ISSN 2355-3286

An Analysis Of The Performance Of Autonomous Navigation On An Ardupilot-Controlled Rover

Adik Susilo Wardoyo[1], Indri Purwita Sary[2], Ilham Taufik Maulana[3]
[1] Prodi Teknik Elektronika, Politeknik Gajah Tunggal, Tangerang, Banten, Indonesia
[2] Prodi S1 Teknik Elektro, Fakultas Teknik , Universitas Singaperbangsa, Karawang, Jawa Barat, Indonesia
[3] Prodi Teknik Mesin, Politeknik Gajah Tunggal, Tangerang, Banten, Indonesia
[1] adiksusilo@poltek-gt.ac.id, [2] indripurwitasary@gmail.com, [3] ilham@poltek-gt.ac.id

Accepted 25 October 2022
Approved 23 November 2022

***Abstract*— Monitoring forests is one of the strategies in the overall preventive strategy. Monitoring the forest can quickly and permanently manage how tree illnesses emerge, spread, and evolve. To help monitor forest fires, a robot platform that can operate independently and assist in data collection can be created. In this paper, the accuracy of the Ardupilot-controlled autonomous navigation system of the rover was examined. The metode are used is experimental study, the study consists of a comparison between the GPS rover log and the SITL simulation within the mission planner tool. The average accuracy achieved by altering the route's distance and shape is 94.58%. The lengthy path may be the source of the rover's inaccurate autonomous navigation. In this case, the turning angle problem has no real effect on how well and accurately the rover navigates on its own.**

***Index Terms*— Ardupilot, Autonomous, GPS, Navigation, Rover.**

I. Introduction

A. Robot for Forest Fire Monitoring

Monitoring forests is one of the strategies in the overall preventive strategy since it is crucial to stopping the spread of tree diseases and forest fires. In addition to determining the general health of the forest, monitoring the forest can quickly and permanently manage how tree illnesses emerge, spread, and evolve. On the other hand, pathologists who research forests usually discover that they cannot visit many distant areas of the forest within a reasonable length of time or at a reasonable cost. To help monitor forest fires, a robot platform that can operate independently and assist in data collection in the forest can be created [1]. In their paper, Khaled et al. have already conducted a simulation to investigate the effectiveness of their proposed algorithm using teams of unmanned ground vehicles (UAV and Unmanned Ground Vehicles (UGV) for fire detection in the forest [2]. Merino et al. have previously produced a study that demonstrates it is possible to construct unmanned aircraft systems (UAS) for detecting forest fires. Experiments have shown that systems based on airplanes can be highly helpful for firefighting tasks such as fire monitoring. This is because aircraft systems can bridge the gap between the geographical scales provided by systems based on satellites and those based on cameras on towers. The UAS is able to modify its deployment such that it sidesteps the drawbacks of traditional methods, such as the presence of smoke, or covers areas that are more conveniently located [3]. Quenzel et al. already make robots capable of doing their assigned jobs on their own, and their vision, motion planning, and fire extinguishing systems are reliable [4]. Based on some of the references above, it can be concluded that the use of autonomous robots can be carried out for monitoring, one of which is forest fires.

B. Mobile Robot

A wheeled autonomous robot is one of the existing robot types. A wheeled robot system can be created by combining several electronic and mechanical components. As an autonomous controlling device, a guiding component can be added to the robot's navigation. Typically, the control function uses GPS as a position reference, but other guiding components, such as cameras, radars, and others, can also be added. Mobile robots are robots that can travel from one location to another to do required and difficult activities, simple jobs that are time-consuming, repetitive, or dangerous. These days, people are being replaced by robots in a variety of settings, including offices, the military, medical operations, sports, agricultural tasks, and many more. Mobile robots can be built in a variety of ways, but thanks to the recent proliferation of embedded systems and microcomputers, it is now feasible to create low-cost solutions. Mobile robots come in a variety of shapes and sizes [5].

Mobile robots can have a variety of configurations, a variety of sensors (infrared, ultrasonic, webcams, GPS, magnetic, etc.), and a variety of command and control algorithms, depending on where they are going.

