For the Thrill of it All: A bridge among Linux, Robot Operating System, Android and Unmanned Aerial Vehicles

Daniel V. Ruiz, Leonardo A. Vidal, and Eduardo Todt
Department of Informatics, Federal University of Paraná (UFPR), Curitiba, PR, Brazil
drvruiz@inf.ufpr.br, leonardo.vidal@escola.pr.gov.br, todt@inf.ufpr.br

Abstract—Civilian Unmanned Aerial Vehicles (UAVs) are becoming more accessible for domestic use. Currently, UAV manufacturer DJI dominates the market, and their drones have been used for a wide range of applications. Model lines such as the Phantom can be applied for autonomous navigation where Global Positioning System (GPS) signal are not reliable, with the aid of Simultaneous Localization and Mapping (SLAM), such as monocular Visual SLAM. In this work, we propose a bridge among different systems, such as Linux, Robot Operating System (ROS), Android, and UAVs as an open source framework, where the gimbal camera recording can be streamed to a remote server, supporting the implementation of an autopilot. Finally, we present some experimental results showing the performance of the video streaming validating the framework.

Keywords: Unmanned Aerial Vehicles, Video Streaming, ROS

I. INTRODUCTION

In recent years, there has been a growing interest in Unmanned Aerial Vehicles (UAVs), commonly referred to as drones, due to the increasing accessibility for domestic use. According to the Global Consumer Drone Market Report 2016-2020 [1], the current top vendors are DJI, Parrot, 3D Robotics, Cheerson Hobby, Walkera, and Yuneec. With currently the manufacturer SZ DJI Technology Co.(DJI), based in Shenzhen, China, being the global market share leader in drone aircraft sales and industrial use [2], [3]. According to SkyLogic Research [3], DJI is the dominant brand for drone aircraft purchases, with a 74% global market share across all price points. With an even higher share (86%) of the core [$1,000 , $2,000] price segment.

Due to the accessible price, DJI UAVs have been used for a diversity of works such as photogrammetry to analyze the accuracy of a digital elevation map [4], locating, identifying, and monitoring courtship and mating behavior of the green turtle [5], bridge related damage quantification [6] and power line detection and tracking [7].

To develop autonomous navigation for such DJI UAVs, an interface with the hardware is necessary. To do so, the manufacturer offers a DJI Onboard Software Development Kit (SDK) [8] and a DJI Mobile SDK [9]. The compatibility depends on the model. Jiang et al. [10] propose an extendable flight system for commercial UAVs that employ the Robot Operating System (ROS) [11]. However, they focus on the Onboard SDK available for a specific model line, the Matrice, while lines such as the most popular Phantom are not supported.

According to Jiang et al. [10], ROS has been largely used to build and test robot applications. One of the most attractive features of ROS is its distributed and modular design. In this case, each algorithm can be made into an independent module without several difficulties, such as drivers of different hardware components and communications between multiple threads. Furthermore, most of the state-of-the-art aerial robotics groups [12], [13], [14], [15], [16] have implemented their algorithms on ROS.

In this work, we propose an open source framework that is essentially a bridge for the DJI Mobile SDK to be used together with the ROS environment, allowing the use of Simultaneous Localization and Mapping (SLAM) algorithms already ROS compatible such as ORB-SLAM2 [17] to achieve autonomous navigation.

II. RELATED WORK

In this section, DJI Phantom and Matrice drones related works are briefly presented. Jiang et al. [10] developed an extendable flight system for commercial UAVs, and they focus on the DJI Onboard SDK with the ROS framework. Sagitov et al. [18] propose a more realistic simulation of the DJI Phantom 4 using the ROS framework and Gazebo robot simulator [19].

Z. Lu et al. [20] propose four basic functionalities, obtaining compass information, controlling a gimbal, autopilot function for return, and video preview, which are developed using the DJI Mobile SDK and are implemented for iOS devices.

Sa et al. [21] present full dynamics system identification using only onboard Inertial Measurement Unit (IMU) that is used by a subsequent model predictive controller (MPC) based position controller, their system relies on the DJI Onboard SDK and focus on the DJI Matrice line.

