Teesside University

# Low-Cost Solar-Powered Real-Time AI-Driven Vehicle for Security Applications

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# Outline

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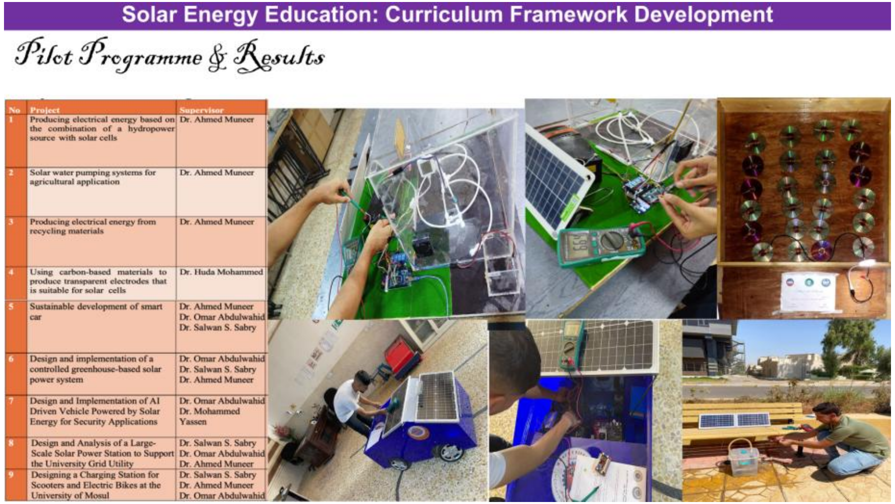


| No | Project | Supervisor |
|---|---|---|
| 1 | Producing electrical energy based on the combination of a hydropower source with solar cells | Dr. Ahmed Muneer |
| 2 | Solar water pumping systems for agricultural application | Dr. Ahmed Muneer |
| 3 | Producing electrical energy from recycling materials | Dr. Ahmed Muneer |
| 4 | Using carbon-based materials to produce transparent electrodes that is suitable for solar cells | Dr. Huda Mohammed |
| 5 | Sustainable development of smart car | Dr. Ahmed Muneer<br>Dr. Omar Abdulwahid<br>Dr. Salwan S. Sabry |
| 6 | Design and implementation of a controlled greenhouse-based solar power system | Dr. Omar Abdulwahid<br>Dr. Salwan S. Sabry<br>Dr. Ahmed Muneer |
| 7 | Design and Implementation of AI Driven Vehicle Powered by Solar Energy for Security Applications | Dr. Omar Abdulwahid<br>Dr. Mohammed Yassen |
| 8 | Design and Analysis of a Large-Scale Solar Power Station to Support the University Grid Utility | Dr. Salwan S. Sabry<br>Dr. Omar Abdulwahid<br>Dr. Ahmed Muneer |
| 9 | Designing a Charging Station for Scooters and Electric Bikes at the University of Mosul | Dr. Salwan S. Sabry<br>Dr. Ahmed Muneer<br>Dr. Omar Abdulwahid |

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**2024 IEEE International Symposium on Systems Engineering**

The IEEE ISSE 2024 symposium seeks to create an interactive forum for the advancement of the practice of systems engineering across the multiple disciplines and specialty areas associated with the engineering of complex systems.

# Overview

This work presents a **deployable, low-cost unmanned ground vehicle (UGV)** that fuses embedded AI perception with on-board solar energy harvesting to enable sustained, off-grid surveillance and environmental monitoring.

