Trabajo Fin de Máster Máster en Ingeniería Electrónica, Robótica y Automática

Aerial co-workers: a task planning approach for multi-drone teams supporting inspection operations

Autor: Álvaro Calvo Matos

Tutor: Jesús Capitán Fernandez

Dpto. Ingeniería de Sistemas y Automática Escuela Técnica Superior de Ingeniería Universidad de Sevilla

Sevilla, 2021







Trabajo Fin de Máster Máster en Ingeniería Electrónica, Robótica y Automática

Aerial co-workers: a task planning approach for multi-drone teams supporting inspection operations

Autor:

Álvaro Calvo Matos

Tutor:

Jesús Capitán Fernandez

Associate Professor

Dpto. Ingeniería de Sistemas y Automática Escuela Técnica Superior de Ingeniería Universidad de Sevilla

Sevilla, 2021

| Trabajo Fin de Máster: | | Aerial co-workers: a task planning approach for multi-drone teams supporting inspection operations | | |
|------------------------|-----------------|--|--|--|
| Autor: Tutor: | | alvo Matos itán Fernandez | | |
| El tribunal nom | ıbrado para ju | zgar el trabajo arriba indicado, compuesto por los siguientes profesores: | | |
| | Presidente: | | | |
| | Vocal/es: | | | |
| | | | | |
| | Secretario: | | | |
| acuerdan oto | organia la cali | ficación de: | | |
| acucidan otc | ngane ia can | neación de. | | |
| | | | | |
| | | El Secretario del Tribunal | | |
| | | Fecha: | | |

Agradecimientos

Lorem itsum

Álvaro Calvo Matos Máster en Ingeniería Electrónica, Robótica y Automática

Sevilla, 2021

Abstract

Lorem itsum

Short Outline

| ΑŁ | straci | t | III | | |
|-----|--------------|--------------------------------------|-----|--|--|
| Sł | ort O | Outline | V | | |
| 1 | Introduction | | | | |
| | 1.1 | Motivation | 1 | | |
| | 1.2 | Objectives | 1 | | |
| 2 | Prel | 3 | | | |
| | 2.1 | Current technology | 3 | | |
| | 2.2 | Related work | 3 | | |
| | 2.3 | Previous study | 3 | | |
| 3 | Prob | blem Formulation | 5 | | |
| | 3.1 | Description of tasks | 5 | | |
| | 3.2 | Battery recharges | 5 | | |
| | 3.3 | Connection losses | 5 | | |
| | 3.4 | Task replanning situations | 5 | | |
| 4 | Des | ign of the proposed solution | 7 | | |
| | 4.1 | Node diagram | 7 | | |
| | 4.2 | Centralized module: task planner | 7 | | |
| | 4.3 | Distributed module: behavior manager | 7 | | |
| | 4.4 | Lower and upper level modules faker | 7 | | |
| 5 | Results | | | | |
| | 5.1 | Task planning | 9 | | |
| | 5.2 | Drone behaviour manager results | 9 | | |
| | 5.3 | Simulations | 9 | | |
| 6 | Con | clusions and future work | 11 | | |
| | 6.1 | Conclusions | 11 | | |
| | 6.2 | Future work | 11 | | |
| Lis | st of F | igures | 13 | | |
| Lis | st of T | ābles | 15 | | |

| VI | Short Outline |
|----|---------------|
| | |

| List of Codes | 17 |
|---------------|----|
| Bibliography | 19 |
| Index | 23 |
| Glossary | 23 |
| | |