Y. Lu et al. [22] developed a mobile application for Android 6.0 platform on Huawei MT7-CL00 as the system server. The Google Glass and Moto360 smart devices make the flight and camera control of DJI Phantom 3 Professional UAV with Android Mobile SDK providing their interfaces. The wearable devices sample frequency is set at 50Hz. The aim of this project is an implementation using commercial devices.
Remote Server

ROS Melodic

roscore

publisher ROS nodes

subscriber ROS nodes

Android Device

Wi-Fi

RosAPI*

ROSJAVA Nodes

DJI Mobile SDK

Remote Controller

Wi-Fi

DJI Lightbridge

UAV

Fig. 1. Flowchart of operation. ROS messages are sent and received between the Android Device and the Remote Server via Wi-fi. The Mobile SDK manages the messages between the remote controller and the Android device. Communication between the UAV and the remote controller are managed by their firmware. RosAPI* is used for the proposed Android application.

Christansen et al. [23] design and test a UAV mapping system that uses a LiDAR sensor which can map the overflown environment in point clouds. LiDAR data are combined with data from the Global Navigation Satellite System (GNSS) and IMU sensors to conduct environment mapping for point clouds. The LiDAR point clouds are recorded, mapped, and analyzed using the functionalities of the ROS framework and the Point Cloud Library (PCL).

Landau and van Delden [24] describe an UAV system architecture implemented with DJI Mobile SDK in Swift programming language for iOS operating system. It enables a DJI Phantom 3 drone to be controlled through voice commands using Nuance speech recognition platform and regular expressions are used as language control.

Accuware offers a video streaming library [25], called Dragonfly DJI streamer library, which only supports Android 7 or above. Its license is proprietary and its source code is not publicly available. The library uses the WebRTC [26], an Application Programming Interface (API) for browser based Real-Time Communications (RTC).

The related work here presented have some limitations; for instance, the proposed autonomous navigation systems only operate with the Onboard SDK, which is for the Matrice line only. The systems compatible with the mobile SDK are limited by the smartphone utilized and usually limited by GPS signal or to a different mode of Human-computer interaction such as voice and gesture, instead of a fully autonomous system.

III. PROPOSED WORK

The Mobile SDK, available for iOS and Android, has broader compatibility, supporting the Mavic, Spark, Inspire, Matrice, and Phantom series, while the Onboard SDK is only compatible with the Matrice line. We propose a link between technologies, in order to shorten this gap and enable a computer with higher computational power, running an operating system, such as Linux, to operate the UAV, so the goal is an Android application that works as a bridge and allows the use of ROS nodes to control the UAV.

There are places where Global Positioning System (GPS) signal is not reliable, such as indoors, canyons and close to
tall buildings, hindering flight missions which heavily rely on those coordinates for navigation. To mitigate this SLAM can be used, in this work, we focus on video streaming so that each frame can be used as input for a Visual SLAM algorithm.

Fig. 1 presents a flowchart of the execution of the proposed system. The Android application, here named RosAPI, allows the heavy processing to be done on a remote server, with the use of the rosjava, an implementation of ROS in pure Java with Android support.

The navigation uses the body frame coordinate system and operates using the virtual stick control from the Mobile SDK. Commands are sent via ROS nodes, which should be sent in a frequency of between 5 Hz and 25 Hz, are interpreted by the SDK in the Android and sent to the remote controller and to the drone. The gimbal motor can be operated via messages in the publisher-subscriber model employed as well. See Fig. 2. Flags for skip frame and compression rate are also available.

Image streaming from the gimbal camera is encoded as H.264 [28], and the decoder employed in the mobile SDK, which is based on the FFmpeg library, decode it to YUV:4:2:0. The goal is to stream grayscale images due to their smaller size in bytes, thus speeding up transmission over the Wi-Fi. To further compress the byte size, an intermediary NV21 image format is used and then encoded as JPEG [29]. An optimization trick was employed to convert the YUV:4:2:0 format to NV21 using grayscale, by removing the UV channels (chrominance) there is no need to change the UV planes to an interleaved format.

