Net-Centric and Cloud Software and Systems I/UCRC

FPGA-based Subsampling Algorithms for Space-based Computational Imaging

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Project Overview

❑ Problem Statement

- Optimize image sensor readout power consumption
  - Adaptively subsample frames via predictive ROI tracking

❑ Applications

- Always-on imaging and defense applications
- Autonomous vehicles, surveillance

❑ Challenges

- Developing an adaptive subsampling method
  - Latency and energy optimization
- Implementing our adaptive subsampling framework on an FPGA
  - Demonstrating digital ROI-ing capability with a webcam as a proof-of-concept

Project Overview (cont.)

Tasks:

Task#	Task Description
1■	Develop neural network-based algorithm for tracking with adaptive subsampling
2■	Image sensor energy optimization
3■	Implement algorithm on hardware for latency optimization
4■	Identify a robust solution and compare proposed method against baselines

Project Milestones:

Task#	Planned Completion	Milestone (Deliverable)
1■	08/21	Develop FPGA-compatible adaptive subsampling algorithm
2■	09/21	Quantize and compile neural network for the DPU
3■	10/21	Adapt algorithm for FPGA compatibility
4■	11/21	Perform digital ROI-ing with webcam
5■	12/21	Implement baselines
6■	01/22	Conduct extensive experiments – keyframing, memoization, power analysis, ablation studies

Research Goals:

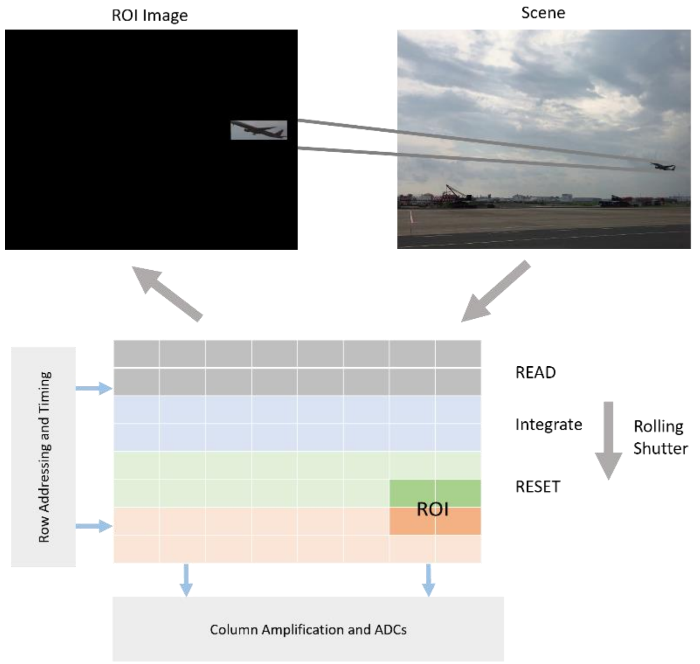
1. Develop an adaptive subsampling algorithm geared towards energy optimization of the image sensor in tracking applications
2. Leverage hardware acceleration techniques to reduce both latency and sensor power consumption
3. Evaluate the algorithm against baselines and generate quantitative and qualitative results

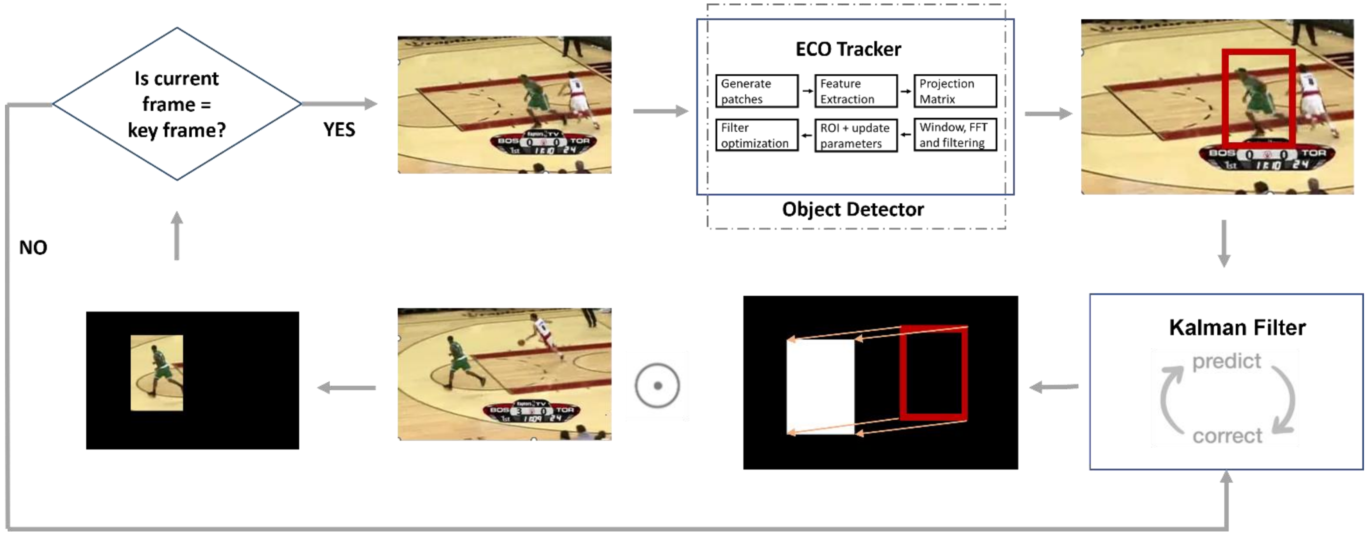
Benefits to Industry Partners:

1. Reduction of power consumption by the image sensor readout circuitry
2. Potentially useful for always-on imaging applications
3. Useful for tracking and vision applications like surveillance, autonomous driving etc.
4. Performance optimization with hardware acceleration is useful for tracking applications

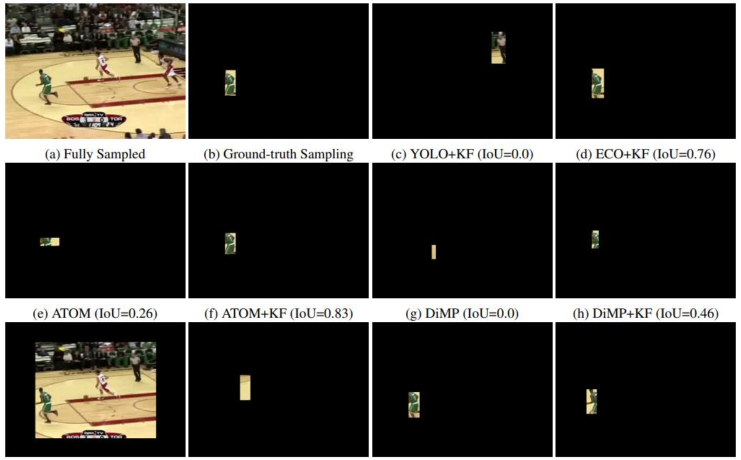
[2] ■ Milestone complete or is on track for planned completion date
■ Milestone has changed from original sponsor-approved date (Why?)