**Solar-Powered Operation:** Dual 30W PV panels with PWM charge controller for sustained off-grid capability

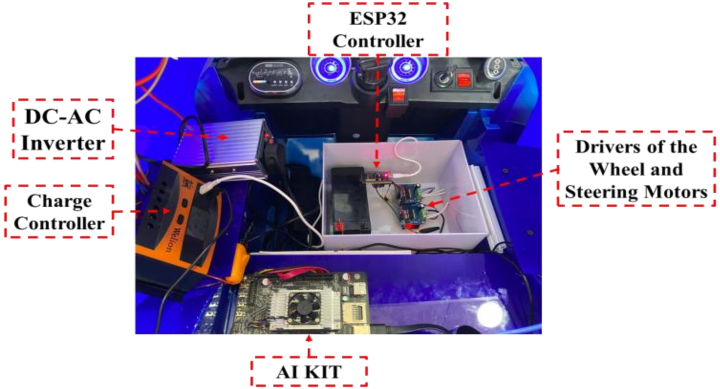
**Edge AI Computing:** NVIDIA Jetson TX2 running optimized YOLOv5s for real-time object detection

**Stereo Perception:** ZED stereo camera enabling depth sensing and obstacle avoidance

**Remote Monitoring:** Wi-Fi/4G connectivity with web dashboard for telemetry and control

**Gap in literature:** Prior solar vehicles are often costly, bulky, or lack real-time AI; small UGVs with PV frequently omit robust perception or sustained autonomy


Solar-Powered Security Rover Prototype Showing Front and Back Photovoltaic (PV) Panels




Internal Electronics Layout of the Solar-Powered Security Rover (Compute, Power, and Control Modules)

# Research Questions

**RQ1** Can a **low-cost embedded platform** deliver real-time object detection comparable to heavier systems?

**RQ2** Is **sustained outdoor operation** feasible using a lightweight dual-panel PV system and modest batteries?

**RQ3** What are the **trade-offs** among energy availability, AI performance, and responsiveness in embedded UGVs?

These questions address the intersection of **embedded AI**, **energy harvesting**, and **autonomous systems** in resource-constrained environments.

# System Overview

## Perception & Control

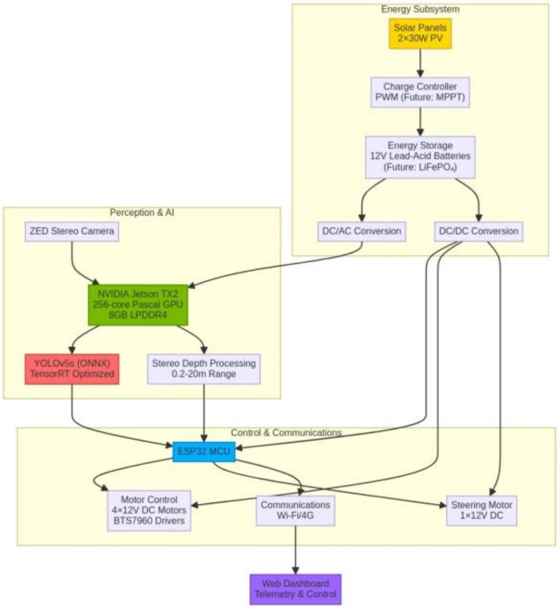
**NVIDIA Jetson TX2** + ZED stereo camera; YOLOv5s (ONNX) optimized with TensorRT; ESP32 for motor control and comms; web dashboard over Wi-Fi/4G.

## Energy Subsystem

Two **30W PV panels** (angled front/back), PWM charge controller, dual 12V 9Ah lead-acid batteries, DC/AC conversion for AI kit.

## Chassis & Actuation

4×12V brushed DC wheel motors (differential drive) + 1 × 12 V steering motor; **BTS7960 drivers**.




