UNIVERSITY OF ALICANTE

PHD THESIS

TBD

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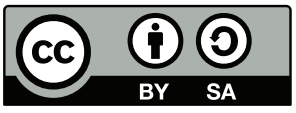

"Will robots inherit the earth? Yes, but they will be our children."

Marvin Minsky

Abstract

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Resumen

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Acknowledgements

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List of Acronyms

CNN Convolutional Neural Network

Chapter 1

Introduction

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1.1 Motivation

1.2 Approach

1.3 Contributions

1.4 Co-Authored Papers

This thesis is the result of continuous effort throughout the last years. Such efforts have sometimes crystallized in form of co-authored publications and conference talks.

1.4.1 Chapter 2

- Alberto Garcia-Garcia, Francisco Gomez-Donoso, Jose Garcia-Rodriguez, et al. "PointNet: A 3D Convolutional Neural Network for real-time object class recognition". In: *2016 International Joint Conference on Neural Networks, IJCNN 2016, Vancouver, BC, Canada, July 24-29, 2016*. 2016, pp. 1578–1584. DOI: 10.1109/IJCNN.2016.7727386. URL: https://doi.org/10.1109/IJCNN.2016.7727386

- Alberto Garcia-Garcia, Jose Garcia-Rodriguez, Sergio Orts-Escolano, et al. "A study of the effect of noise and occlusion on the accuracy of convolutional neural networks applied to 3D object recognition". In: *Computer Vision and Image Understanding* 164 (2017), pp. 124–134. DOI: 10.1016/j.cviu.2017.06.006. URL: https://doi.org/10.1016/j.cviu.2017.06.006

- Francisco Gomez-Donoso, Alberto Garcia-Garcia, Jose Garcia-Rodriguez, et al. "LonchaNet: A Sliced-based CNN Architecture for Real-time 3D Object Recognition". In: *2017 International Joint Conference on Neural Networks, IJCNN 2017, Anchorage, Alaska, May 14-19, 2017*. 2017. URL: https://ieeexplore.ieee.org/document/7965883/

1.4.2 Chapter 3

- Alberto Garcia-Garcia, Jose Garcia-Rodriguez, Sergio Orts-Escolano, et al. "A study of the effect of noise and occlusion on the accuracy of convolutional neural networks applied to 3D object recognition". In: *Computer Vision and Image Understanding* 164 (2017), pp. 124–134. DOI: 10.1016/j.cviu.2017.06.006. URL: https://doi.org/10.1016/j.cviu.2017.06.006

- Alberto Garcia-Garcia, Pablo Martinez-Gonzalez, Sergiu Oprea, et al. "The RobotriX: An eXtremely Photorealistic and Very-Large-Scale Indoor Dataset of Sequences with Robot Trajectories and Interactions". In: *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE. 2018, pp. 6790–6797. URL: https://ieeexplore.ieee.org/abstract/document/8594495

- TODO: UnrealROX

1.4.3 Chapter 4

- TODO: TactileGCN

1.4.4 Other

During the years spent working on the main topics of this thesis, several collaborations and side works were carried out that also were published either as journal papers, conference proceedings, or preprints:

- Sergiu Oprea, Alberto Garcia-Garcia, Jose Garcia-Rodriguez, et al. "A Recurrent Neural Network based Schaeffer Gesture Recognition System". In: *2017 International Joint Conference on Neural Networks, IJCNN 2017, Anchorage, Alaska, May 14-19, 2017*. 2017. URL: https://ieeexplore.ieee.org/document/7965885/

- Francisco Gomez-Donoso, Sergio Orts-Escolano, Alberto Garcia-Garcia, et al. "A robotic platform for customized and interactive rehabilitation of persons with disabilities". In: *Pattern Recognition Letters* 99 (2017), pp. 105–113. DOI: 10.1016/j.patrec.2017.05.027. URL: https://doi.org/10.1016/j.patrec.2017.05.027

- Sergiu Oprea, Alberto GarciaGarcia, Sergio OrtsEscolano, et al. "A long short-term memory based Schaeffer gesture recognition system". In: *Expert Systems* 0.0 (2017), e12247. DOI: 10.1111/exsy.12247. URL: https://onlinelibrary.wiley.com/doi/abs/10.1111/exsy.12247

- Alberto Garcia Garcia, Andreas Beckmann, and Ivo Kabadshow. "Accelerating an FMM-Based Coulomb Solver with GPUs". In: *Software for Exascale Computing-SPPEXA 2013-2015*. Springer, 2016, pp. 485–504. URL: https://link.springer.com/chapter/10.1007/978-3-319-40528-5_22

- Alberto Garcia-Garcia, Sergio Orts-Escolano, Sergiu Oprea, et al. "Multi-sensor 3D object dataset for object recognition with full pose estimation". In: *Neural Computing and Applications* 28 (2016), pp. 941–952. ISSN: 1433-3058. DOI: 10.1007/s00521-016-2224-9. URL: http://dx.doi.org/10.1007/s00521-016-2224-9