Contents

| | stract | | | III |
|----|---------------|---------------------|------------------------------------|-----|
| Sh | ort O | utline | | V |
| 1 | Intro | 1 | | |
| | 1.1 | Motiva | ation | 1 |
| | 1.2 | Objec | ctives | 1 |
| 2 | Preliminaries | | | 3 |
| | 2.1 | Curre | ent technology | 3 |
| | | 2.1.1 | UAVs | 3 |
| | | 2.1.2 | Aerial co-workers | 3 |
| | | 2.1.3 | Multi-drone teams | 3 |
| | 2.2 | Relate | ed work | 3 |
| | | 2.2.1 | Inspection applications with UAVs | 3 |
| | | 2.2.2 | Task planning in multi-drone teams | 3 |
| | | 2.2.3 | Drone behavior management | 3 |
| | 2.3 | Previo | ous study | 3 |
| | | 2.3.1 | ROS | 3 |
| | | 2.3.2 | Gazebo | 3 |
| | | 2.3.3 | Behaviour Trees | 3 |
| | | 2.3.4 | Groot | 3 |
| | | 2.3.5 | Rviz | 3 |
| 3 | Prob | olem Fo | ormulation | 5 |
| | 3.1 | Descr | 5 | |
| | | 3.1.1 | Inspection tasks | 5 |
| | | 3.1.2 | Monitoring tasks | 5 |
| | | 3.1.3 | Tool delivery tasks | 5 |
| | 3.2 | 2 Battery recharges | | 5 |
| | 3.3 | Conne | ection losses | 5 |
| | 3.4 | Task r | replanning situations | 5 |
| 4 | Desi | gn of t | the proposed solution | 7 |
| | 4.1 | - | diagram | 7 |
| | 4.2 | | ralized module: task planner | 7 |
| | 4.3 | | buted module: behavior manager | 7 |

VIII Contents

| | | 4.3.1 | Main tree | 7 |
|-----|----------|---------|-------------------------------|----|
| | | 4.3.2 | Inspection task tree | 7 |
| | | 4.3.3 | Monitoring task tree | 7 |
| | | 4.3.4 | Tool delivery task tree | 7 |
| | 4.4 | Lower | and upper level modules faker | 7 |
| 5 | Res | ults | | 9 |
| | 5.1 | Task p | olanning | 9 |
| | | 5.1.1 | Battery | 9 |
| | | 5.1.2 | Connection lost | 9 |
| | | 5.1.3 | Replanning | 9 |
| | 5.2 | Drone | behaviour manager results | 9 |
| | | 5.2.1 | Battery management | 9 |
| | | 5.2.2 | Connection lost management | 9 |
| | | 5.2.3 | Replanning management | 9 |
| | 5.3 | Simula | ations | 9 |
| | | 5.3.1 | One drone simulations | 9 |
| | | 5.3.2 | Multi-drone simulations | 9 |
| 6 | Con | clusion | ns and future work | 11 |
| | 6.1 | Conclu | usions | 11 |
| | 6.2 | Future | e work | 11 |
| | | 6.2.1 | Augmented reality | 11 |
| Lis | st of F | igures | | 13 |
| | st of Ta | - | | 15 |
| Lis | st of C | odes | | 17 |
| Bi | bliogra | aphy | | 19 |
| | dex | - | | 23 |
| Gl | lossar | V | | 23 |

1 Introduction

Lorem itsum

- 1.1 Motivation
- 1.2 Objectives

2 Preliminaries

T orem itsum

2.1 Current technology

- 2.1.1 UAVs
- 2.1.2 Aerial co-workers
- 2.1.3 Multi-drone teams

2.2 Related work

- 2.2.1 Inspection applications with UAVs
- 2.2.2 Task planning in multi-drone teams
- 2.2.3 Drone behavior management

2.3 Previous study

- 2.3.1 ROS
- 2.3.2 Gazebo
- 2.3.3 Behaviour Trees
- 2.3.4 Groot
- 2.3.5 Rviz

3 Problem Formulation

T orem itsum

- 3.1 Description of tasks
- 3.1.1 Inspection tasks
- 3.1.2 Monitoring tasks
- 3.1.3 Tool delivery tasks
- 3.2 Battery recharges
- 3.3 Connection losses
- 3.4 Task replanning situations