Functional Architecture of the Solar-Powered Edge-AI Security Rover (Energy, Perception & AI, and Control/Communications)


System architecture showing energy, perception, and control subsystems integration

# Embedded AI Stack (Edge Compute)

**Hardware Platform:** NVIDIA Jetson TX2

256-core Pascal GPU, 8 GB LPDDR4 memory

Power-efficient edge AI design (7.5W - 15W)

**AI Model & Runtime:** YOLOv5s

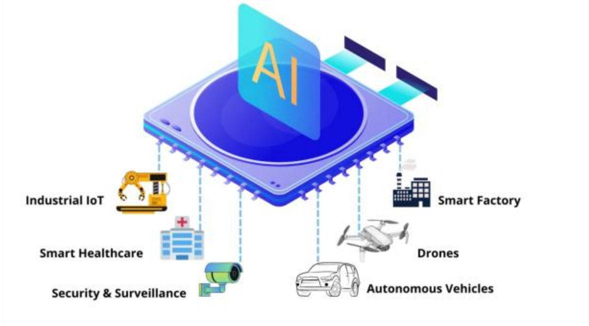
ONNX format with TensorRT optimization

~47 FPS with <79.1% mAP@0.5 accuracy

**Perception System:** ZED 2 Stereo Camera

Depth sensing range: ~0.2 to 20 meters

Enables obstacle detection and motion planning




## AI Processing Pipeline

1. **Image Acquisition**
   ZED stereo camera captures RGB + depth data

2. **Pre-processing & Optimization**
   Image resizing, normalization, TensorRT acceleration

3. **Inference & Detection**
   YOLOv5s model execution with confidence threshold ≥0.75

4. **Decision & Control**
   Automatic deceleration/evasion within ~3m range

# Power Architecture & Sizing Principles

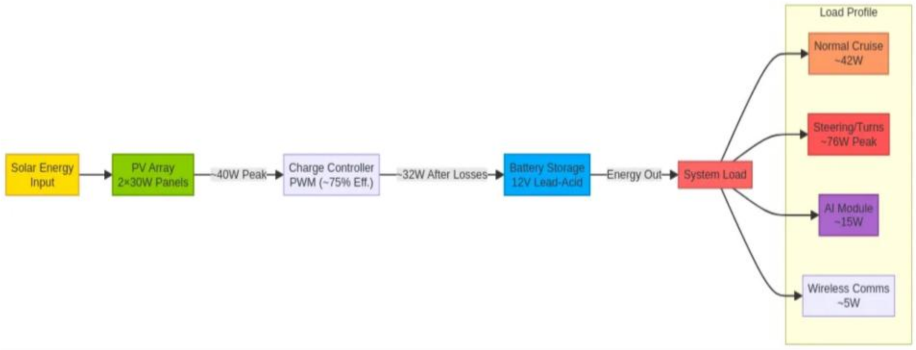
**PV Array:** 2×30W panels, mounted with offset tilts (≈32° & ≈12°) to capture varying sun angles during movement

**Charging:** PWM controller (≈75% eff.) used for cost reasons; future design shifts to MPPT for higher net energy yield

**Storage:** 12V lead-acid batteries sized using standard practice (load profile, autonomy, DoD, efficiency chain)

**Methodology:** IEEE Std 485-2020 underpins sizing methodology (stationary context; principles inform our approach)

The power architecture balances **cost constraints** with **operational requirements**, providing sufficient energy for sustained field operation while maintaining a lightweight, deployable form factor.



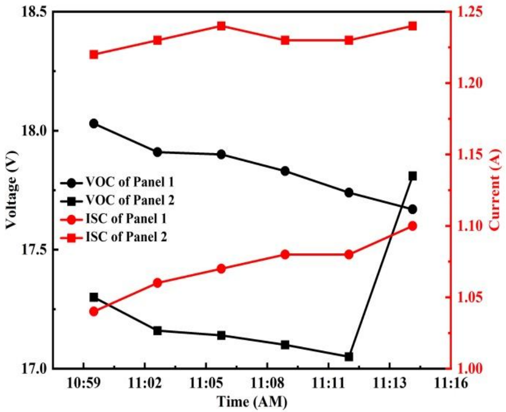

Energy flow diagram showing the relationship between solar input, storage, and system loads

