Optimizing Edge Robotics with YOLO, SORT, and TinyMPC for Enhanced Object Tracking and Control

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Background

TinyMPC

- Lightweight model predictive control (MPC) library designed for embedded systems and small-scale robotics applications
- Developed by researchers focusing on efficient control algorithms for resource-constrained devices
- Features
  - Lightweight and efficient
  - Real-time control
  - Integrable with tiny drones
- Applications
  - Emergency search and rescue
  - Routine monitoring of infrastructure

CrazyFlie 2.1

- Open-source quadcopter drone
- Developed by Bitcraze
- AI Deck
  - Equipped with GAP8 IoT processor and camera
  - Enables onboarding image processing for computer vision and object detection
- Features
  - Robust
  - Compatible with TinyMPC
- Applications
  - Dynamic control
  - Collision obstacle avoidance
  - Navigation accuracy

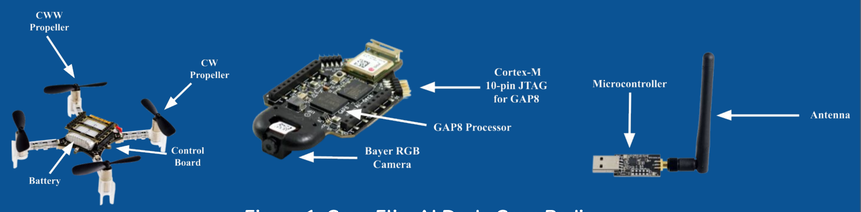


Figure 1. CrazyFlie, AI Deck, CrazyRadio

Algorithms	Object Detection	Obstacle Avoidance	Object Identification
YOLO [5] (You Only Look Once)	✔		✔
SORT [6] (Simple Online & Realtime Tracking)			✔
TinyMPC [1]		✔	
Our Algorithm: TinyMPC with Trajectory Estimation	✔	✔	✔

	Crazyflie2.1	DeepPicar Micro	PIXHAWK PX4	Petoi Bittle
Processor	STM32F405 168 MHz 32-bit M4 MCU	RP2040 133 MHz Dual-Core 32-bit M0+ MCU	STM32F765 216 MHz Dual-Core 32-bit M7 MCU	ESP32-WROOM-32D 240MHz Dual-Core 32-bit LX7 MCU
RAM	196 kB	264 kB	512 kB	512 kB
Flash	1 MB	2 MB	2 MB	16 MB
Processor Power	0.15 W	0.15 W	0.5 W	0.5-1 W

Tiny Platforms

Figure 2. Comparison of tiny platforms and their respective hardware [1]

Objective

Improve navigation accuracy in dynamic environments by integrating YOLO, SORT, and TinyMPC for enhanced object tracking and trajectory estimation in edge robotics

Method

01 Object Detection

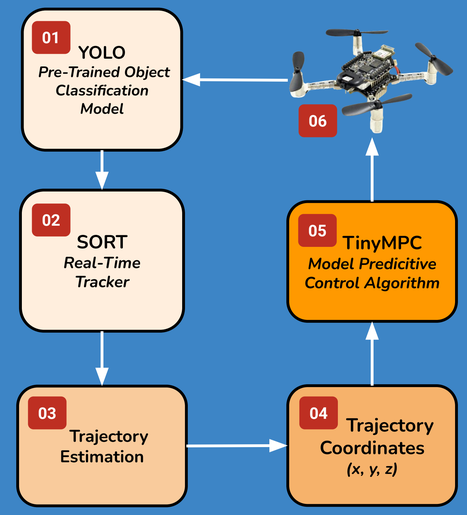
- **YOLO** (You Only Look Once): Utilized a pretrained model to perform real-time object detection and classification
- **YOLOv8**: Tested with model which sends bounding box data to the tracker for further processing

02 Object Tracking

- **SORT** (Simple Online & Realtime Tracking): Realtime tracking algorithm used to track objects across frames
- **Integration with YOLO**: Receives bounding box data from YOLO for continuous object tracking and identification

03 Trajectory Estimation

- **Trajectory Estimation**: Calculated the desired trajectory by estimating Euclidean distances between objects.
- **Integration**: Used YOLO for object detection and SORT for tracking to provide the positional data required for trajectory estimation.
- **Output**: Provided measurements of object movement in the 2D plane for accurate trajectory planning.



