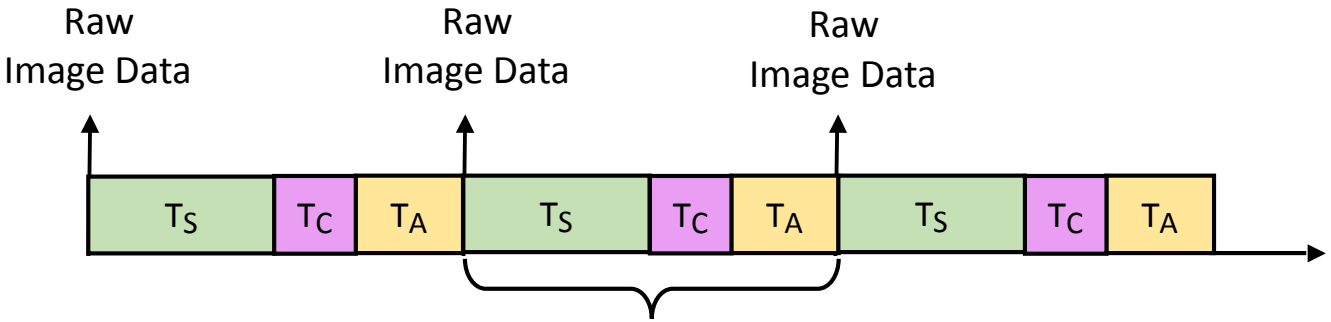

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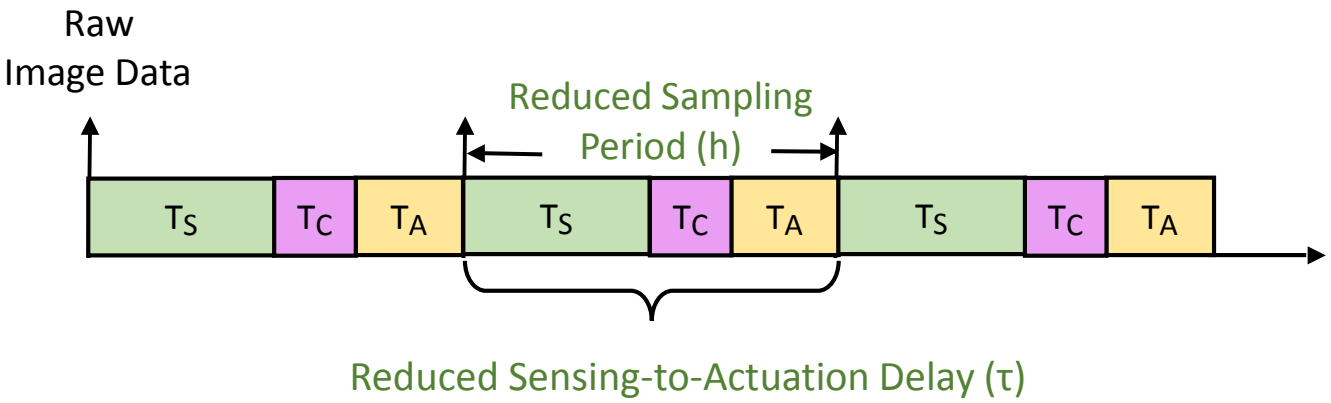
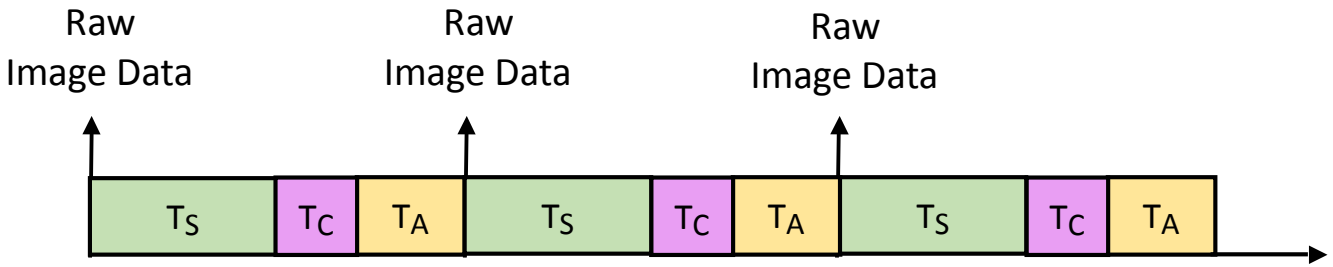


3 **Apply Approximations + Reduce Sampling Period(h)**

What should we approximate?

Profiling

- Intel i9 8-core, 200 different images



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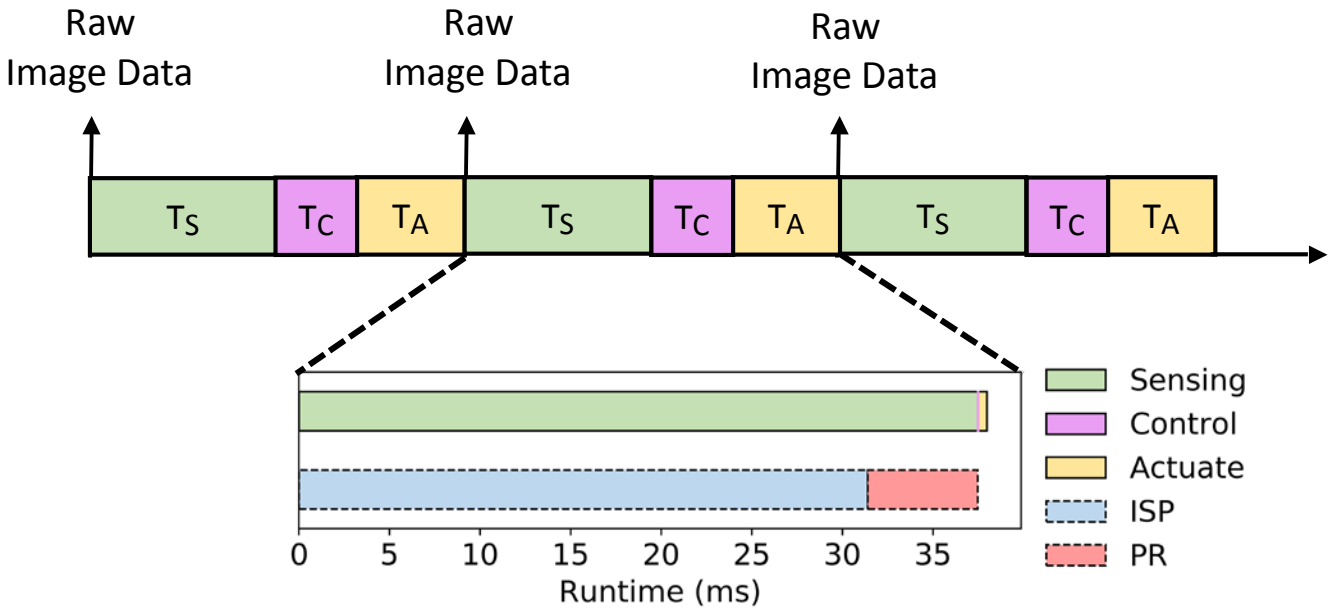

