Towards Large-Scale Scalable MAV Swarms with ROS2 and UWB-based Situated Communication

Jorge Peña Queralta, Yu Xianjia, Li Qingqing, Tomi Westerlund

Turku Intelligent Embedded and Robotic Systems (TIERS) Lab
University of Turku, Finland
Emails: {jopequ, xianjia.yu, qingqli, tovewe}@utu.fi

Abstract

The design and development of swarms of micro-aerial vehicles (MAVs) has recently gained significant traction [1, 2, 3]. Collaborative aerial swarms have potential applications in areas as diverse as surveillance and monitoring [4, 5], inventory management [6, 7], search and rescue [8], or in the entertainment industry [9, 10].

Swarm intelligence has, by definition, a distributed nature. Yet performing experiments in truly distributed systems is not always possible, as much of the underlying ecosystem employed requires some sort of central control. Indeed, in experimental proofs of concept, most research relies on more traditional connec-

Figure 1: Scalable swarm concept with mesh connectivity and UWB-based relative localization and communication (orientative links). The UWB range can be affected, e.g., by NLOS propagation while Wi-Fi is more prone to interference.
tivity solutions (e.g., Wi-Fi) [11], and robotics middlewares [12, 13]. In terms of positioning, external localization solutions, such as motion capture (MOCAP) systems, visual markers, or ultra-wideband (UWB) anchors [14, 15, 16] are often used. Alternatively, intra-swarm solutions are often limited in terms of, e.g., range or field-of-view [17, 18, 19].

Essential to efficient collaboration within aerial swarms are reliable communication and accurate localization. Multiple works rely on situated communication as the basis for effective collaboration [20, 21, 22, 23]. Research and development has been supported by platforms such as the e-puck [24, 25], the kilobot [26], or the crazyflie quadrotors [27]. In terms of reproducibility, it is also worth mentioning the MRS Multi-UAV platform [28]. However, we believe there is a need for inexpensive platforms such as the Crazyflie with more advanced onboard processing capabilities and sensors, while offering scalability and robust communication and localization solutions. In the following, we present a platform for research and development in aerial swarms currently under development, where we leverage Wi-Fi mesh connectivity and the distributed ROS2 middleware together with UWB ranging and communication for situated communication.

Mesh Networking, ROS2 and UWB Localization

We present a platform for building towards large-scale swarms of autonomous MAVs leveraging the ROS2 middleware, Wi-Fi mesh connectivity, and UWB ranging and communication. The platform is based on the Ryze Tello Drone, a Raspberry Pi Zero W as a companion computer together with a camera module, and a Decawave DWM1001 UWB module for ranging and basic communication. A conceptual illustration is shown in Figure 1. Additionally, a TFMini micro-lidar module can be added to increase the range and accuracy of altitude estimation. When the swarm is deployed, the following provides the underlying methods and systems allowing for complex collaborative behavior:

(i) A Wi-Fi mesh network with predefined settings is deployed using batman-adv [29], and defining network interfaces for the auto-discovery services in DDS under ROS2 to automatically detect new nodes. A gateway in the mesh network may provide internet access to the swarm.

(ii) One-to-one UWB ranging, or alternatively more scalable ranging systems such as SnapLoc [30], are utilized based on the node IDs identified within the Wi-Fi mesh. Relative localization is then propagated through the swarm with the possibility for global localization if the position of the gateway or a subset of nodes is known. We assume a common orientation reference, but alternatively a decentralized approach with sliding time window optimization can be applied [2].

(iii) Concurrent localization and communication are implemented by embedding data, published to a predefined ROS2 topic, within the UWB ranging messages. We limit this to basic signaling to ensure scalability.
(iv) Larger bandwidth is available through the Wi-Fi mesh network while throttling when necessary different ROS2 topics to control network load.

In conclusion, we have presented an inexpensive MAV platform based on off-the-shelf components opening the door to wider adoption and reproducibility, and more complex proofs of concept in aerial swarms. At the same time, such a multi-MAV system maintains a distributed and scalable nature. Potential applications range from formation control or drone shows to distributed perception and multi-agent search or monitoring.

References

[1] Martin Saska. Mav-swarms: unmanned aerial vehicles stabilized along a given path using onboard relative localization. In 2015 International Conference on Unmanned Aircraft Systems (ICUAS), pages 894–903. IEEE, 2015.

