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# Machine Learning Algorithms for Robotic Navigation and Perception and Embedded Implementation Techniques

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## Research context and motivation

According to ISO 8373, service robot is a robot that performs useful tasks for humans or equipment with a certain degree of autonomy. In order to solve complex tasks, such as in Precision Agriculture, robots requires the ability to sense the world and plan an action accordingly. Learning-based methods can be used to extract knowledge from data and experience to optimize robotics tasks for service applications.

## Addressed research questions/problems

- Apply Machine Learning algorithms to tackle navigation and perception for service robotic applications
- Solve navigation task in complex environments such as row-based crops for precision agriculture applications

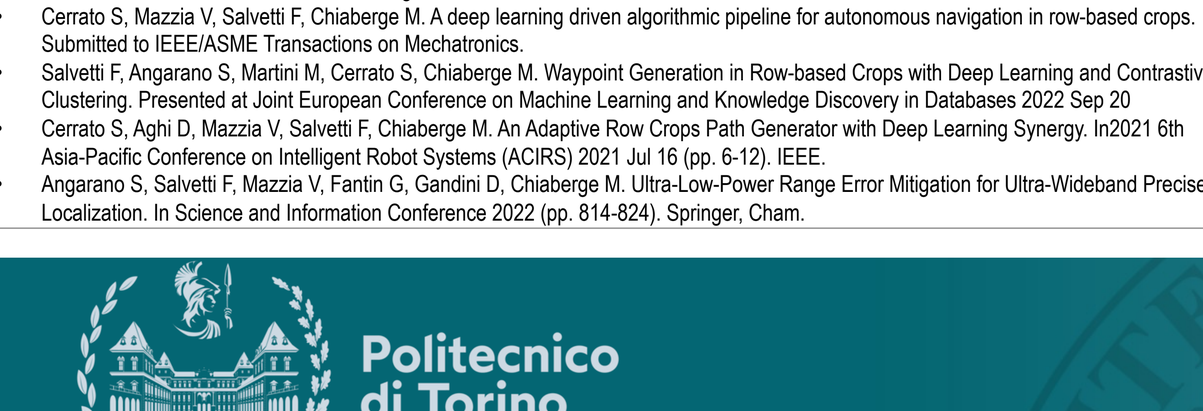

- Avoid data transmission and ensure on-board execution at the edge
- Real-time inference on low-power devices
- Network optimization and quantization to uint8 of fp32

## Novel contributions

PERCEPTION AT THE EDGE
- Real-time apple detection system at the edge
- Super Resolution at the edge for robotic image transmission
- Short-time pose-based Human Action Recognition with Transformer
- Real-time NLOS ranging error compensation for UWB localization at the edge

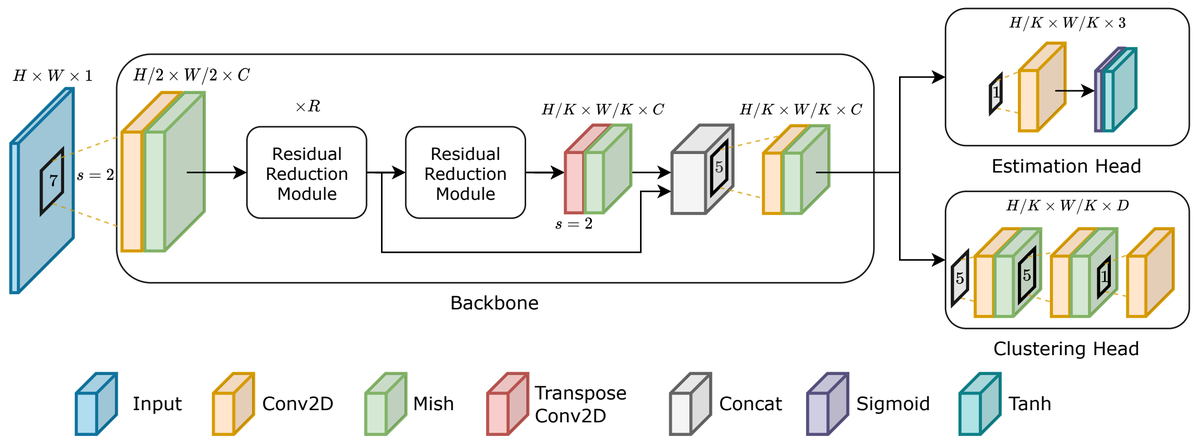
LEARNING THEORY
- CapsuleNet with self-attention routing for image classification
- Back-to-Bones: Rediscovering the role of backbones in Domain Generalization