Mobile robots can also be supervised either locally or remotely [6]. Ananta et al. in their research have already built their autonomous rover controlled by Ardupilot, and the result of accuracy is about 89,43% [7]. Rahim et al., who have succeeded in designing a lawnmower that works autonomously using an Ardupilot made to cut weeds [8]. Hassan and his team were able to design a Robot Unmanned Ground Vehicle that can follow and move waypoints sent from the ground station by using the Ardupilot APM 2.6 controller and the Mission Planner program [9].

C. *Ardupilot and APM*

The firmware for the autonomous unmanned system is typically developed with the help of ArduPilot, which is a very common framework [10]. Ardupilot is an open source navigation software that allows the development of reliable autonomous unmanned vehicle systems, e.g. for multirotor drones, fixed-wing and VTOL aircraft, helicopters, ground rovers, ships, submarines, and tracking antennas. To support the use of Ardupilot, the mission planner application can be used as an interface with the controller to set up, configure, test, and tune the vehicle. Mission planner is a Ground Control System (GCS) application that has full features and is compatible with Ardupilot [11]. According to the findings of Carlson's investigation, one of the most popular open-source platforms for drones is called Ardupilot. This platform is compatible with a variety of hardware and software options. Some examples of hardware that is compatible include the Pixhawk line, the Ardupilot Mega, etc. There is compatible software such as Mission Planner, APM Planner, and QGroundControl, etc. [12].

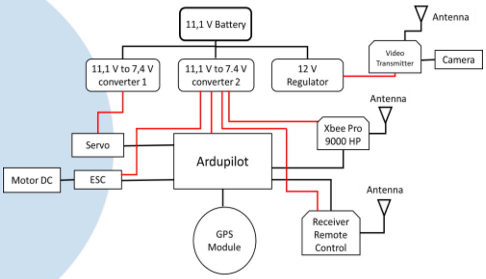
D. *Ardupilot Analysis*

In a study carried out by Liu et al., it was revealed that when comparing the simulated SIL and the experimental performance of the Ardupilot controller on UAV, a promising result was obtained [13]. In their experiment, Janarthanan et al. get the result that the Ardupilot APM 2.8 is capable of controlling the UAV by path planning with an 82 % success rate from 3 trials [14]. Jung and Ariyur's research already tests and improves the GPS performance of the Unmanned Ground Vehicle (UGV) controller by Ardupilot APM 2.6 [15]. In their research, Timpitak et al. have succeeded in comparing simulations of autonomous navigation systems using the Matlab simulink program and experiments, with good results in heading to the target position autonomously. The experiment was carried out with the coordinates of the GPS logger in the robot, compared with the simulation, then from these results the error difference was sought [16]. This research will be conducted by testing the performance of the rover's navigation system in light of these investigations. Rover will be controlled using Ardupilot APM 2.8 while Mission Planner will serve as the base station application. GPS log data from the simulation will be compared to data from the experiment.

II. METHOD

A. *Hardware Configuration*

The method used is an experimental study that consists of a comparison between the GPS rover log and the SITL simulation within the mission planner tool. The GPS logs analyzed in the study are GPS log data from simulations and GPS logs for robot rovers. The rover is assembled using the chassis of a modified remote control car, as the rover controller uses Ardupilot Mega 2.8, the GPS module uses the M8N GPS module, and 1 servo and 1 ESC as controller and driver. An 11.1 volt, 5000 mAh battery is used to power the robot. The XBee Pro 900HP wireless module, with a working frequency of 2.4 GHz, is used to connect the Ardupilot telemetry system to the base station, The schematic and the assembled rover are shown in Fig 1.



(a)

(b)

Fig. 1. (a) Rover Schematic, (b) Rover with Ardupilot controller

The data from the rover is then sent in real time to the base station, using the Xbee module as the transmission medium. The data is then displayed and saved via the Mission Planner application. In addition, through this application, it can be used to program the rover parameters and program the route to be traversed by the rover. Apart from being in auto mode, the rover also has a manual mode in which the control of the rover can be controlled manually via the Flysky FS I6 remote control with a 6 channel FS i6B receiver. The robot also has a camera and a transmitter system. The video is sent to the receiver, where it will be shown and saved in the Mission Planner application. The rover system and base station application are depicted in Fig 2.

