Bridging the controller design-implementation gap for image-based control systems

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1. Image-based Control (IBC)
- IBC systems are a class of data-intensive feedback control systems whose feedback is provided by image-based sensing [1].
- Embedded platform (discrete-time)
- Dynamic system (continuous time)

![Camera](image)

Figure 1. An image-based control system: block diagram
- Here, the sampling period (h) and the sensor-to-actuator delay (τ) are greater than the frame arrival duration (see Fig. 2), i.e. \( h > \text{fps} \). fps denotes the camera frame rate per second.

2. Controller Design vs Implementation
- The timing values for the worst-case (WC) workload are used for controller design [2].
- Sensing task is a black box
- Controller design is a black box

![Gantt Chart](image)

Figure 2. IBC system gantt chart
- The execution time for sensing task depends on image workload variations that can be statistically analysed (e.g. as a PERT [3]).
- The designer can classify frequently occurring workload scenarios and always we observe that worst-case workload rarely occurs.
- An average workload scenario results in idling of the resource.
- A WC workload-based implementation means that frames have to be dropped even though the resource is idle/available.

3. Bridging The Gap
Can we jointly optimise control performance and platform resource utilisation considering workload variations?

4. Approach
- We propose a structured Scenario- and Platform-Aware Design (SPADe) flow for IBC systems assuming it is a white box [1]:
  1. optimises control performance or quality-of-control (QoC),
  2. maximises effective resource utilisation and
  3. adheres to platform constraints (given allocation and fps).

![Model Diagram](image)

Figure 4. SPADe approach for IBC
- The SPADe approach involves the following aspects (see Fig. 4):
  a) Formal Modelling: i) identify and model the parameters that characterise workload variations, and ii) model application considering workload variations and platform considering platform constraints.
  b) Analysis and Design: Analyse application and platform models to design system configurations.
  c) Reconfiguration mechanism for run-time implementation.

5. Results & Conclusion
- SPADe maximises effective resource utilisation and improves the settling time for the control system compared to WC design.
- Considering workload variations is definitely beneficial for design.

![Graph](image)

Figure 5. SPADe results: vision-based lateral control system [1]

6. Next Challenges
Extend SPADe approach for: i) (reconfigurable) pipelined controller design and implementation; ii) approximated image processing algorithms; and iii) communication-aware design for distributed IBC.

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References