# PV Generation: Bench & Outdoor Results

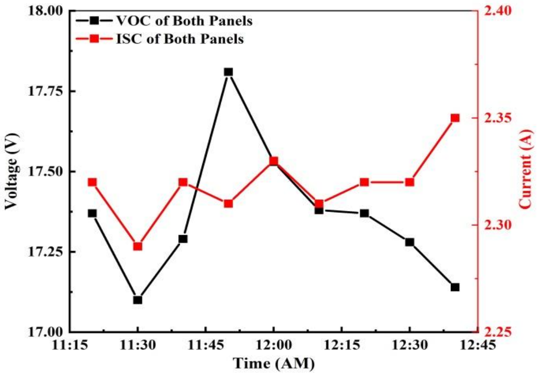
- **Panel-level tests (AM):** Voc ≈ 17–18V; Isc > 1 A per panel →
  ~19–21W each under test.

- **Parallel (mid-day): V ≈** 17.36V; Itotal ≈ 2.3A →
  ~40W net (~67% of nameplate 60W),
  consistent with non-optimal orientation, elevated temps, and motion.

- **Energy per day (5h useful sun):** ≈ 200Wh pre-conversion;
  PWM losses reduce deliverable energy further.
  MPPT expected to recover a material fraction.




Measured open circuit voltages and short circuit currents of panels.




Measured data of the panels connected in parallel connection.

# Energy Balance & Autonomy

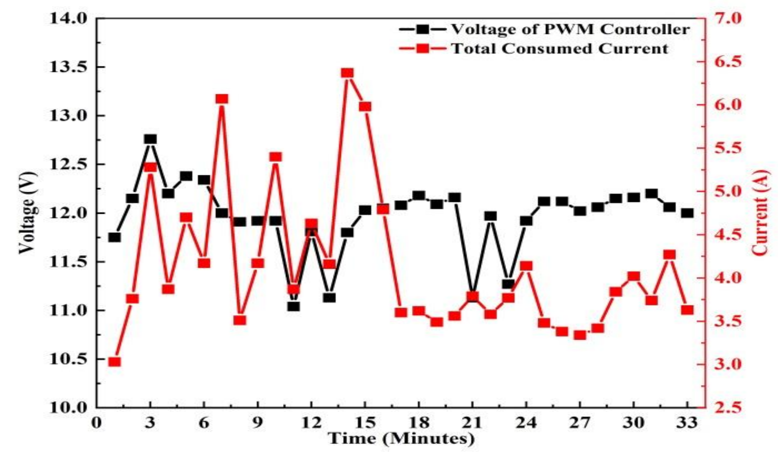
**Normal Cruise (~42W):** PV (~32W after PWM) + battery supplement → steady operation feasible under good sun

**High-demand Maneuvers (~76W):** Battery covers peaks; autonomy depends on duty cycle of turns/loads

**Daily Energy:** ~200Wh pre-conversion from PV; PWM losses reduce deliverable energy further

**Battery Capacity:** 216Wh (12V × 9Ah × 2) provides buffer for peak loads and intermittent sun

**Key Implication:** Energy-aware perception (dynamic FPS, event-triggered inference) and MPPT can extend mission time without upsizing the battery pack.

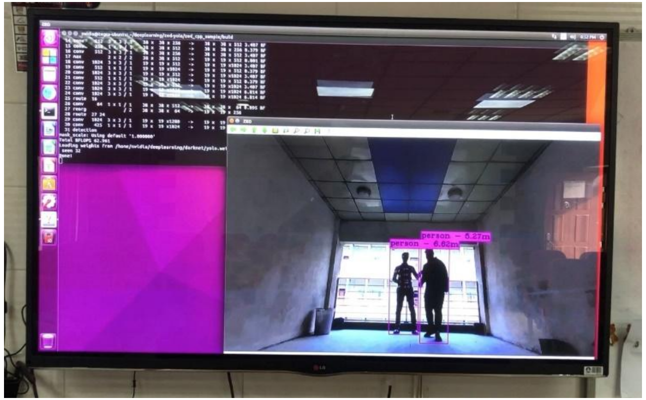



Mixed-Duty Field Run: PWM Controller Bus Voltage (V) and Total Consumed Current (A) vs Time (minutes)