Fig. 2. (a) Rover Schematic, (b) Rover with Ardupilot controller

B. *Data Collection and Analysis*

The GPS logs between simulations and experiments were collected using a 4 waypoint configuration. Waypoints 1 and 2 have almost the same distance, while waypoint 3 is similar to waypoint 4. Each waypoint is tested in four trials. So a total of 16 trials. The characteristics of waypoints 1 and 2 are characteristics of long routes and not sharp turns. While routes 3 and 4 have shorter characteristics but with a greater number of bends and are sharper.The waypoint in the study can be seen in Fig. 3.

(a)

(b)

Fig. 3. (a) Rover Schematic, (b) Rover with Ardupilot controller

By referring to these waypoints, GPS points will be obtained, which are stored in the Ardupilot memory. Then, using the Mission Planner application, the GPS points are downloaded for analysis. The simulation used in this study is a SITL simulation on the Mission Planner application with the Rover vehicle selection mode. The GPS log from this simulation is analyzed to be compared with the experiment. Finding the difference between two GPS locations can be done with the use of the haversine formula. The difference between the two GPS points will be regarded as an error, and the accuracy value will be determined based on the data collected from the errors. The Haversine formula, which is based on the length of the straight line that connects the two points on the longitude and latitude axes, can be used to compute the distance between two points. The formula is based on the length of the straight line [17]:

$$\Delta lat = latitude2 - latitude1 \quad (1)$$

$$\Delta long = longitude2 - longitude1 \quad (2)$$

$$distance = 2.R.arcsin\left(\sqrt{sin^2\left(\frac{\Delta lat}{2}\right) + \cos(latitude2).\cos(latitude1).sin^2\left(\frac{\Delta long}{2}\right)}\right) \quad (3)$$

Where *R* is radius of earth in about 6371 km. After the experiment is complete, the difference between the simulation and experiment coordinates is determined by comparing them. The Root Mean Square Error *(RMSE*) is a commonly employed measure of the difference between the values predicted by the model and the observed values from the environment being modeled. This *RMSE* parameter comes from the prediction model, and the square root of the squared mean error is used to describe the estimated variable *X* [18].

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(X_{sim,i} - X_{exp,i}\right)^2}{n}} \quad (4)$$

Where, X_{sim} is value from simulation, and X_{exp} is value from experiment. Chen et al. analyzed the error of different GPS coordinates of experimental results and predictions using *RMSE* [19], in addition to Koo et al., who analyze GPS displacement using *RMSE* [20], so this study also uses the same method.

III. RESULT

A. Comparison of Mission Data

The data that has been obtained is then displayed in several types of data. The first result is the result of a comparison between routes (waypoints) compared to simulations and experiments. The data used to create the graph below consists of 100 coordinate points for each simulation and experiment, as well as four reference waypoints. The results of the comparison of missions, experiments, and simulations are as follows.

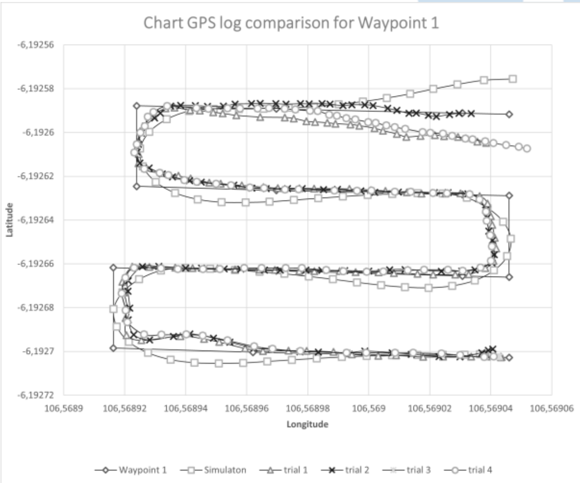


Fig. 4. GPS log comparison for Waypoint 1

Fig. 4 shows the route comparison between waypoint 1, as a reference, simulation, experiment 1, experiment 2, experiment 3, and experiment 4 with the number of coordinate points used of 100 data point coordinates, except for waypoint 1.