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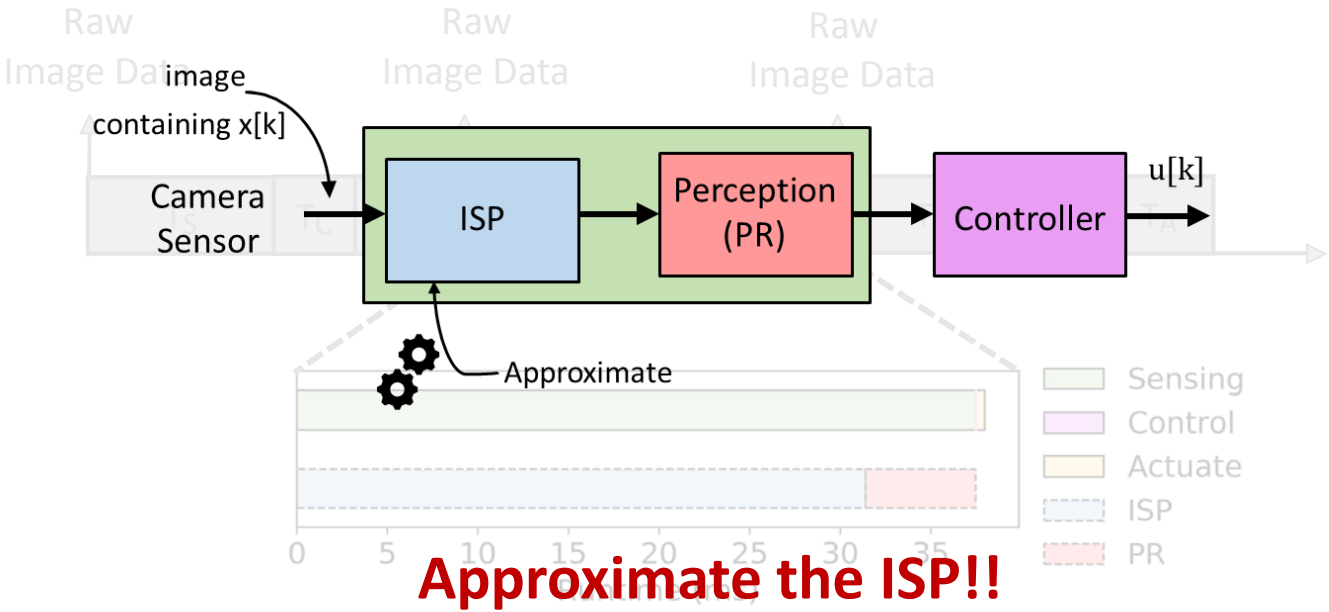
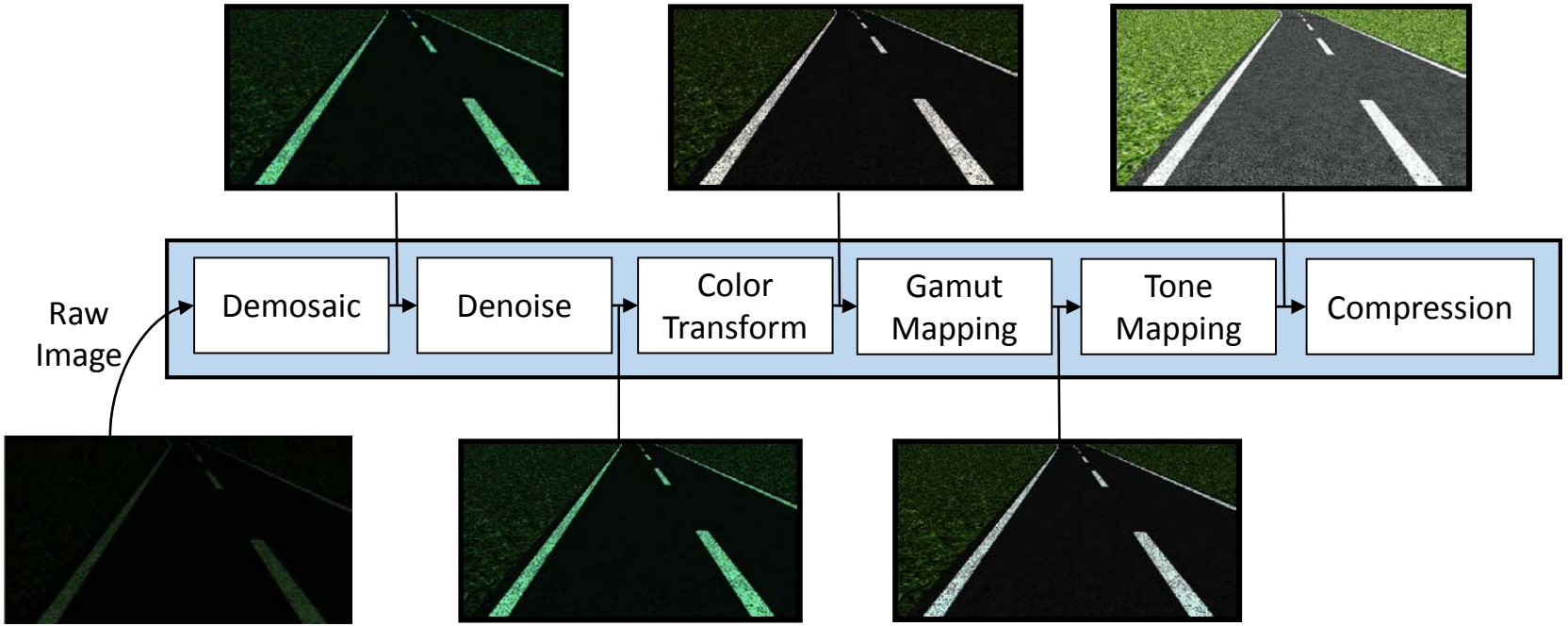


Approximate the ISP!!

