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Research article

APPLYING TRAJECTORY TRACKING AND POSITIONING TECHNIQUES FOR REAL-TIME AUTONOMOUS FLIGHT PERFORMANCE ASSESSMENT OF UAV SYSTEMS

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Abstract

This research presents a Performance Visualized Assessment (PVA) archetype via which the performance of autonomous Unmanned Aerial Vehicles (UAV) or drone framework can be scrutinized and evaluated. The PVA is a performance-based assessment method that appropriately fits in assessing the flight point of the UAV in an indoor situation and outside the requirement of GPS aid. The PVA prototype came up with is comprised of Visualized Mission Grid (VMG) and Chi-square (CSI) modules. The VMG maps viewable field information of the surrounding including the situation of the route mission. In addition, the utilization of restriction and optical stream indoor direction monitoring and trailing is used in the CSI. The PVA follows and evaluates the execution of the UAV autonomous operations by checking and envisioning the direction and the UAV action amid route missions. The implementation outcomes demonstrate that the PVA is able to precisely assess and envision the execution quality of three aerial missions.

Keywords: Autonomous system, Unmanned Aerial Vehicle (UAV), performance-based assessment, trajectory tracking technique.

摘要 该研究提出了一种性能可视化评估（PVA）原型，通过该原型可以仔细检查和评估自主无人驾驶飞行器（UAV）或无人机框架的性能。 PVA 是一种基于性能的评估方法，适用于在室内情况下评估无人机的飞行点，并超出 GPS 辅助的要求。推出的 PVA 原型由可视化任务网格（VMG）和卡方（CSI）模块组成。VMG 映射周围的可视字段信息，包括路线任务的情况。此外，在 CSI 中使用限制和光流室内方向监视和尾随。 PVA 通过在路线任务中检查和设想方向和无人机动作来跟踪和评估无人机自主操作的执行。实施结果表明，PVA 能够精确评估和设想三个空中任务的执行质量。

关键词: 自主系统，无人机（UAV），基于性能的评估，轨迹跟踪技术。

I. INTRODUCTION

An Autonomous Unmanned Aerial Vehicle (UAV) or drone framework is a synthesis or amalgamation of mechatronic, state-of-the-art aeronautical and programming advancements. Lately, one of the domains of study with an increased interest and acclaim is micro or small scale UAVs. This is as a result of the accomplished headway in this innovation. [1], [2] These micro-machines have the characteristics of little sizes, a huge measure of availability, inexpensive nature, mobility and other various application purposes. Small scale UAVs have been utilized in the advancement of numerous implementations. Instances of implementations are information acquisition, observing, reconnaissance, search and recovery, remote detecting and control. [3] Be that as it may, the command of a considerable lot of these applications is reliant on manual human administration. [4] There is an expanding development in the territory of autonomous UAVs. The job of autonomous small scale UAVs in military and non-military utilizations will in the nearest future be increasingly compelling. [5]

Currently, the positioning service which offered by GPS resolves the route of UAVs, and this makes the UAVs experience the ill effects of multipath impact and blockage of the observable pathway. In addition, the reliance of the UAV on GPS improves its capacity to perform inside an indoor situation, an urban domain and woodland. [3] There are numerous possible uses of the miniaturized or micro UAVs, and they incorporate examination, capturing, reconnaissance, checking and remote assignment, for example, patrolling, aeroplane terminal, games, stockpiles and industrial facilities observations. In a domain where GPS is unavailable, the indoor autonomous flight needs cutting-edge strategies of situating and direction tracking. [6]

The existing indoor UAV systems look at distribution displacement deprecation procedures i.e. positioning, path tracking systems and numerical strategies. [7] Using these methods, the location, direction and movement are supposed for the UAV. These methods gauge the UAV's location, movement and direction. The methods are additionally viewed as unstable for long haul use. [8] In this way, the writing consists of a broad scope of strategies and techniques that have been suggested for evaluating different locations and direction tracking. Excellent UAV situating or positioning involves a framework via which the entire subtleties of the surrounding is costly and complicated. [9]

In previous writings, the proposition of a few autonomous prototypes and methodologies are available, with every one of these proposals created dependent on certain contentions, while offering or suggesting resolutions that can take care of the issues identified with explicit autonomy. [10], [11] Numerous agents are in agreement that autonomous design calculations like autonomous agents can behave in a way that is unwanted because of different conditions which are outside their control. [1], [12] The instances of controlled agents, learning agents and constrained agents are classic instances of such circumstances. [13] In like manner, it is imperative to have an observing method that is involved with following a framework's autonomous act, while assessing its execution. [14] For the impacts of these activities to be resolved, while recognizing variation from the norm between the genuine accomplishments and the proposed outcomes, the assessment must be completed. Here, a deduction component, just as sufficient domain-explicit information, is required so as to have the capacity to do the evaluation.