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Fig. 3. Image format conversions. H.264 as video streaming input and JPEG as image frame output. A optimization trick is used to convert the YUV:4:2:0 format to NV21 using grayscale, by removing the UV channels (chrominance) there is no need to change the UV planes to an interleaved format.

The quality flag used for the JPEG encoding was 90 for all devices, and a skipframe was set to 2. The experiment was conducted in an indoor environment were multiple Wi-Fi networks were operating. The obtained results are displayed in Table II.

The data show that the Galaxy J2 Prime presents the most stable streaming, the Mi Mix 3 with the highest FPS, while the MOTO G6 had the worst performance both in FPS and Delay. Since VSLAM algorithms rely on visual information the highest FPS is desirable, but due to the multi-hardware wireless communication nature of the system, there are physical limitations on the throughput of the frames, specially since decoding is done on a smartphone. Problems due to delay can be mitigated with the help of the IMU measurements. Higher delays implies in lower flying speeds to keep reliable navigation. There are still room for optimization on the framework aiming to obtain higher FPS and lower delay.

V. CONCLUSIONS

In this work, we propose a bridge among different systems Linux, Robot Operating System, Android, and Unmanned

IV. EXPERIMENTS

The experiments performed consist of alternating image between white and black every two seconds. The UAV camera record this event and feed forward to the remote controller which send to the android device and the remote server. The remote server is responsible for controlling and displaying the alternating image and receiving the perceived frame. Thus the \( \delta_t \) difference between the timestamp of the exhibition of the image and the timestamp of the first frame that display that event can be used as the system delay. A timer is used for measurement of the \( \delta_t \) between each received frame, which is then used for the Frame Per Second (FPS) metric. Five different smartphones were evaluated, see Table I for more detailed description of each device. The experiments were performed with a DJI Phantom 3 Standard drone.

| Manufacturer | Device       | CPU                  | GPU                |
|--------------|--------------|----------------------|--------------------|
| Samsung      | Galaxy J2 Prime | Quad-core 1.4 GHz Cortex-A53 | Mali-T720MP2       |
|              | Galaxy A8     | 2x2.2 GHz Cortex-A73 & 6x1.6 GHz Cortex-A53 | Mali-G71           |
| ASUS         | ZenFone Go    | Quad-core 1.0 GHz Cortex-A53 | Adreno 306         |
| Xiaomi       | Mi Mix 3      | 4x2.8 GHz Kryo 385 Gold & 4x1.7 GHz Kryo 385 Silver | Adreno 630         |
| Motorola     | Moto G6       | Octa-core 1.8 GHz Cortex-A53 | Adreno 506         |

TABLE II VIDEO STREAMING EXPERIMENT, FPS STANDS FOR FRAMES PER SECOND, DELAY IS MEASURED IN MILISECONDS.

| Device       | Android | FPS | Delay |
|--------------|---------|-----|-------|
| Galaxy J2 Prime | 6.0.1   | 13.04 | 0.48 | 319.90 | 154.09 |
| Galaxy A8     | 9       | 12.50 | 2.60 | 409.20 | 241.82 |
| ZenFone Go    | 6.0.1   | 9.57  | 1.47 | 1295.95 | 551.18 |
| Mi Mix 3      | 9       | 13.49 | 4.57 | 545.12 | 371.02 |
| Moto G6       | 9       | 8.20  | 2.10 | 1280.70 | 826.91 |

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Aerial Vehicles. Bridging the gap of using DJI Mobile SDK with ROS can motivate future works using the Phantom series with an autonomous flight robust enough to operate without a reliable GPS signal. Furthermore, it was left for future works the analysis of decoding the H.264 stream in the remote server, instead of doing it in the Android device, this could be a potential improvement on the transmission since H.264 supports Hardware-accelerated decoding on GPU, could be a potential improvement on the transmission of the frames.

Additionally, our proposed framework ease the addition of other modules such as image processing, classification, object detection, semantic segmentation, and some others novel deep learning methods that explore domain adaptation and data generation that can run on the remote server and make use of Hardware-accelerated Deep Neural Networks running on GPU [30], [31], [33], [32].