Project Pictorial

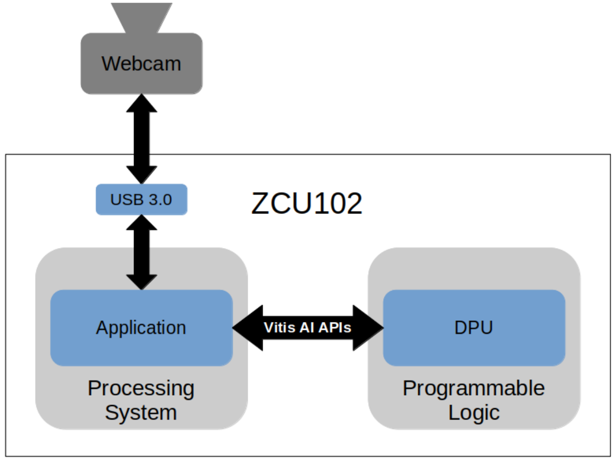


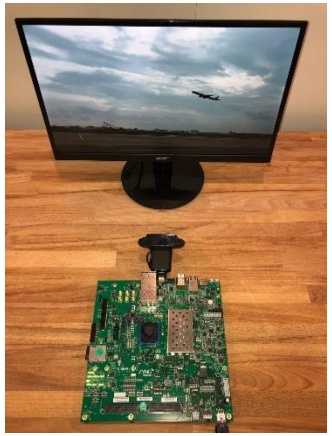


Project Pictorial

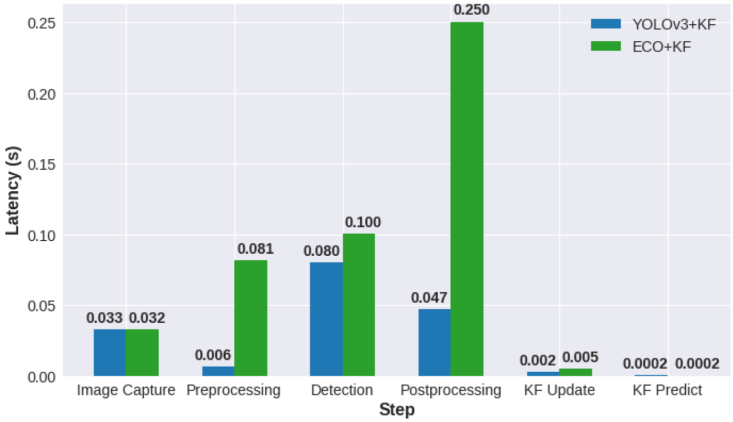


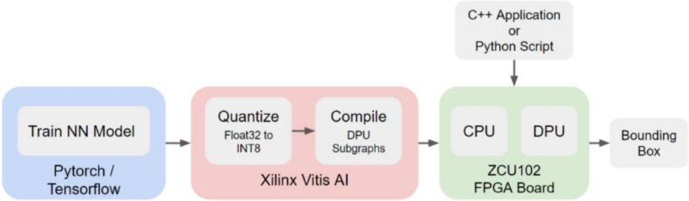
(a) Fully Sampled (b) Ground-truth Sampling (c) YOLO+KF (IoU=0.0) (d) ECO+KF (IoU=0.76)
(e) ATOM (IoU=0.26) (f) ATOM+KF (IoU=0.83) (g) DiMP (IoU=0.0) (h) DiMP+KF (IoU=0.46)
(i) Tiny-YOLO+KF (IoU=0.02) (j) KCF+KF (IoU=0.0) (k) MS+KF (IoU=0.74) (l) DAT+KF (IoU=0.30)





Dataset	MS+KF	YOLO [51]+KF	KCF [78]+KF	DAT [79]+KF	ECO [46]+KF	ATOM [48]	DiMP [49]	Tiny-YOLO+KF	ATOM+KF	DiMP+KF
OTB100	0.2051	0.2709	0.2567	0.2573	0.4568	0.2859	0.3398	0.0809	0.4625	0.4817
LaSOT	0.1928	0.2733	0.1809	0.1712	0.3471	0.2425	0.2942	0.1103	0.4282	0.4702





Algorithm	Algorithm FPS	System FPS	Keyframe
ECO [46]+KF	19.23	13.42	10
YOLO [51]+KF	65.39	24.6	10

Progress to Date and Accomplishments

Task#/Description	Status	Progress and Accomplishments
1. Develop the first component of the algorithm – location detector	■	- Zeroed in on the optimum object detector – the ECO – as the location detector.
2. Develop the second component – location predictor	■	- Used a Kalman filter as the location predictor to make predictions about object trajectories.
3. Implement proposed algorithm on an FPGA and obtain quantitative results	■	- Leveraged Xilinx's Vitis AI tools to accelerate our adaptive subsampling algorithm. - Quantized and compiled pre-trained neural network (ECO) for the DPU using Vitis. - Performed performance study against baselines. - Evaluated error tolerance of algorithm with increasing keyframing intervals and absent Kalman filter (memoization).
4. Documentation of research and development	■	- Paper entitled "Design and fpga implementation of an adaptive video subsampling algorithm for energy-efficient single object tracking" was published in ICIP 2020. - A journal paper titled "Adaptive Subsampling for ROI-Based Visual Tracking: Algorithms and FPGA Implementation" was published in IEEE Access 2022.

■Significant Finding/Accomplishment ■Task Complete ■Task Partially Complete ■Task Not Started

Objective Evidence Supporting NCSS Value Proposition

Category	Objective Evidence
Papers, Publications, Presentations/Venue	1. O. Iqbal, S. Siddiqui, J. Martin, S. Katoch, A. Spanias, D. Bliss, and S. Jayasuriya, "Design and fpga implementation of an adaptive video subsampling algorithm for energy-efficient single object tracking," 2020 IEEE International Conference on Image Processing (ICIP), pp. 3065–3069, 2020. 2. O. Iqbal, Vl. Muro, S. Katoch, A. Spanias, and S. Jayasuriya, "Adaptive Subsampling for ROI-Based Visual Tracking: Algorithms and FPGA Implementation," IEEE Access, vol. 10, pp. 90507-90522, 2022.
Products (Software, Data, Designs, etc.)	1. ECO used for feature extraction and object detection and Kalman filter used for ROI prediction and subsequent adaptive subsampling while tracking. Pytorch code for ECO and Kalman filter-based ROI-ing is available. 2. Quantization and compilation of the neural network performed using Vitis AI tools. 3. Pytorch code available for proposed method, baseline experiments and ablation studies.