Image Signal Processor (ISP)



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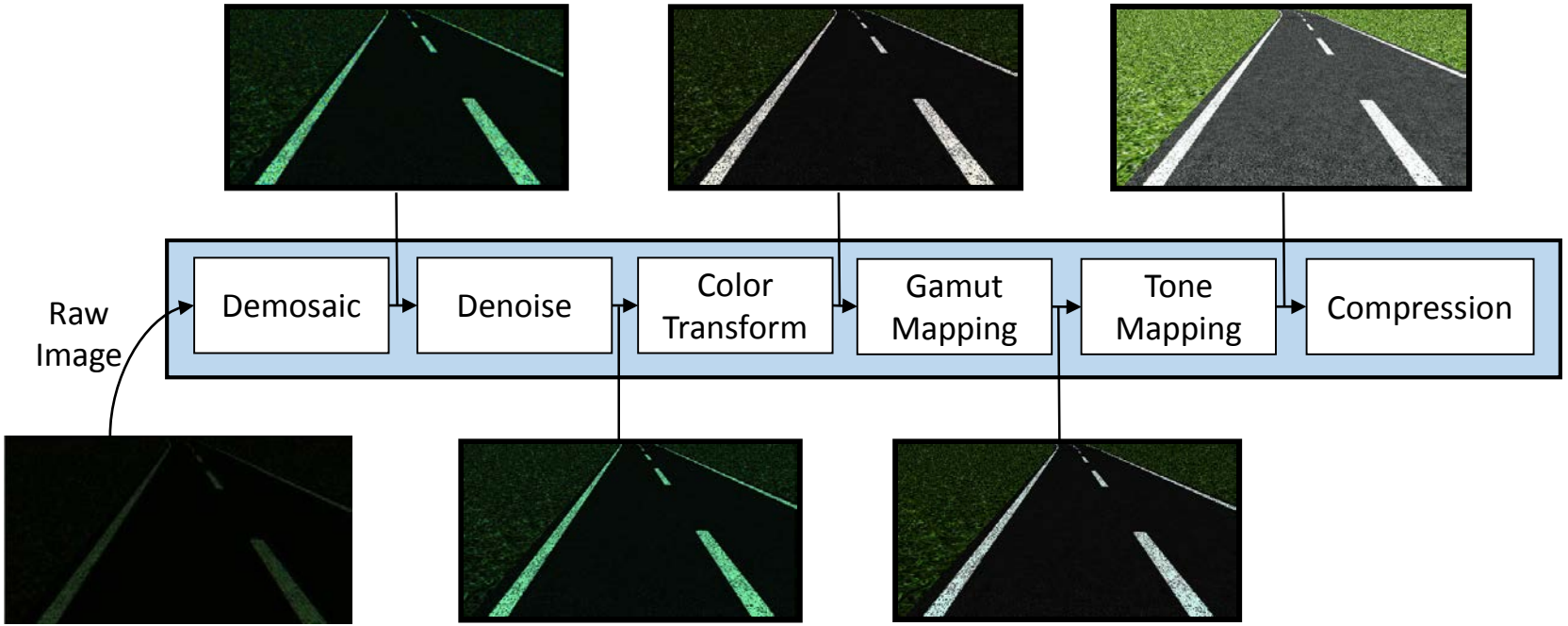
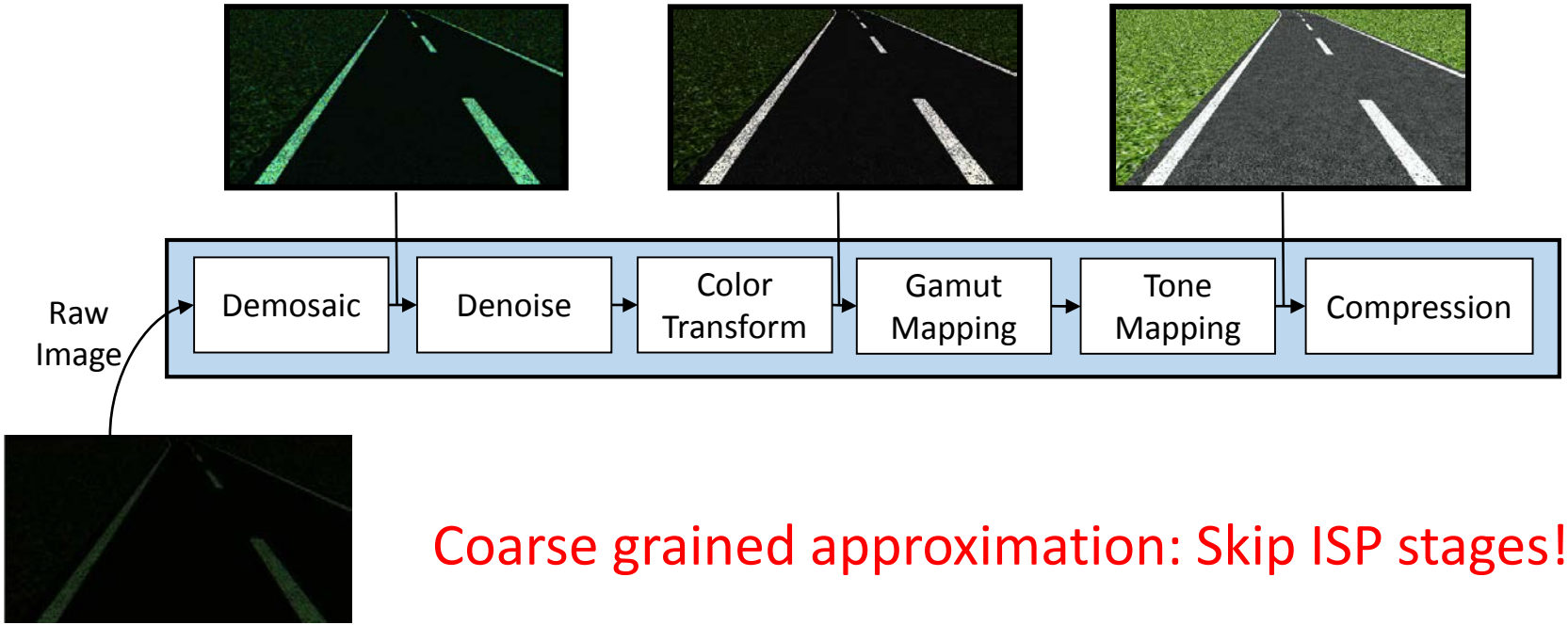


Do we really need a vision optimized pipeline for control?

Image Signal Processor (ISP)



Coarse grained approximation: Skip ISP stages!