REFERENCES

[1] R. Ltd and Markets, “Global consumer drone market 2016-2020.” [Online]. Available: https://www.researchandmarkets.com/reports/3946590/global-consumer-drone-market-2016-2020
[2] Bill, “Unmanned aircraft systems (uas): Commercial outlook for a new industry,” Nov 2015. [Online]. Available: https://digital.library.unt.edu/ark:/67531/metadc770623/
[3] S. Research, “2018 drone market sector report,” Oct 2018. [Online]. Available: https://pt.slideshare.net/ColinSnow/2018-drone-market-sector-report
[4] B. Krk, P. Blian, A. Paulikov, P. Pukrov, . Kovani, J. Palkov, and V. Zelizakov, “Use of low-cost uav photogrammetry to analyze the accuracy of a digital elevation model in a case study,” Measurement, vol. 91, pp. 276 – 287, 2016. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0263224116301749
[5] E. Bevan, T. Wibbels, E. Navarro, M. Rosas, B. M.Z. Najera, L. Sarti, F. Illescas, J. Montano, L. J. Pena, and P. Burchfeld, “Using unmanned aerial vehicle (uav) technology for locating, identifying, and monitoring courtship and mating behavior in the green turtle (chelonia mydas),” Hertpetological Review, vol. 47, pp. 27–32, 01 2016.
[6] A. Ellenberg, A. Kontsos, F. Moon, and I. Bartoli, “Bridge related damage quantification using unmanned aerial vehicle imagery,” Structural Control and Health Monitoring, vol. 23, no. 9, pp. 1168–1179, 2016. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/stc.1831
[7] G. Zhou, J. Yuan, I. Yen, and F. Bastani, “Robust real-time uav based power line detection and tracking,” in 2016 IEEE International Conference on Image Processing (ICIP), Sep 2016, pp. 744–748.
[8] DJI, Onboard SDK, 2019 (accessed June 27, 2019), https://developer.dji.com/onboard-sdk/
[9] —, Mobile SDK, 2019 (accessed June 27, 2019), https://developer.dji.com/mobile-sdk/
[10] J. Jiang, X. Zhang, J. Yuan, K. Tang, and X. Zhang, “Extendable flight system for commercial uavs on ros,” in 2018 37th Chinese Control Conference (CCC), July 2018, pp. 1–5.
[11] M. Quigley, B. Gerkey, K. Conley, J. Faust, T. Foote, J. Leibs, E. Berger, R. Wheeler, and A. Ng, “Ros: an open-source robot operating system,” in Proc. of the IEEE Intl. Conf. on Robotics and Automation (ICRA) Workshop on Open Source Robotics, Kobe, Japan, May 2009.
[12] M. Bloesch, M. Burri, S. Omari, M. Hutter, and R. Siegwart, “Iterated extended kalman filter based visual-inertial odometry using direct photometric feedback,” The International Journal of Robotics Research, vol. 36, no. 10, pp. 1053–1072, 2017. [Online]. Available: https://doi.org/10.1177/0278364917723874
[13] S. Leutenegger, S. Lynen, M. Bosse, R. Siegwart, and P. Furgale, “Keypoint-based visual-inertial odometry using nonlinear optimization,” Int. J. Rob. Res., vol. 34, no. 3, pp. 314–334, Mar. 2015. [Online]. Available: http://dx.doi.org/10.1177/0278364914554813
[14] Z. Yang, F. Gao, and S. Shen, “Real-time monocular dense mapping on aerial robots using visual-inertial fusion,” 05 2017, pp. 4552–4559.
[15] T. Liu and S. Shen, “High altitude monocular visual-inertial state estimation: Initialization and sensor fusion;” 05 2017, pp. 4544–4551.
[16] Y. Lin, F. Gao, T. Qin, W. Gao, T. Liu, W. Wu, Z. Yang, and S. Shen, “ Autonomous aerial navigation using monocular visual-inertial fusion: Lin et al.,” Journal of Field Robotics, vol. 35, 07 2017.
[17] R. Mur-Artal and J. D. Tardos, “Osb-slam2: An open-source slam system for monocular, stereo, and rgb-d cameras,” IEEE Transactions on Robotics, vol. 33, no. 5, pp. 1255–1262, Oct 2017.