# AI Performance (Measured)

- **Detector:** YOLOv5s (TensorRT) on Jetson TX2
- **Throughput:** ~47 FPS, per-frame latency < 50 ms
- **Accuracy:** mAP@0.5 ≈ 79.1% on common classes (persons, vehicles, boxes)
- **Behavior:** Automatic deceleration/evasion within ~3m range using stereo depth

**Key Finding:** The system achieves a favorable balance between detection accuracy and processing speed, enabling real-time operation on a power-constrained platform.



Real-Time On-Board Person Detection with Distance Estimation on Jetson TX2 (YOLOv5s + ZED Stereo, Ubuntu)


Real-Time Face Mesh with Facial Attribute/Expression Scores (Edge Inference ≈10 FPS)

# AI Performance (Measured)

- **PS-YOLO (YOLOv11-s variant):** ~86 FPS, est. ~84% mAP, UAV focus, higher model complexity.
- **YOLOv8 + ByteTrack:** 92.1% mAP, 18 FPS on embedded Linux robot for agriculture.
- **REFIT (key point-based):** 60 FPS on Jetson Orin; mAP not directly comparable.

Our novelty: Only system among these integrating fully solar-powered UGV with real-time detection on Jetson TX2.

**Key Finding:** The system achieves a favorable balance between detection accuracy and processing speed, enabling real-time operation on a power-constrained platform.

| Ref. | Model Used | mAP@ 0.5(%) | FPS | Platform | Application |
|---|---|---|---|---|---|
| This work | YOLOv5s (ONNX + TensorRT) | 79.1 | 47 | NVIDIA Jetson TX2 | Solar-powered mobile robot for object detection and surveillance |
| [23] | PS-YOLO (YOLOv11-s variant) | ~84.0 (estimated, +2% over YOLOv11-s baseline) | 86 | Embedded UAV platform | UAV-based object detection (small objects in aerial imagery) |
| [24] | YOLOv8 + ByteTrack | 92.1 | 18 | Embedded Linux robot (ROS) | Autonomous weed detection in agriculture |
| [3] | REFIT (keypoint-based model inspired by CenterNet) | N/A (keypoint-based approach) | 60 | Jetson Orin | UAV-based solar panel inspection |

Performance comparison with other embedded AI systems showing accuracy (mAP) and speed (FPS)

# Limitations & Risks

## Navigation Maturity

Current platform lacks full autonomous path planning/SLAM; requires human in the loop for mission definition.

## Energy Headroom

PWM losses + thermal derating limit surplus energy for heavy maneuvers or night operations.

## Ageing & Environment

PV and lead-acid capacity degrade; heat in Mosul summers challenges longevity.

These limitations inform our **roadmap priorities**, including MPPT controller integration, $LiFePO_4$ battery replacement, and development of visual SLAM capabilities to enhance autonomy.

# Roadmap & Conclusions

### Immediate Upgrades

**Energy Efficiency:** MPPT controller; $LiFePO_4$ pack with small supercap buffer; under/over-voltage protections

**Perception:** Power-aware perception with adaptive FPS and event-triggering for optimal energy use

### Autonomy Development

**Navigation:** Visual SLAM/RTK integration, robust obstacle avoidance, and mission planners

**Performance:** Quantify MPPT gains under diffuse light; conduct long-term degradation trials

## Questions?

### Key Conclusions

Low-cost embedded AI platforms **can deliver** real-time object detection performance suitable for security applications

Solar power integration **enables sustained operation** with appropriate energy management strategies

Energy-aware perception techniques offer a promising path to **optimize the performance-autonomy trade-off**

## Thank You For Your Attention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