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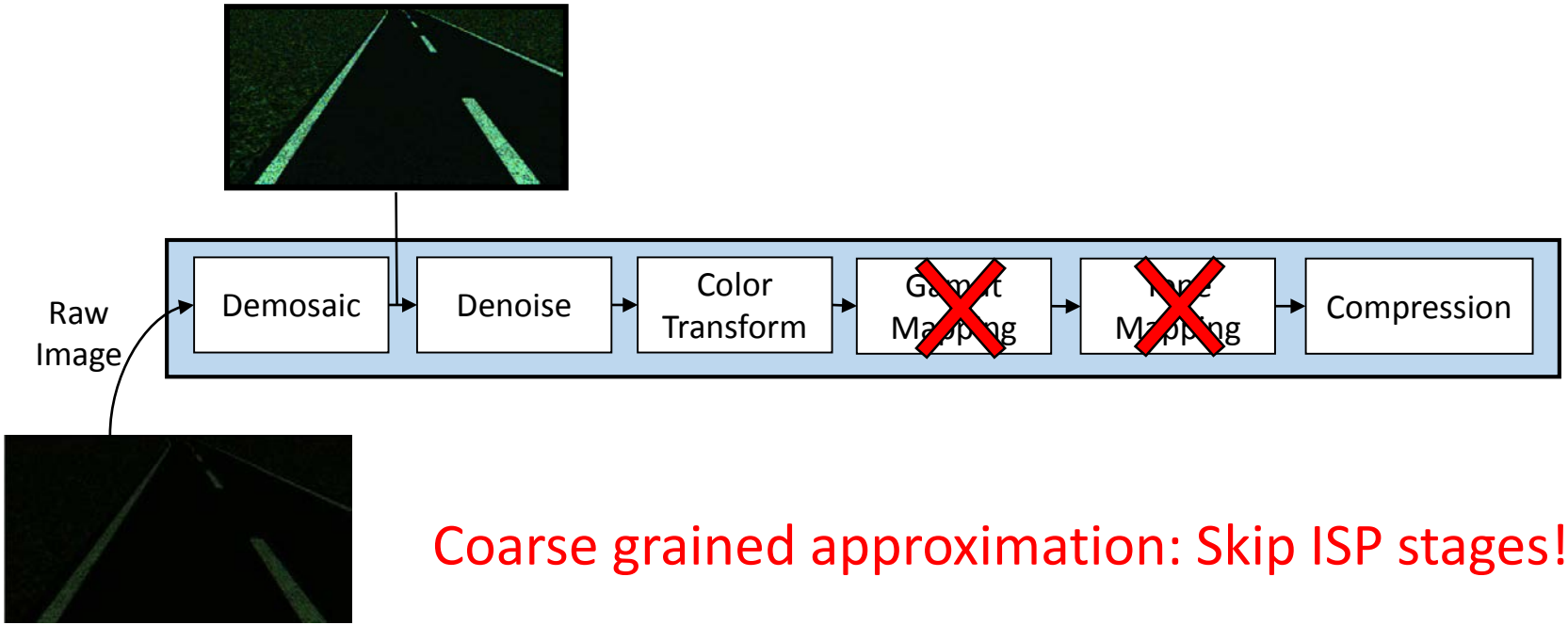

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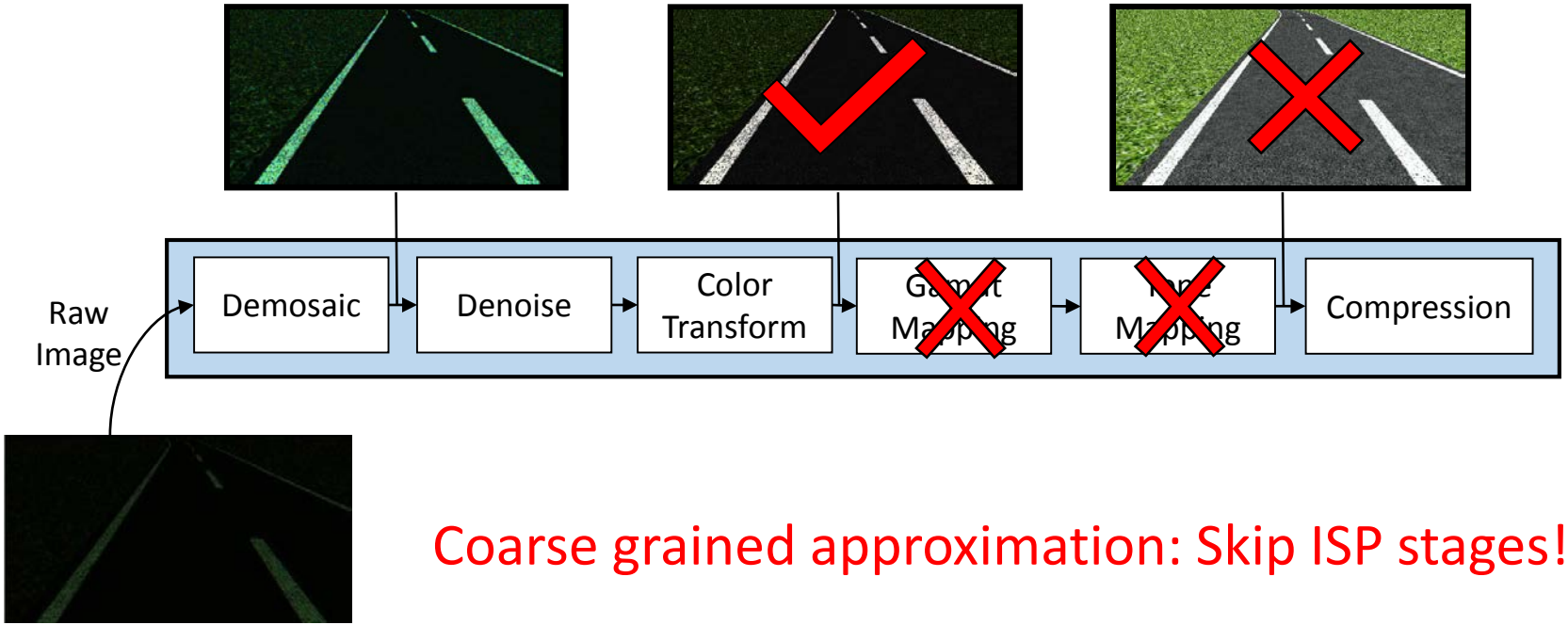
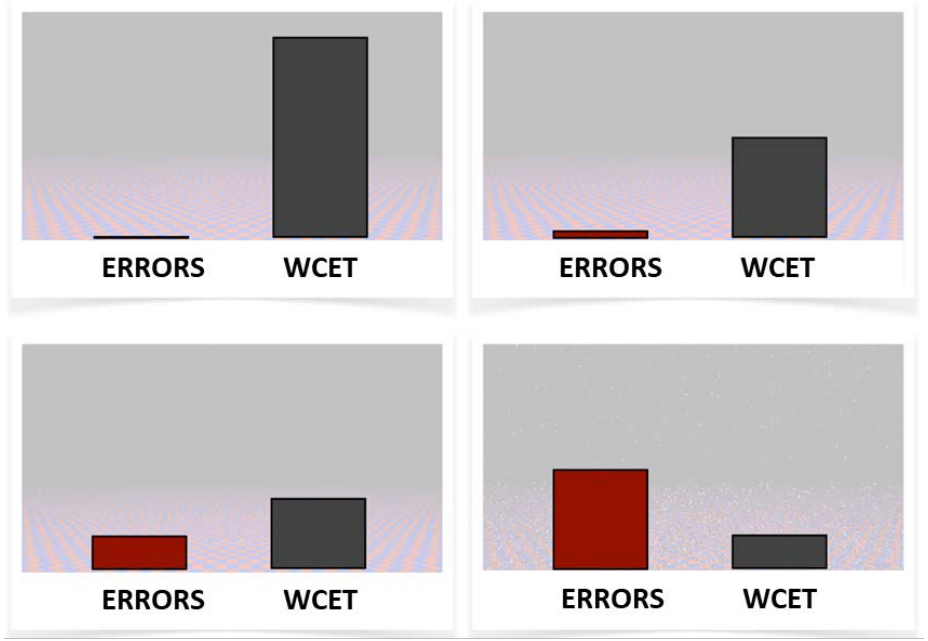