[18] A. Sagitov and Y. Gerasimov, “Towards dji phantom 4 realistic simulation with gimbal and rc controller in ros/gazebo environment,” in 2017 10th International Conference on Developments in eSystems Engineering (DeSe), June 2017, pp. 262–266.
[19] N. Koenig and A. Howard, “Design and use paradigms for gazebo, an open-source multi-robot simulator,” in IEEE/RSJ International Conference on Intelligent Robot and Systems, Sendai, Japan, 09 2004, pp. 2149–2154.
[20] Z. Lu, F. Nagata, K. Watanabe, and M. K. Habib, “Ios application for quadrotor remote control,” Artificial Life and Robotics, vol. 22, no. 3, pp. 374–379, Sep 2017. [Online]. Available: https://doi.org/10.1007/s10515-017-0372-3
[21] I. Sa, M. Kamel, R. Khanna, M. Popović, J. Nieto, and R. Siegwart, “Dynamic system identification, and control for a cost-effective and open-source multi-rotor mav,” in Field and Service Robotics, M. Hutter and R. Siegwart, Eds. Cham: Springer International Publishing, 2018, pp. 605–620.
[22] Y. Lu, F. Han, L. Xie, Y. Yin, C. Shi, and S. Lu., “I am the uav: A wearable approach for manipulation of unmanned aerial vehicle;” in 2017 IEEE International Conference on Smart Computing (SMART-COMP), May 2017, pp. 1–3.
[23] M. P. Christiansen, M. S. Laursen, R. N. Ingelsen, S. Skovsen, and R. Gislum, “Designing and testing a uav mapping system for agricultural field surveying,” Sensors, vol. 17, no. 12, 2017. [Online]. Available: https://www.mdpi.com/1424-8220/17/12/2703
[24] M. Landau and S. van Delden, “A system architecture for hands-free uav drone control using intuitive voice commands,” in Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human-Robot Interaction, ser. HRI ’17. New York, NY, USA: ACM, 2017, pp. 181–182. [Online]. Available: http://doi.acm.org/10.1145/3029798.3038329
[25] Accuware, “How to capture the real-time video stream from dji drones?” [Online]. Available: https://www.dragonflycv.com/
[26] WebRTC, “WebRTC home.” [Online]. Available: https://webrtc.org/
[27] DJI, “Mobile sdk.” [Online]. Available: https://developer.dji.com/mobile-sdk/documentation/introduction/flightController_concepts.html
[28] T. Wiegand, G. J. Sullivan, G. Bjontegaard, and A. Luthra, “Overview of the h.264/avc video coding standard,” IEEE Trans. Circ. and Sys. for Video Technol., vol. 13, no. 7, pp. 560–576, July 2003. [Online]. Available: https://doi.org/10.1109/TCVT.2003.815165
[29] G. K. Wallace, “The jpeg still picture compression standard,” Commun. ACM, vol. 34, no. 4, pp. 30–44, Apr. 1991. [Online]. Available: http://doi.acm.org/10.1145/103085.103089
[30] H. Zhang, W. Yang, H. Yu, H. Zhang, and G.-S. Xia, “Detecting power lines in uav images with convolutional features and structured constraints,” Remote Sensing, vol. 11, no. 11, p. 1342, 2019.
[31] B. A. Krinski, D. V. Ruiz, G. Z. Machado, and E. Toto, “Masking salient object detection, a mask region-based convolutional neural network analysis for segmentation of salient objects,” in 2019 Latin American Robotics Symposium (LARS), 2019 Brazilian Symposium on Robotics (SBR) and 2019 Workshop on Robotics in Education (WRE), 2019, pp. 55–60.
[32] D. V. Ruiz, B. A. Krinski, and E. Toto, “Anda: A novel data augmentation technique applied to salient object detection,” in 2019 19th International Conference on Advanced Robotics (ICAR), 2019, pp. 487–492.
[33] D. V. Ruiz, G. Salomon, and E. Toto, “Can giraffes become birds? an evaluation of image-to-image translation for data generation.” preprint arXiv 2001.03637, 2020.