4 Design of the proposed solution

T orem itsum

- 4.1 Node diagram
- 4.2 Centralized module: task planner
- 4.3 Distributed module: behavior manager
- 4.3.1 Main tree
- 4.3.2 Inspection task tree
- 4.3.3 Monitoring task tree
- 4.3.4 Tool delivery task tree
- 4.4 Lower and upper level modules faker

5 Results

| T orem itsum |
|--------------|
|--------------|

5.1 Task planning

- 5.1.1 Battery
- 5.1.2 Connection lost
- 5.1.3 Replanning

5.2 Drone behaviour manager results

- 5.2.1 Battery management
- 5.2.2 Connection lost management
- 5.2.3 Replanning management

5.3 Simulations

- 5.3.1 One drone simulations
- 5.3.2 Multi-drone simulations

6 Conclusions and future work

- 6.1 Conclusions
- 6.2 Future work
- 6.2.1 Augmented reality

List of Figures

List of Tables

List of Codes

Bibliography

- [1] M. Santarini, "Cosmic radiation comes to asic and soc design," May 2005. [Online]. Available: https://www.edn.com/cosmic-radiation-comes-to-asic-and-soc-design/
- [2] H. G. Miranda, "Aportaciones a las técnicas de emulación y protección de sistemas microelectrónicos complejos bajo efectos de la radiación," Ph.D. dissertation, Universidad de Sevilla, May 2010.
- [3] J. M. Mogollón, J. Nápoles, H. Guzmán-Miranda, and M. A. Aguirre, "Real time seu detection and diagnosis for safety or mission-critical ics using hash library-based fault dictionaries," in 2011 12th European Conference on Radiation and Its Effects on Components and Systems, 2011, pp. 705–710.
- [4] M. G. Valderas, M. P. García, C. López, and L. Entrena, "Extensive seu impact analysis of a pic microprocessor for selective hardening," in 2009 European Conference on Radiation and Its Effects on Components and Systems, 2009, pp. 333–336.
- [5] C. Carmichael, "Triple module redundancy design techniques for virtex fpgas," *Xilinx Application Note XAPP197*, vol. 1, 2001.
- [6] Zhou Jing, Liu Zengrong, Chen Lei, Wang Shuo, Wen Zhiping, Chen Xun, and Qi Chang, "An accurate fault location method based on configuration bitstream analysis," in *NORCHIP* 2012, 2012, pp. 1–5.
- [7] W. Tao and W. Xingsong, "Fault diagnosis of a scara robot," in 2008 15th International Conference on Mechatronics and Machine Vision in Practice, 2008, pp. 352–356.
- [8] S. Jian, J. Jiang, K. Lu, and Y. Zhang, "Seu-tolerant restricted boltzmann machine learning on dsp-based fault detection," in 2014 12th International Conference on Signal Processing (ICSP), 2014, pp. 1503–1506.
- [9] R. Pettit and A. Pettit, "Detecting single event upsets in embedded software," in 2018 IEEE 21st International Symposium on Real-Time Distributed Computing (ISORC), 2018, pp. 142–145.
- [10] N. Naber, T. Getz, Y. Kim, and J. Petrosky, "Real-time fault detection and diagnostics using fpga-based architectures," in 2010 International Conference on Field Programmable Logic and Applications, 2010, pp. 346–351.
- [11] Su Wei, Fan Tongshun, and Du Mingfang, "Research for digital circuit fault testing and diagnosis techniques," in 2009 International Conference on Test and Measurement, vol. 1, 2009, pp. 330–333.