Coarse grained approximation: Skip ISP stages!

What is the impact of approximation on IBC?

Reduced Execution Time



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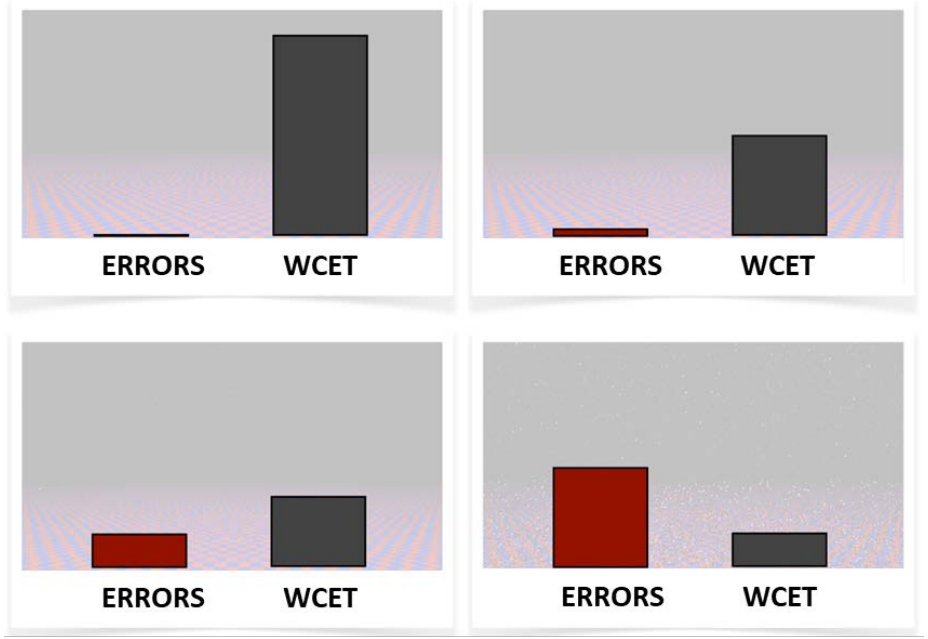

Loss in Image Quality

What is the impact of approximation on IBC?

Reduced Execution Time

→ shorten both sampling period *h* and delay τ

→ better control performance

Loss in Image Quality

→ inaccurate computation of state y_L

→ errors might be significant

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Reduced Execution Time

→ shorten both sampling period *h* and delay τ

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Loss in Image Quality

→ inaccurate computation of state y_L

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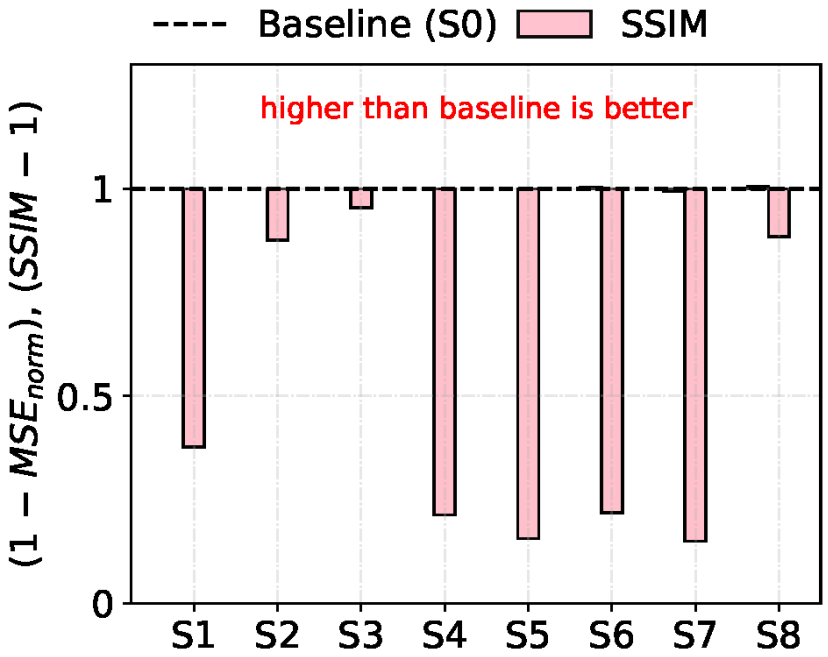
Their interplay determines if we gain or lose on IBC performance

Impact on Image Quality

Low SSIM [More Noise]



Setting	ISP Stages	Description
S0	DM, DN, CM, GM, TM, C	Accurate (all stages included)
S1	DM, CM, GM, TM, C	Skip Denoising
S2	DM, DN, GM, TM, C	Skip Color Mapping
S3	DM, DN, CM, TM, C	Skip Gamut Mapping
S4	DM, DN, CM, GM, C	Skip Tone Mapping
S5	DM, DN, C	Keep only Denoising
S6	DM, CM, C	Keep only Color Mapping
S7	DM, GM, C	Keep only Gamut Mapping
S8	DM, TM, C	Keep only Tone Mapping