[2] Hao Xu, Luqi Wang, Yichen Zhang, Kejie Qiu, and Shaojie Shen. Decentralized visual-inertial-uwb fusion for relative state estimation of aerial swarm. In 2020 IEEE International Conference on Robotics and Automation (ICRA), pages 8776–8782. IEEE, 2020.

[3] Jorge Peña Queralta, Li Qingqing, Fabrizio Schiano, and Tomi Westerlund. Vio-uwb-based collaborative localization and dense scene reconstruction within heterogeneous multi-robot systems. arXiv preprint arXiv:2011.00830, 2020.

[4] Jürgen Scherer and Bernhard Rinner. Persistent multi-uav surveillance with energy and communication constraints. In 2016 IEEE International Conference on Automation Science and Engineering (CASE), pages 1225–1230. IEEE, 2016.

[5] Jingjing Gu, Tao Su, QiuHong Wang, Xiaojing Du, and Mohsen Guizani. Multiple moving targets surveillance based on a cooperative network for multi-uav. IEEE Communications Magazine, 56(4):82–89, 2018.

[6] Nicola Macoir, Jan Bauwens, Bart Jooris, Ben Van Herbruggen, Jen Rossey, Jeroen Hoebeke, and Eli De Foorter. Uwb localization with battery-powered wireless backbone for drone-based inventory management. Sensors, 19(3):467, 2019.

[7] Woong Kwon, Jun Ho Park, Minsu Lee, Jongbeom Her, Sang-Hyeon Kim, and Ja-Won Seo. Robust autonomous navigation of unmanned aerial vehicles (uavs) for warehouses’ inventory application. IEEE Robotics and Automation Letters, 5(1):243–249, 2019.
[8] Jorge Peña Queralta, Jussi Taipalmaa, Bilge Can Pullinen, Victor Kathan Sarker, Tuan Nguyen Gia, Hannu Tenhunen, Moncef Gabbouj, Jenni Raitoharju, and Tomi Westerlund. Collaborative multi-robot search and rescue: Planning, coordination, perception, and active vision. *IEEE Access*, 8:191617–191643, 2020.

[9] Markus Waibel, Bill Keays, and Federico Augugliaro. Drone shows: Creative potential and best practices. Technical report, ETH Zurich, 2017.

[10] Wang Shule, Carmen Martínez Almansa, Jorge Peña Queralta, Zhaou Zou, and Tomi Westerlund. Uwb-based localization for multi-uav systems and collaborative heterogeneous multi-robot systems: a survey. *arXiv preprint arXiv:2004.08174*, 2020.

[11] Mitch Campion, Prakash Ranganathan, and Saleh Faruque. Uav swarm communication and control architectures: a review. *Journal of Unmanned Vehicle Systems*, 7(2):93–106, 2018.

[12] Morgan Quigley, Ken Conley, Brian Gerkey, Josh Faust, Tully Foote, Jeremy Leibs, Rob Wheeler, Andrew Y Ng, et al. Ros: an open-source robot operating system. In *ICRA workshop on open source software*, volume 3, page 5. Kobe, Japan, 2009.

[13] Carlo Pinciroli and Giovanni Beltrame. Buzz: An extensible programming language for heterogeneous swarm robotics. In *2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 3794–3800. IEEE, 2016.

[14] Jorge Peña Queralta, Carmen Martínez Almansa, Fabrizio Schiano, Dario Floreano, and Tomi Westerlund. Uwb-based system for uav localization in gnss-denied environments: Characterization and dataset. *arXiv preprint arXiv:2003.04380*, 2020.

[15] Thien Minh Nguyen, Abdul Hanif Zaini, Kexin Guo, and Lihua Xie. An ultra-wideband-based multi-uav localization system in gps-denied environments. In *2016 International Micro Air Vehicles Conference*, 2016.

[16] Carmen Martínez Almansa, Wang Shule, Jorge Peña Queralta, and Tomi Westerlund. Autocalibration of a mobile uwb localization system for ad-hoc multi-robot deployments in gnss-denied environments. *arXiv preprint arXiv:2004.06762*, 2020.