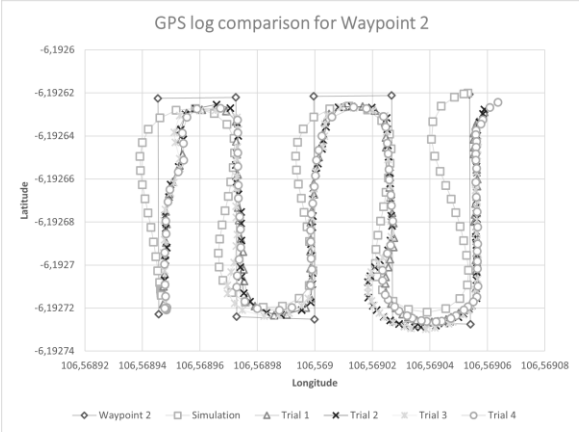


Fig. 5. Chart GPS log comparison for Waypoint 2

Fig. 5 shows the route comparison between waypoint 2, as a reference, simulation, experiment 1, experiment 2, experiment 3, and experiment 4 with the number of coordinate points used of 100 data point coordinates, except for waypoint 2.

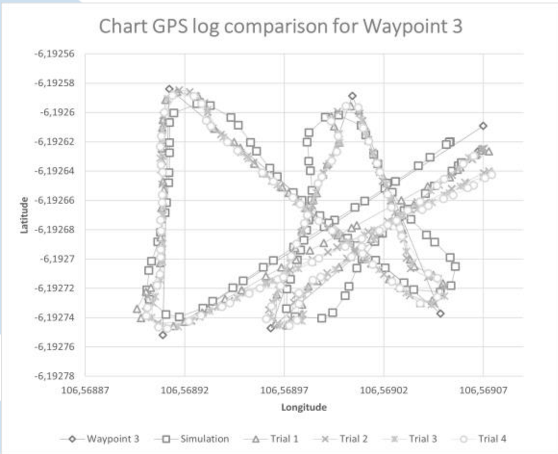


Fig. 6. Chart GPS log comparison for Waypoint 3

Fig. 6 shows the route comparison between waypoint 3, as a reference, simulation, experiment 1, experiment 2, experiment 3, and experiment 4 with the number of coordinate points used of 100 data point coordinates, except for waypoint 3.

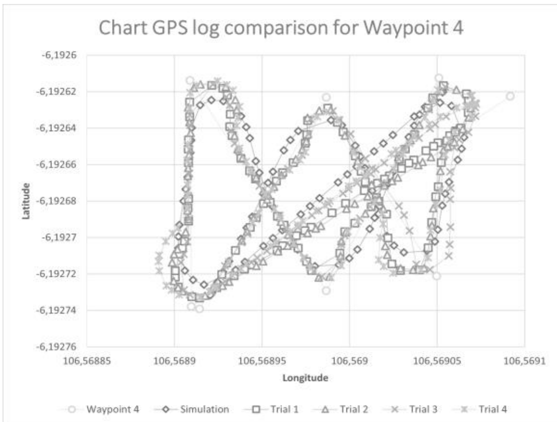


Fig. 7. Chart GPS log comparison for Waypoint 4

Fig. 7 shows the route comparison between waypoint 4, as a reference, simulation, experiment 1, experiment 2, experiment 3, and experiment 4 with the number of coordinate points used of 100 data point coordinates, except for waypoint 4.

B. Accuracy Analysis

Based on the data visualized in Fig 4, Fig 5, Fig 6, and Fig 7, accuracy analysis is carried out by calculating the difference in coordinates between the simulation and each experiment. The calculation of the distance between the coordinates using the haversine formula (1), (2), and (3). The results of the calculation of the average accuracy shown in Table I.

TABLE I. ACCURACY ANALYSIS RESULTS

No	Waypoint	Trial	Accuracy (%)
1	Waypoint 1	1st	92,54
		2nd	92,31
		3rd	92,47
		4th	91,87
2	Waypoint 2	1st	94,42
		2nd	94,28
		3rd	94,73
		4th	94,87
3	Waypoint 3	1st	97,78
		2nd	96,86
		3rd	97,00
		4th	97,58
4	Waypoint 4	1st	94,16
		2nd	94,79
		3rd	94,12
		4th	93,47
Average			94,58

Based on the data in Table I, it can be seen that the average accuracy of the robot navigation system based on a comparison of simulations and experiments can be seen to be 94.58%. The smallest experimental accuracy is in the waypoint 1 experiment, with the characteristics of a long route and relatively blunt bends. The highest experimental accuracy value is found in the waypoint 3 experiment, which has the characteristics of the shortest route even though it has the sharpest bend, but the accuracy level remains the highest.