Impact on Image Quality

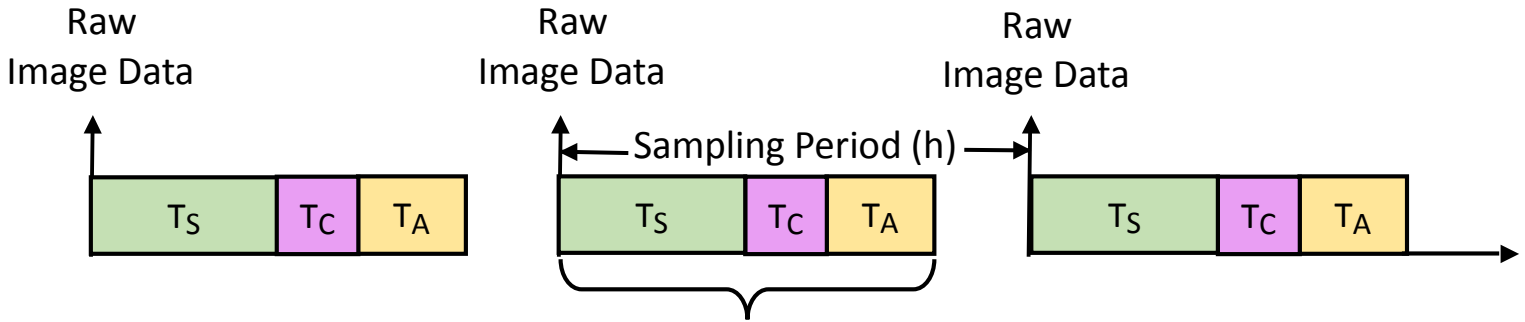
- Features of image may not be detected
  - Algorithm should be resilient to approximation
  - Application-specific testing needed!

Impact of Image Quality on QoC

Without considering improved timing

Impact of Image Quality on QoC

Without considering improved timing

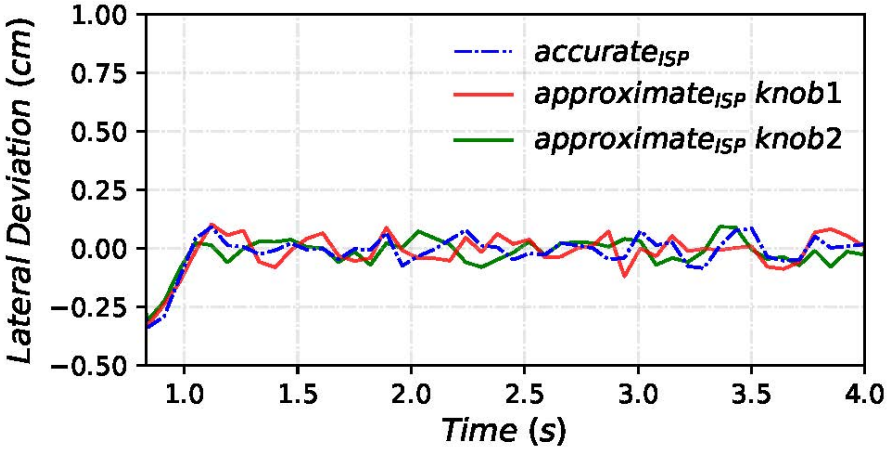


Reduced Sensing-to-Actuation Delay (τ)

2 **Apply Approximations to reduce the Sensor to Actuation Delay (τ)**

Impact of Image Quality on QoC

Without considering improved timing



Impact of Image Quality on QoC

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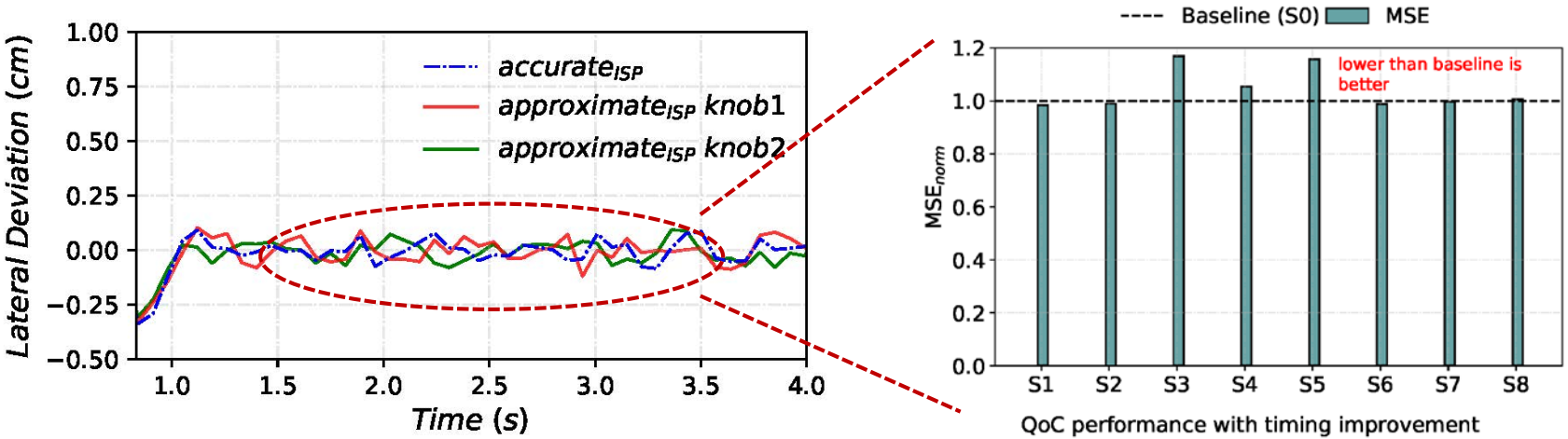
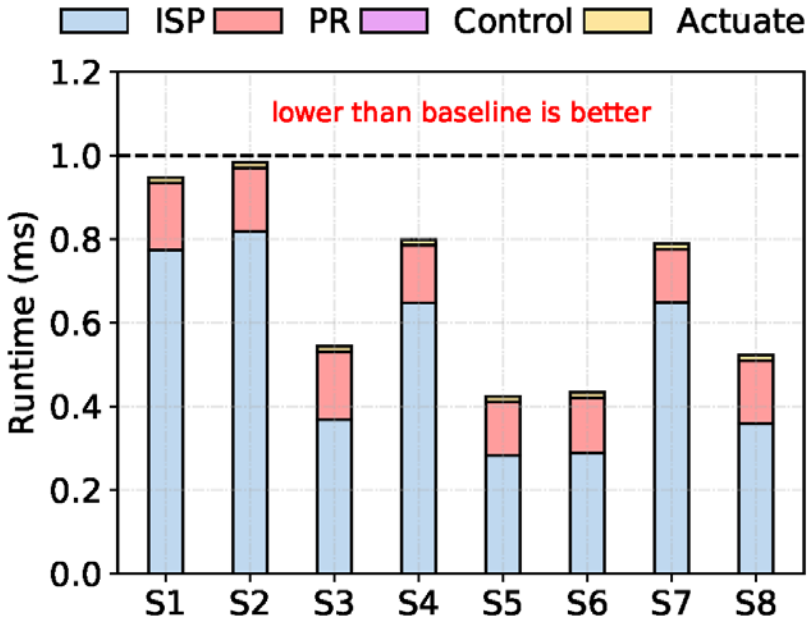
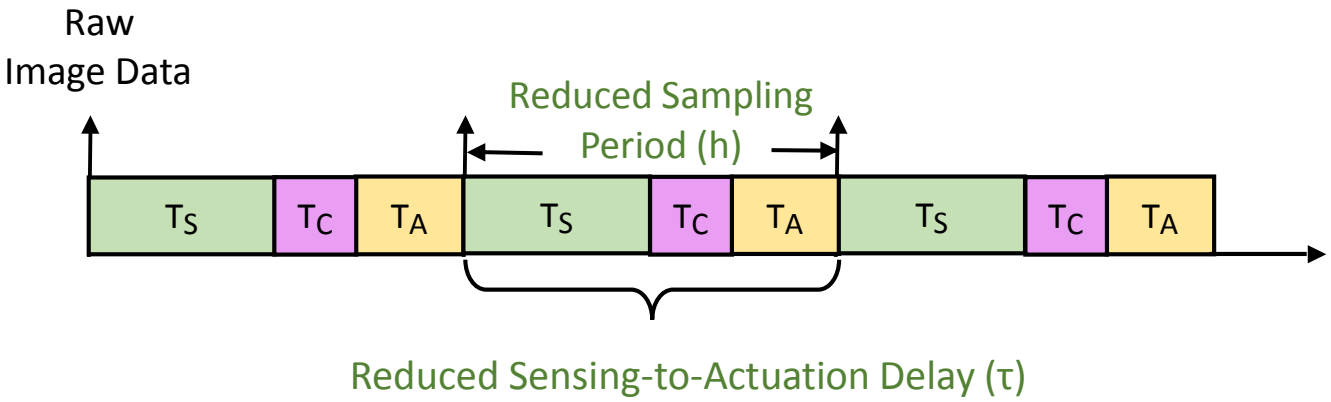


