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

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El tribunal nombrado para juzgar el trabajo arriba indicado, compuesto por los siguientes profesores:

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Abstract

This Master's Thesis has addressed problems arising from the recent increase in the applications of cooperative teams, which are the autonomy to operate over a long period of time with robustness to possible failures, and the difficulty of providing the team with cognitive capabilities to be able to operate in dynamic environments with humans.

Many of these applications are currently being executed by humans, making the activities much more expensive, time-consuming, and in some cases even dangerous. This is why there is currently a great deal of interest and effort being put into developing solutions to the problems posed.

The aim of the work was to develop cognitive planning techniques for coordinating fleets of quadrotors to assist human operators in inspection and maintenance tasks on high-voltage power lines. These techniques should also extend the autonomy of the system, ensure that safety requirements between drones and human workers are met, and ensure the success of the mission.

A software architecture has been proposed based on a central planner and a distributed behaviour manager. To carry out the planning, a cost has been defined, which is calculated for each task. Thus, each one is assigned to the Unmanned Aerial Vehicle (UAV) that costs the least to execute. On the other hand, to control the behaviour of the drones and ensure the safety of the aerial equipment, a behaviour tree has been implemented.

As a result, it has been possible to develop a software architecture capable of dynamically planning missions while ensuring the safety of the equipment involved. This provides a good base that can be easily adapted and from which more complex planners can be developed in the future. Compared to the typical way of implementing behaviour managers, involving complex finite state machines that are difficult to read, reuse and extend, the use of behaviour trees is a great improvement and will allow the creation of increasingly complex behaviours.

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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] "I^2s 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.

Glossary

UAV Unmanned Aerial Vehicle. III