Trajectory Coordinates 04

- Outputs coordinates representing the predicted path of the objects over time
- Coordinates are derived from object coordinates provided by YOLO and tracked by SORT

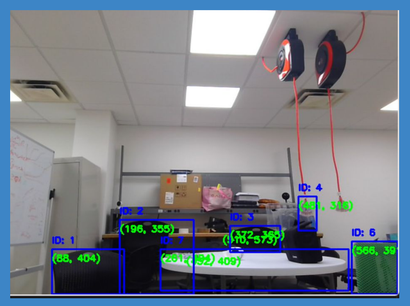
TinyMPC 05

- The trajectory coordinates serve as reference points for the TinyMPC system
- Uses coordinates as the desired path for the drone to follow
- Computes control inputs to adjust flight path

CrazyFlie 06

- TinyMPC runs on the CrazyFlie to compute control inputs for precise navigation
- AI Deck handles image processing and object detection using YOLO

Results & Discussion



- Captures video frames and identifies various objects within the scene
- Each detected object is assigned a unique ID with position tracked across consecutive frames
- Bounding boxes and labels overlaid on the video feed demonstrate the system's capability to accurately identify and localize objects in real-time.

Time to Process & Infer an Image (ms)

Stages	Minimum	Maximum	Average
Pre-Process	2.0	57.7	10.0
Inference	592.9	882.4	734.3
Post-Process	2.0	73.7	11.0

```
0: 480x640 1 bottle, 4 chairs, 1 dining table, 183.5ms
Distance between object ID 7: 0.41 pixels
Distance between object ID 6: 0.07 pixels
Distance between object ID 4: 0.04 pixels
Distance between object ID 3: 0.20 pixels
Distance between object ID 2: 3.98 pixels
Distance between object ID 1: 0.05 pixels
```

Future Work & Applications

Future Work
- Integrate computer vision algorithm with the TinyMPC codebase
- Deploy integrated algorithm onto the CrazyFlie
- Replace trajectory estimation with an efficient 3D depth estimation algorithm

Applications
- Search and Rescue Operations
- Agriculture Monitoring
- Wildlife Monitoring
- Security and Surveillance
- Logistics & Delivery
- Environmental Monitoring
- Disaster Response

References

1. A. Alavilli, K. Nguyen, S. Schoedel, B. Plancher, and Z. Manchester, "TinyMPC: Model-predictive control on resource-constrained microcontrollers," arXiv preprint arXiv:2310.16985, 2023.
2. A. Farooq, S. Z. Nain Zukhraf, S. Shafi, M. Kamal and N. Chumuang, "Vision-Based Navigation for a Small-Sized Drone: A Simple AI Strategy at IMAV'22," 2024 IEEE International Conference on Cybernetics and Innovations (ICCI), Chonburi, Thailand, 2024, pp. 1-5, doi: 10.1109/ICCI60780.2024.10532299.
3. E. Lindgren, 'Target Recognition and Following in Small Scale UAVs', Dissertation, 2022.
4. B. Ke, A. Obukhov, S. Huang, N. Metzger, R. C. Daudt, and K. Schindler, "Repurposing diffusion-based image generators for monocular depth estimation," in Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition, 2024, pp. 9492-9502.
5. J. Redmon, S. Divvala, R. Girshick and A. Farhadi, "You Only Look Once: Unified, Real-Time Object Detection," 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), Las Vegas, NV, USA, 2016, pp. 779-788, doi: 10.1109/CVPR.2016.91.
6. Alex Bewley, Zongyuan Ge, Lionel Ott, Fabio Ramos, Ben Upcroft. "Simple Online and Realtime Tracking," 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR),

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