- Performance deteriorates up to 18% for approximated images (S3, S4, S5)
- For the rest, performance is the same as accurate (S0)

But timing is improved due to approximation!



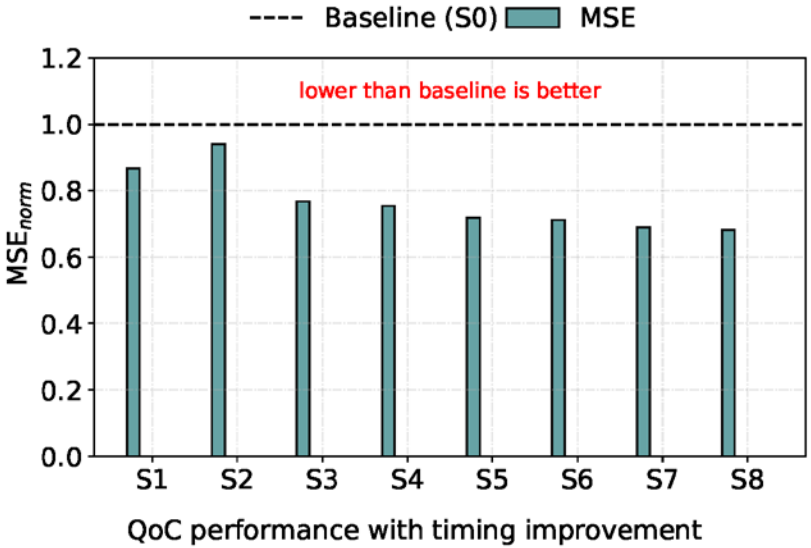
Considering improved timing



3 **Apply Approximations + Reduce Sampling Period(h)**

Results: Degree of approximation vs QoC

Considering improved timing



Reduced sensing delay has improvements in Quality-of-Control (QoC)

Results: Degree of approximation vs QoC

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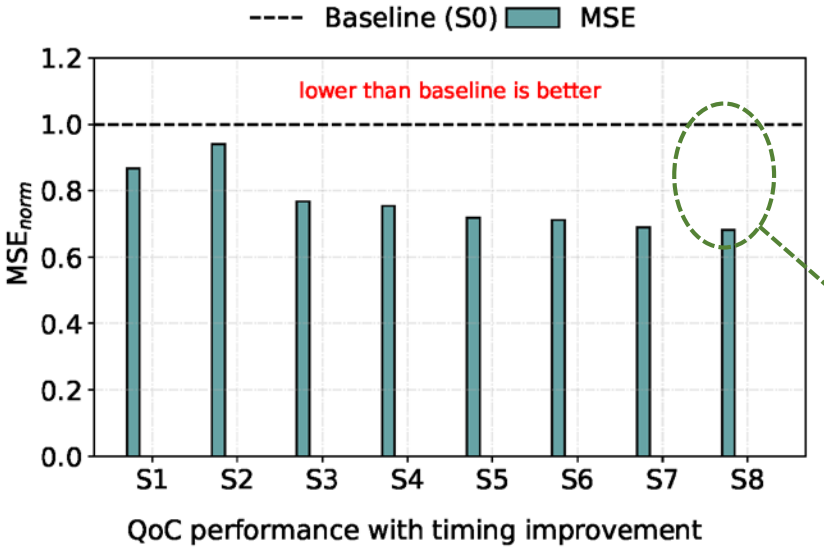
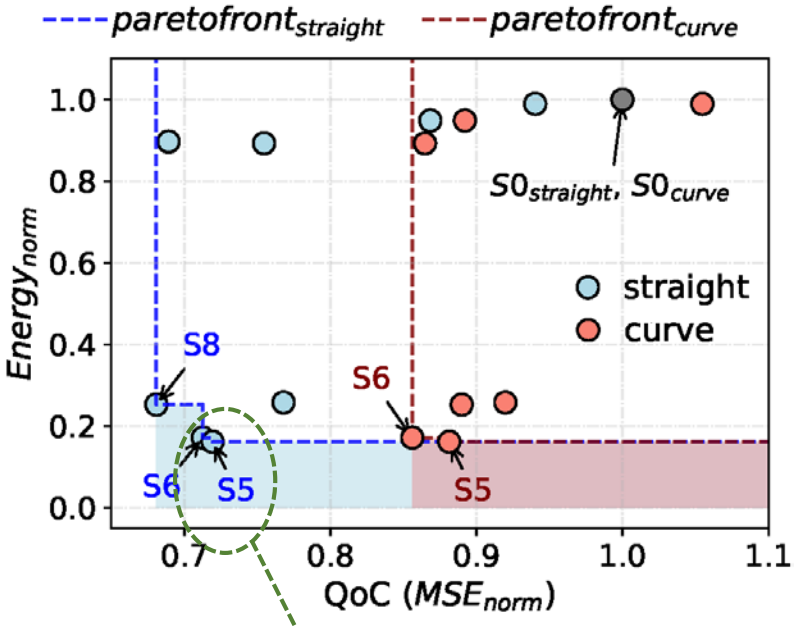