C. GPS Data Analysis with RMSE

The formula used to determine the *RMSE* between experimental results and simulation results is as follows (4). Each research utilizes a sample size of 100. Table II shows the results of the *RMSE* analysis.

TABLE II. THE RESULT OF THE RMSE ANALYSIS OF THE COORDINATES

No	Waypoint	Trial	Accuracy (%)
1	Waypoint 1	1st	7,63 x10^{-5}
		2nd	7,86 x10^{-5}
		3rd	7,74 x10^{-5}
		4th	8,08 x10^{-5}
2	Waypoint 2	1st	5,74 x10^{-5}
		2nd	5,88 x10^{-5}
		3rd	5,40 x10^{-5}
		4th	5,29 x10^{-5}
3	Waypoint 3	1st	2,40 x10^{-5}
		2nd	2,90 x10^{-5}
		3rd	2,84 x10^{-5}
		4th	2,50 x10^{-5}
4	Waypoint 4	1st	5,74 x10^{-5}
		2nd	5,19 x10^{-5}
		3rd	5,79 x10^{-5}
		4th	6,70 x10^{-5}

According to Table II, the *RMSE* value for the waypoint 3 experiment is the one with the least amount of variance. The results of this investigation are the same as the analysis of accuracy shown in Table I.

IV. CONCLUSION

The accuracy of the robot navigation system, based on a comparison of simulations and experiments, can be seen to be 94.58%. The smallest experimental accuracy is in the waypoint 1 experiment, with the characteristics of a long route and relatively blunt bends, with an average accuracy of about 92,30% . The highest experimental accuracy value is found in the waypoint 3 experiment, with an average accuracy of about 97,31 %, which has the characteristics of the shortest route even though it has the sharpest bend, but the accuracy level remains the highest. Accordingly, the *RMSE* value is also the smallest in the waypoint 3 experiment and the largest in the waypoint 1 experiment. The long route may be the cause of the lack of accuracy in the rover's autonomous navigation. The turning angle problem in this case does not have an appreciable effect on the accuracy and performance of the rover's autonomous navigation.

ACKNOWLEDGEMENT

The authors are grateful to the Ministry of Education and Culture of Indonesia, Director of Polytechnic Gajah Tunggal, Head of Research and Community Service, Head of Electronic Engineering Study Program, and Head of Mechanical Engineering Study Program of Polytechnic Gajah Tunggal. Ministry of Education, Culture, Research and Technology of the Republic of Indonesia Grant.

REFERENCES

[1] M. N. Mikhaylov and I. A. Lositskii, "Control and navigation of forest robot," 25th Saint Petersbg. Int. Conf. Integr. Navig. Syst. ICINS 2018 - Proc., pp. 1–2, 2018, doi: 10.23919/ICINS.2018.8405881.

[2] [K. A. Ghamry, M. A. Kamel, and Y. Zhang, “Cooperative forest monitoring and fire detection using a team of UAVs-UGVs,” 2016 Int. Conf. Unmanned Aircr. Syst. ICUAS 2016, no. December 2017, pp. 1206–1211, 2016, doi: 10.1109/ICUAS.2016.7502585.

[3] L. Merino, F. Caballero, J. R. Martínez-De-Dios, I. Maza, and A. Ollero, “An unmanned aircraft system for automatic forest fire monitoring and measurement,” J. Intell. Robot. Syst. Theory Appl., vol. 65, no. 1–4, pp. 533–548, 2012, doi: 10.1007/s10846-011-9560-x.

[4] J. Quenzel et al., “Autonomous Fire Fighting with a UAV-UGV Team at MBZIRC 2020,” 2021 Int. Conf. Unmanned Aircr. Syst. ICUAS 2021, pp. 934–941, 2021, doi: 10.1109/ICUAS51884.2021.9476846.

[5] Z. Luo, X. Xiang, and Q. Zhang, Autopilot system of remotely operated vehicle based on ardupilot, vol. 11742 LNAI. Springer International Publishing, 2019.

[6] S. Oltean, “Mobile Robot Robot Platform Platform with with Arduino Arduino Uno and Raspberry Raspberry Pi for Autonomous Navigation,” Procedia Manuf., vol. 32, pp. 572–577, 2019, doi: 10.1016/j.promfg.2019.02.254.