NAVIGATION
- Multi-image Super Resolution of satellite images with Deep Residual Attention
- Position-agnostic autonomous navigation in vineyards with Deep Reinforcement Learning
- A pipeline for autonomous navigation in row-based crops




## Adopted methodologies

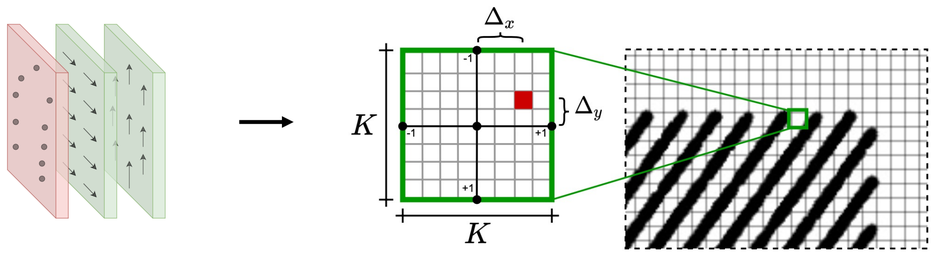
### Waypoint Generation in Row-based Crops with Deep Learning and Contrastive Clustering




The model as a convolutional neural network characterized by a feature extraction backbone, followed by two specialized heads, one responsible for the estimation task, the other for the clustering task.

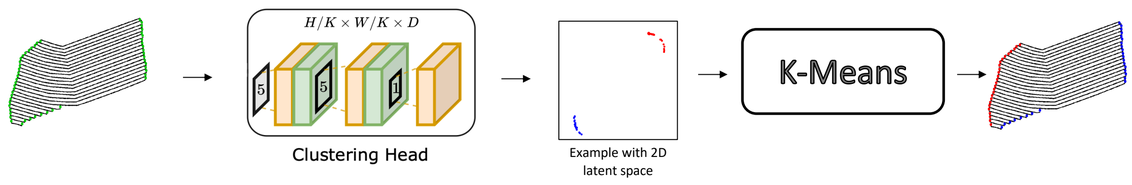
### Estimation

Modelled as a **regression** task. Prediction of **confidence** map and horizontal and vertical **compensation** maps over a sub-grid of the input image.




### Clustering

Modelled as a **representation learning** task. We project wps to a **separable** latent space.




Trained **contrastively** with **binary** cross-entropy and **sigmoid** of the embeddings **cosine similarity**.

$$l_i^{\text{clus}} = -\frac{1}{N-1}\sum_{\substack{j=1 \\ j\neq i}}^{N}\Bigg[\ \mathbb{1}_{\substack{\boldsymbol{p_i},\boldsymbol{p_j}\in A \\ \vee\, \boldsymbol{p_i},\boldsymbol{p_j}\in B}}\ \log\Big(\text{sig}\left(\text{sim}\left(f(\boldsymbol{p_i}),f(\boldsymbol{p_j})\right)\right)\Big) + \Big(1-\mathbb{1}_{\substack{\boldsymbol{p_i},\boldsymbol{p_j}\in A \\ \vee\, \boldsymbol{p_i},\boldsymbol{p_j}\in B}}\Big)\ \log\Big(1-\text{sig}\left(\text{sim}\left(f(\boldsymbol{p_i}),f(\boldsymbol{p_j})\right)\right)\Big)\Bigg]$$

$sim \rightarrow +1$ for wps in the **same** cluster
$sim \rightarrow -1$ for wps in **different** clusters

## Results

| Test | Method | Train | Adjusted Accuracy | Clustering Error |
|---|---|---|---|---|
| Curved Synth | K-means | Straight | 0.9714 ± 0.0336 | 1.0000 ± 1.0000 |
| | | Curved | 0.9885 ± 0.0199 | 0.3333 ± 0.5774 |
| | DBSCAN | Straight | 0.9563 ± 0.0757 | 1.3333 ± 2.3094 |
| | | Curved | 0.8898 ± 0.0337 | 3.0000 ± 1.0000 |
| | Ours | Straight | 0.9823 ± 0.0138 | 0.3414 ± 0.3278 |
| | | Curved | **0.9992 ± 0.0006** | **0.0127 ± 0.0038** |

| Test | Method | Train | Adjusted Accuracy | Clustering Error |
|---|---|---|---|---|
| Curved Real | K-means | Straight | 0.2443 ± 0.0984 | 73.3333 ± 29.2632 |
| | | Curved | 0.2721 ± 0.1493 | 70.0000 ± 19.5192 |
| | DBSCAN | Straight | 0.7247 ± 0.2734 | 27.0000 ± 25.5343 |
| | | Curved | 0.5181 ± 0.1061 | 45.3333 ± 6.6583 |
| | Ours | Straight | 0.8571 ± 0.0924 | 3.4667 ± 2.4437 |
| | | Curved | **0.9344 ± 0.0116** | **1.1933 ± 0.1858** |