- [12] S. Wei, Z. Shide, and X. Lijun, "Research on digital circuit fault location procedure based on lasar," in 2008 ISECS International Colloquium on Computing, Communication, Control, and Management, vol. 2, 2008, pp. 322–326.
- [13] B. K. Sikdar, N. Ganguly, and P. P. Chaudhuri, "Fault diagnosis of vlsi circuits with cellular automata based pattern classifier," *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, vol. 24, no. 7, pp. 1115–1131, 2005.
- [14] S. S. Yau and Yu-Shan Tang, "An efficient algorithm for generating complete test sets for combinational logic circuits," *IEEE Transactions on Computers*, vol. C-20, no. 11, pp. 1245– 1251, 1971.
- [15] S. S. Yau and M. Orsic, "Fault diagnosis and repair of cutpoint cellular arrays," *IEEE Transactions on Computers*, vol. C-19, no. 3, pp. 259–262, 1970.
- [16] V. Amar and N. Condulmari, "Diagnosis of large combinational networks," *IEEE Transactions on Electronic Computers*, vol. EC-16, no. 5, pp. 675–680, 1967.
- [17] D. R. Schertz and G. Metze, "A new representation for faults in combinational digital circuits," *IEEE Transactions on Computers*, vol. C-21, no. 8, pp. 858–866, 1972.
- [18] J. P. Roth, W. G. Bouricius, and P. R. Schneider, "Programmed algorithms to compute tests to detect and distinguish between failures in logic circuits," *IEEE Transactions on Electronic Computers*, vol. EC-16, no. 5, pp. 567–580, 1967.
- [19] A. D. Friedman, "Fault detection in redundant circuits," *IEEE Transactions on Electronic Computers*, vol. EC-16, no. 1, pp. 99–100, 1967.
- [20] R. Zhang, L. Xiao, J. Li, X. Cao, C. Qi, and M. Wang, "A fast fault injection platform of multiple seus for sram-based fpgas," in 2017 Prognostics and System Health Management Conference (PHM-Harbin), 2017, pp. 1–5.
- [21] A. da Silva and S. Sanchez, "Leon3 vip: A virtual platform with fault injection capabilities," in 2010 13th Euromicro Conference on Digital System Design: Architectures, Methods and Tools, 2010, pp. 813–816.
- [22] J. M. Mogollon, H. Guzmán-Miranda, J. Nápoles, J. Barrientos, and M. A. Aguirre, "Ftunshades2: A novel platform for early evaluation of robustness against see," in 2011 12th European Conference on Radiation and Its Effects on Components and Systems, 2011, pp. 169–174.
- [23] Wikipedia, "Distancia de levenshtein wikipedia, la enciclopedia libre," 2020, [Internet; descargado 15-junio-2020]. [Online]. Available: https://es.wikipedia.org/w/index.php?title=Distancia_de_Levenshtein&oldid=125248609
- [24] M. Muñoz-Quijada, S. Sanchez-Barea, D. Vela-Calderon, and H. Guzman-Miranda, "Fine-grain circuit hardening through vhdl datatype substitution," *Electronics*, vol. 8, no. 1, p. 24, 2019.
- [25] "Vhdl implementation of fft algorithm(s)," Available online: https://github.com/thasti/fft, accessed on 17 June 2020.
- [26] "Vhdl standard fifo," Available online: http://www.deathbylogic.com/2013/07/vhdl-standard-fifo/, accessed on 17 June 2020.

- [27] "Fpga4student. a low pass fir filter for ecg denoising in vhdl," Available online: https://www.fpga4student.com/2017/01/a-low-pass-fir-filter-in-vhdl.html, accessed on 17 June 2020.
- [28] "I²s interface designed for the pcm3168 audio interface from texas instruments," Available online: https://github.com/wklimann/PCM3168, accessed on 17 June 2020.
- [29] "Simple uart controller for fpga written in vhdl," Available online: https://github.com/jakubcabal/uart-for-fpga, acceded on 17 June 2020.
- [30] Wikipedia, "Momentos de imagen wikipedia, la enciclopedia libre," 2020, [Internet; descargado 18-junio-2020]. [Online]. Available: https://es.wikipedia.org/w/index.php?title=Momentos_de_imagen&oldid=124767713
- [31] C. Wolf, J. Glaser, and J. Kepler, "Yosys-a free verilog synthesis suite," in *Proceedings of the 21st Austrian Workshop on Microelectronics (Austrochip)*, 2013.

Index 23