- Marcelo Saval-Calvo, Jorge Azorin-Lopez, Andres Fuster-Guillo, et al. "Evaluation of sampling method effects in 3D non-rigid registration". In: *Neural Computing and Applications* 28 (2016), pp. 953–967. ISSN: 1433-3058. DOI: 10.1007/s00521-016-2258-z. URL: http://dx.doi.org/10.1007/s00521-016-2258-z

- Sergio Orts-Escolano, Jose Garcia-Rodriguez, Miguel Cazorla, et al. "Bioinspired point cloud representation: 3D object tracking". In: *Neural Computing and Applications* 29 (2016), pp. 663–672. ISSN: 1433-3058. DOI: 10.1007/s00521-016-2585-0. URL: https://doi.org/10.1007/s00521-016-2585-0

- Alberto Garcia-Garcia, Sergio Orts-Escolano, Jose Garcia-Rodriguez, et al. "Interactive 3D object recognition pipeline on mobile GPGPU computing platforms using low-cost RGB-D sensors". In: *Journal of Real-Time Image Processing* 14 (2016), pp. 585–604. ISSN: 1861-8219. DOI: 10.1007/s11554-016-0607-x. URL: https://doi.org/10.1007/s11554-016-0607-x

- Higinio Mora, Jerónimo M Mora-Pascual, Alberto Garcia-Garcia, et al. "Computational analysis of distance operators for the iterative closest point algorithm". In: *PloS one* 11.10 (2016), e0164694. URL: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0164694

- Sergio Orts-Escolano, Jose Garcia-Rodriguez, Vicente Morell, et al. "3D Surface Reconstruction of Noisy Point Clouds Using Growing Neural Gas: 3D Object/Scene Reconstruction". In: *Neural Processing Letters* 43 (2015), pp. 401–423. DOI: 10.1007/s11063-015-9421-x. URL: http://dx.doi.org/10.1007/s11063-015-9421-x

- Sergio Orts-Escolano, Jose Garcia-Rodriguez, Jose Antonio Serra-Perez, et al. "3D model reconstruction using neural gas accelerated on GPU". in: *Applied Soft Computing* 32 (2014), pp. 87–100. DOI: 10.1016/j.asoc.2015.03.042. URL: http://dx.doi.org/10.1016/j.asoc.2015.03.042

- TODO: ICP

1.5 Thesis Structure

Chapter 2

Object Recognition

Abstract

In this chapter, we address the problem of object class recognition. To approach this challenge, we rely on the geometric information provided by 3D object representations such as point clouds. Furthermore, we focus on learning-based methods to distinguish objects from different classes while capturing the variability of shape of different objects which belong to the same class. More specifically, we leverage deep learning for such task. The chapter begins introducing and formulating the object recognition task in Section 2.1 followed by a review of the most relevant literature in Section 2.2. After that, we present our first proposal towards 3D object recognition using Convolutional Neural Networks (CNNs), namely PointNet, in Section 2.3. Later, PointNet is improved and thoroughly tested in adverse conditions with noise and occlusion throughout the study in Section 2.4. Next, LonchaNet is introduced in Section 2.5 as the last iteration of our system that incorporates all the lessons learned by the previous work. Finally, Section 2.6 draws conclusions and sets future lines of research.

2.1 Introduction

Object recognition is fundamental to computer vision and remains a challenging area of research.

Recognizing objects is one of the problems that must be solved to achieve total visual scene understanding. Such deeper and better knowledge of the environment eases and enables the execution of a wide variety of more complex tasks. For instance, accurately recognizing objects in a room can be extremely useful for any robotic system that navigates within indoor environments. Due to the unstructured nature of those environments, autonomous robots need to do reasoning grounded in the dynamic real world. In other words, they need to understand the information captured by their sensors to perform tasks such as grasping, navigation, mapping, or even providing humans with information about their surroundings. Identifying the classes to which objects belong is one key step to enhance the aforementioned capabilities.

Although we humans recognize numerous objects in difficult settings (e.g., different points of view, sizes, scales, translations, rotations, occlusion, lighting...) with little to no effort, approaching that problem is not that easy for a computer.

For those reasons, object recognition lies at the intersection of computer vision, robotics, and machine learning. That fact makes it one of the most active and important fields at the moment.

2.2 Related Works

2.2.1 2D Object Recognition

2.2.2 RGB-D Object Recognition

2.2.3 3D Object Recognition

2.3 PointNet

2.3.1 Data Representation

The system takes a point cloud of an object as input to recognize it, i.e., predict its class label. However, point clouds are unstructured representations that cannot be easily handled by common CNN architectures due to the lack of a matrix-like organization.

2.3.2 Network Architecture

2.3.3 Experiments

2.3.4 Discussion

2.4 Noise and Occlusion

2.5 LonchaNet

2.6 Conclusion

Chapter 3

Semantic Segmentation

Chapter 4

Tactile Sensing

Chapter 5

Conclusion

5.1 Findings and Conclusions

5.2 Limitations

5.3 Future Work

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