[7] A. Srisuphab, P. Silapachote, W. Tantratorn, P. Krakornkul, and P. Darote, “Insect Detection on an Unmanned Ground Rover,” IEEE Reg. 10 Annu. Int. Conf. Proceedings/TENCON, vol. 2018-Octob, no. October, pp. 954–959, 2019, doi: 10.1109/TENCON.2018.8650312.

[8] M. Syazwan, A. Abdul, and A. Johar, “System Development of an Autonomous Lawnmower System Using Ardupilot Mission Planner,” vol. 2, no. 2, pp. 533–538, 2021.

[9] S. Hassan, M. Alam, N. A. Siddiqui, A. A. Siddiqui, and M. T. Qadri, “Designing and control of autonomous Unmanned Ground Vehicle,” in 2017 International Conference on Innovations in Electrical Engineering and Computational Technologies (ICIEECT), Apr. 2017, pp. 1–5, doi: 10.1109/ICIEECT.2017.7916547.

[10] Q. A. Nguyen, E. Grolleau, and H. K. Ngo, “Results and comparision between different control algorithms for a quadrotor using ArduPilot framework,” Sci. Technol. Dev. J., vol. 18, no. 4, pp. 170–178, 2015, doi: 10.32508/stdj.v18i4.1003.

[11] A. F. Anto and T. Sukardiyono, “Prototype Autonomous Rover Pembersih Sampah Pantai menggunakan ArduPilot,” Elinvo (Electronics, Informatics, Vocat. Educ., vol. 4, no. 2, pp. 202–209, 2019, doi: 10.21831/elinvo.v4i2.28793.

.

[12] D. F. Carlson and S. Rysgaard, “Adapting open-source drone autopilots for real-time iceberg observations,” MethodsX, vol. 5, pp. 1059–1072, 2018, doi: 10.1016/j.mex.2018.09.003.

[13] C. Liu, O. McAree, and W.-H. Chen, “Path-following control for small fixed-wing unmanned aerial vehicles under wind disturbances,” Int. J. Robust Nonlinear Control, vol. 18, no. December 2012, p. n/a-n/a, Dec. 2012, doi: 10.1002/rnc.2938.

[14] A. Janarthanan, H. W. Ho, L. Gopal, V. Shanmugam, and W. K. Wong, “An Unmanned Aerial Vehicle Framework Design for Autonomous Flight Path,” 2019 7th Int. Conf. Smart Comput. Commun. ICSCC 2019, pp. 0–4, 2019, doi: 10.1109/ICSCC.2019.8843618.

[15] S. Jung and K. B. Ariyur, “Compensating UAV GPS data accuracy through use of relative positioning and GPS data of UGV,” J. Mech. Sci. Technol., vol. 31, no. 9, pp. 4471–4480, 2017, doi: 10.1007/s12206-017-0847-0.

[16] S. Timpitak, P. Prempraneerach, M. Janthong, and E. Pengwang, “Small Unmanned Surface Vehicle In Autonomous Way-Point Experiment And Simulations For Straight Path Tracker,” Suranaree J. Sci. Technol., vol. 28, no. 2, pp. 1–7, 2021.

[17] R. A. Azdy and F. Darnis, “Use of Haversine Formula in Finding Distance between Temporary Shelter and Waste End Processing Sites,” J. Phys. Conf. Ser., vol. 1500, no. 1, 2020, doi: 10.1088/1742-6596/1500/1/012104.

[18] W. Widada, “Metode Penggabungan Beberapa Penerima Gps Untuk Roket Balistik (Method of Combining Multi-Gps Receivers To Improve Accuracy and Reliability of the Tracking System of Sounding Rocket),” J. Teknol. Dirgant., vol. 12, no. 1, pp. 1–10, 2013.

[19] B. Chen, H. Mei, Z. Li, Z. Wang, Y. Yu, and H. Yu, “Retrieving three-dimensional large surface displacements in coal mining areas by combining SAR pixel offset measurements with an improved mining subsidence model,” *Remote Sens.*, vol. 13, no. 13, 2021, doi: 10.3390/rs13132541.

[20] G. Koo *et al.*, “Development of a high precision displacement measurement system by fusing a low cost RTK-GPS sensor and a force feedback accelerometer for infrastructure monitoring,” *Sensors (Switzerland)*, vol. 17, no. 12, 2017, doi: 10.3390/s17122745.