## Submitted and published works


- Salvetti F, Mazzia V, Khaliq A, Chiaberge M. Multi-image super resolution of remotely sensed images using residual attention deep neural networks. Remote Sensing. 2020 Jan;12(14):2207.
- Mazzia V, Salvetti F, Aghi D, Chiaberge M. Deepway: a deep learning waypoint estimator for global path generation. Computers and Electronics in Agriculture. 2021 May 1;184:106091.
- Mazzia V, Salvetti F, Chiaberge M. Efficient-CapsNet: Capsule network with self-attention routing. Scientific reports. 2021 Jul 19;11(1):1-3.
- Mazzia V, Khaliq A, Salvetti F, Chiaberge M. Real-time apple detection system using embedded systems with hardware accelerators: An edge AI application. IEEE Access. 2020 Jan 7;8:9102-14
- Mazzia V, Angarano S, Salvetti F, Angelini F, Chiaberge M. Action Transformer: A self-attention model for short-time pose-based human action recognition. Pattern Recognition. 2022 Apr 1;124:108487.
- Angarano S, Mazzia V, Salvetti F, Fantin G, Chiaberge M. Robust ultra-wideband range error mitigation with deep learning at the edge. Engineering Applications of Artificial Intelligence. 2021 Jun ,1;102:104278.
- Angarano S, Salvetti F Martini M, Chiaberge M. Generative Adversarial Super-Resolution at the Edge with Knowledge Distillation. Sumbitted to Engineering Applications of Artificial Intelligence.
- Angarano S, Martini M, Salvetti F, Mazzia V, Chiaberge M. Back-to-Bones: Rediscovering the Role of Backbones in Domain Generalization. Submitted to Pattern Recognition.
- Cerrato S, Mazzia V, Salvetti F, Chiaberge M. A deep learning driven algorithmic pipeline for autonomous navigation in row-based crops. Submitted to IEEE/ASME Transactions on Mechatronics.
- Salvetti F, Angarano S, Martini M, Cerrato S, Chiaberge M. Waypoint Generation in Row-based Crops with Deep Learning and Contrastive Clustering. Presented at Joint European Conference on Machine Learning and Knowledge Discovery in Databases 2022 Sep 20
- Cerrato S, Aghi D, Mazzia V, Salvetti F, Chiaberge M. An Adaptive Row Crops Path Generator with Deep Learning Synergy. In2021 6th Asia-Pacific Conference on Intelligent Robot Systems (ACIRS) 2021 Jul 16 (pp. 6-12). IEEE.
- Angarano S, Salvetti F, Mazzia V, Fantin G, Gandini D, Chiaberge M. Ultra-Low-Power Range Error Mitigation for Ultra-Wideband Precise Localization. In Science and Information Conference 2022 (pp. 814-824). Springer, Cham.


## List of attended classes

- 01UMNRV – Advanced deep learning (15/06/2021, 6 CFU)
- 01UJBRV – Adversarial training of neural networks (01/07/2020, 3 CFU)
- 02LWHRV – Communication (05/05/2020, 1 CFU)
- 01QTEIU – Data mining concepts and algorithms (20/01/2020, 4 CFU)
- 01UJARV – Data science for networks (23/07/2020, 4 CFU)
- 01SHMRV – Entrepreneurial Finance (09/04/2020, 1 CFU)
- 01PJMRV – Etica Informatica (07/05/2021, 4 CFU)
- 01SCSIU – Machine learning for pattern recognition (28/09/2020, 4 CFU)
- 01UNYRV – Personal branding (17/11/2021, 1 CFU)
- 01UMEKG – Principles of deep learning (18/09/2020, 4 CFU)
- 08IXTRV – Project management (21/01/2020, 1 CFU)
- 01RISRV – Public speaking (12/02/2020, 1 CFU)
- 01SYBRV – Research integrity (13/01/2021, 1 CFU)
- 01SWQRV – Responsible research and innovation (20/09/2021, 1 CFU)
- 02QUBRS – Statistical data processing (04/02/2021, 4 CFU)
- 01SCTIU – Text mining and analytics (30/09/2021, 3 CFU)
- 02RHORV – The new Internet Society (28/09/2021, 1 CFU)
- 01UNXRV – Thinking out of the box (17/01/2022, 1 CFU)
- 01SWPRV – Time management (17/04/2020, 1 CFU)
- External Training activity - All You Need To Know About Research Data Management and Open Access Publishing (01/07/2020, 3 CFU)

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