Reduced sensing delay has improvements in Quality-of-Control (QoC)

Upto 27% QoC improvements are obtained (S8)

Results: Degree of Approximation vs Energy



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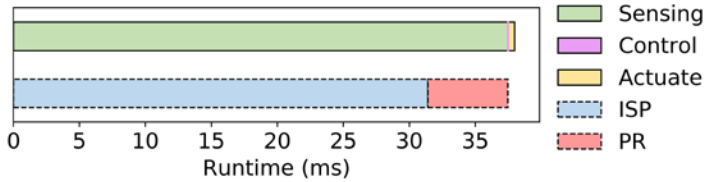
S8	DM, TM, C	Keep only Tone Mapping

Reduced sensing delay has energy improvements of upto 84% (S5) with 28% QoC gains for straight road scenario.

Conclusions

- **Image-based control suffers from long processing delay**



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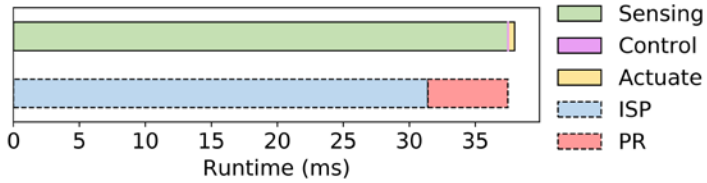
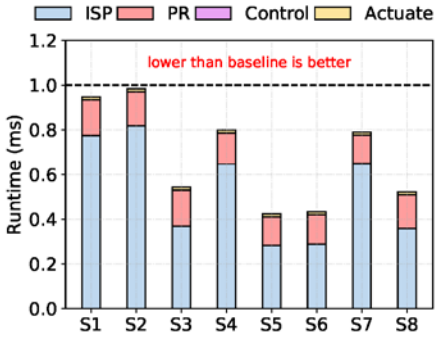
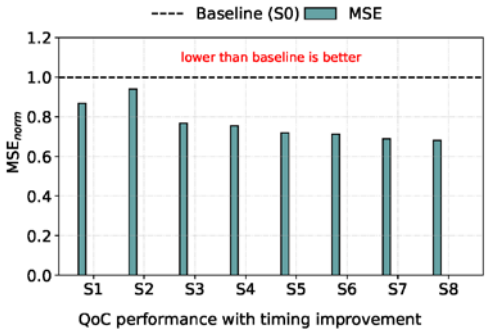
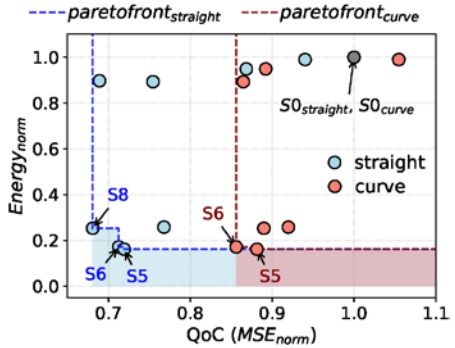


- **Image-approximation is one promising approach to deal with long delay and save compute energy**







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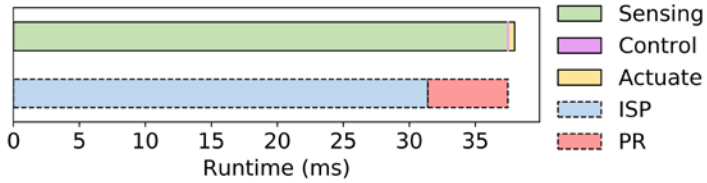

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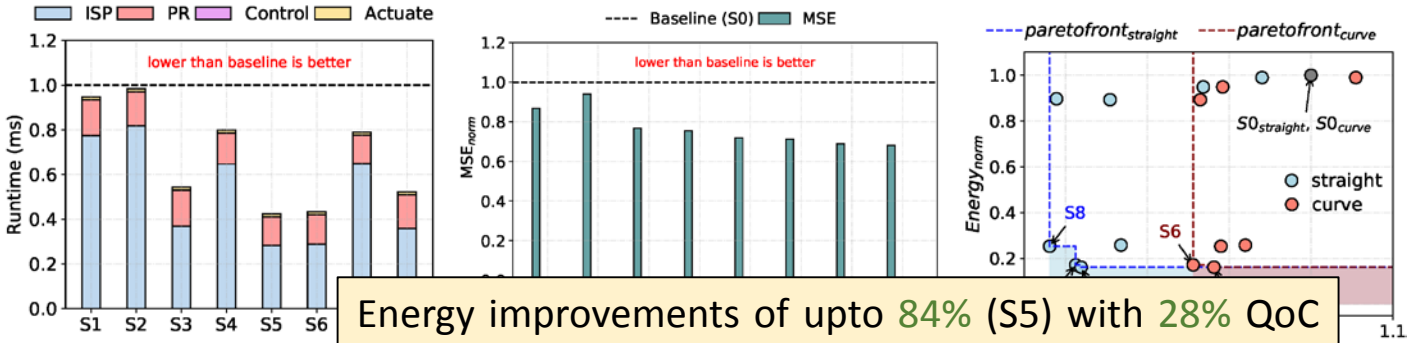

Energy improvements of upto 84% (S5) with 28% QoC gains for straight road scenario.

Open-source Repository

https://github.com/sayandipde/approx_ibc

Thank You

Contact

✉ sayandip.de@tue.nl