[17] Viktor Walter, Nicolas Staub, Antonio Franchi, and Martin Saska. Uvdar system for visual relative localization with application to leader–follower formations of multirotor uavs. *IEEE Robotics and Automation Letters*, 4(3):2637–2644, 2019.

[18] Jorge Peña Queralta, Cassandra McCord, Tuan Nguyen Gia, Hannu Tenhunen, and Tomi Westerlund. Communication-free and index-free distributed formation control algorithm for multi-robot systems. *Procedia Computer Science*, 151:431–438, 2019.
[19] Fabian Schilling, Julien Lecoeur, Fabrizio Schiano, and Dario Floreano. Learning vision-based cohesive flight in drone swarms. *arXiv preprint arXiv:1809.00543*, 2018.

[20] Tiago Rodrigues, Miguel Duarte, Sancho Moura Oliveira, and Anders Lyhne Christensen. Beyond onboard sensors in robotic swarms. In *Proceedings of the International Conference on Agents and Artificial Intelligence—Volume 2*, pages 111–118, 2015.

[21] Cassandra McCord, Jorge Peña Queralta, Tuan Nguyen Gia, and Tomi Westerlund. Distributed progressive formation control for multi-agent systems: 2d and 3d deployment of uavs in ros/gazebo with rotors. In *2019 European Conference on Mobile Robots (ECMR)*, pages 1–6. IEEE, 2019.

[22] Guannan Li, David St-Onge, Carlo Pinciroli, Andrea Gasparri, Emanuele Garone, and Giovanni Beltrame. Decentralized progressive shape formation with robot swarms. *Autonomous Robots*, 43(6):1505–1521, 2019.

[23] Jorge Peña Queralta, Tuan Nguyen Gia, Hannu Tenhunen, Tomi Westerlund, Li Qingqing, and Zhuo Zou. Distributed progressive formation control with one-way communication for multi-agent systems. In *2019 IEEE Symposium Series on Computational Intelligence (SSCI)*, pages 2012–2019. IEEE, 2019.

[24] Francesco Mondada, Michael Bonani, Xavier Raemy, James Pugh, Christopher Cianci, Adam Klaptocz, Stephane Magnenat, Jean-Christophe Zufferey, Dario Floreano, and Alcherio Martinoli. The e-puck, a robot designed for education in engineering. In *Proceedings of the 9th conference on autonomous robot systems and competitions*, volume 1, pages 59–65. IPCB: Instituto Politécnico de Castelo Branco, 2009.

[25] Alan G Millard, Russell Joyce, James A Hilder, Cristian Flešeriu, Leonard Newbrook, Wei Li, Liam J McDaid, and David M Halliday. The pi-puck extension board: a raspberry pi interface for the e-puck robot platform. In *2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 741–748. IEEE, 2017.

[26] Michael Rubenstein, Christian Ahler, Nick Hoff, Adrian Cabrera, and Radhika Nagpal. Kilobot: A low cost robot with scalable operations designed for collective behaviors. *Robotics and Autonomous Systems*, 62(7):966–975, 2014.

[27] Wojciech Giernacki, Mateusz Skwierczyński, Wojciech Witwicki, Paweł Wroński, and Piotr Kozierski. Crazyflie 2.0 quadrotor as a platform for research and education in robotics and control engineering. In *2017 22nd International Conference on Methods and Models in Automation and Robotics (MMAR)*, pages 37–42. IEEE, 2017.
[28] Tomas Baca, Matej Petrlik, Matous Vrba, Vojtech Spurny, Robert Penicka, Daniel Hert, and Martin Saska. The mrs uav system: pushing the frontiers of reproducible research, real-world deployment, and education with autonomous unmanned aerial vehicles. arXiv preprint arXiv:2008.08050, 2020.

[29] Daniel Seither, André König, and Matthias Hollick. Routing performance of wireless mesh networks: A practical evaluation of batman advanced. In 2011 IEEE 36th Conference on Local Computer Networks, pages 897–904. IEEE, 2011.

[30] Bernhard Großwindhager, Michael Stocker, Michael Rath, Carlo Alberto Boano, and Kay Römer. Snaploc: An ultra-fast uwb-based indoor localization system for an unlimited number of tags. In 2019 18th ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN), pages 61–72. IEEE, 2019.