Among the usually utilized appraisal methods covered in writings, one is the execution-dependent evaluation, which is generally employed in autonomous frameworks. [15], [16] The usage of this method is regularly done separately in order to avoid meddling with the range of capabilities of a framework. The objective of this method is to examine how suitable the execution of the autonomous framework is for continuous usages or implementations. [17] A notable issue with this procedure is that ideal execution or the normality of ideal execution isn't ensured by the exceptionally precise outcomes of the method; this absence of assurance is because of the dynamic parts or changing components of the surrounding including the equipment imperatives. [18]

Performing an appraisal of the accomplishment of independent/autonomous navigating ability for UAVs in an intelligent and changing indoor conditions can be a highly demanding task. As of late, a few agents and engineers have come up with different indoor limited planning strategies for mechanical autonomous frameworks as well as a UAV. This is due to new industrialized or technical and investigative utilizations they can be put into. Subsequently, this paper suggests a Performance

Visualized Assessment (PVA) design aimed at running a performance-based assessment in indoor conditions and in the absence of GPS administration or service. The test outcomes demonstrate that the framework is equipped for assessing the execution quality and UAV locating or positioning inside an indoor condition.

The rest of this paper comprises of 5 Section. In Section II, a literature review on indoor route direction tracking of UAV systems is introduced. Section III presents a depiction of the examination strategies and materials including the direction procedure, test quadcopter and the exploratory testing condition. Section IV shows the hypothetical prototype. In Section V, the execution of this proposal is illustrated, accompanied by a discourse on the acquired outcomes. In Section 6 of this research, the conclusion and suggestions for future investigation are introduced.

II. RELATED WORK

The requirement for a cutting-edge study about in the deployment of UAVs inside an indoor surrounding or environment has been recognized. In addition, in the writing, it is discovered that the utilization of the direction strategy has been used in a UAV for different scopes. Instances of such employment incorporate the limitation of the UAV as found in [15], control of the route, e.g., [8] and [19], and autonomous missions as discovered in [1], [2] and [6]. In this segment, a portion of these precedents is inspected.

A collaborative system is brought up by Fowowe [5] that consolidates an UAV (AR.Drone) and UGV with the end goal of synchronous mapping and confinement. The UAV and UGV are coordinated with the goal that they can independently complete observation in an unfamiliar situation or surrounding. Here, the UAV is utilized by the UGV access zones that are unreachable, at that point, carry out an estimation of the plausible routes and afterwards keep away from or avoid obstructions. The undertaking of the collaborative framework is subject to altimeter sensors, installed gyrators and the viewable route which is used in determining the location of UGV and UAV amid runtime. The direction tracking system and EKF decide the viewable or observable route. In Figure. 1, the control cycle of the hybrid framework is shown. The achievement of the mission and time indices are utilized in appraising the autonomy and nature of the system execution.

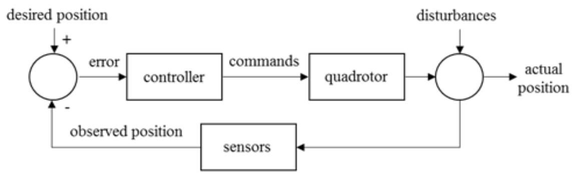

Figure 1.The control cycle of Fowowe [5]

In research performed by Khosiawan and Nielsen [6], an investigation on UAVs deployment in an indoor surrounding is examined. The researchers proposed that such leading investigations be performed to examine the utilization of the UAV for observing and reconnaissance exercises in surrounding such as the assembling fields. In their investigation, a structure for UAV planning tasks is additionally suggested. The structure is intended to empower the activity of an UAV framework inside an indoor implementation. The structure empowers the UAV framework to perform assignments independently, isolates the activities into undertaking/operation and area usage. An indoor radio-dependent situating or locating programming that is contained in the UAV control framework; this product aids the execution of specific assignments by the conceivable directions. In light of three information sources (assignment information, map information and UAV information), and in long reconnaissance missions, the structure makes arrangement for an orderly planning reflection or conception.

The likelihood of utilizing an UAV framework as a flying remote transmitter in wireless networking systems is investigated by Chen and Gesbert [7]. The researcher intended to bolster the limit and capability of giving web administrations or services to clients in areas out of reach or metropolitan topography. The study centers on shared wireless network administrations utilizing a computerized UAV situating component. Here, the system's end to end throughput execution is influenced by the precision of the UAV's location. A local prototype of positioning comprising of search and proliferation calculations is suggested by Chen and Gesbert. The calculations operate depending on the search path distance and a signal quality mapping. The aftereffects of this study are comparable to business items, for example, the Line-of-Sight (LOS) framework.

While trying to improve the path following the system's execution, a calculation or algorithm that handles a picture from a 2D dimension was suggested by Gariepy [8]. This system is pertinent or problematic in circumstances whereby pictures are of poor quality. In the calculation, attribute determination procedure and Random Sample Consensus (RANSAC) with Extended Kalman Filter (EKF) are coordinated. For exceptions in pictures to be removed, RANSAC is utilized. RANSAC is additionally utilized in the enhancement of visual estimation and to evaluate the whole position. The general framework is implemented to assess the situation of an AR. Drone quadcopter inside an indoor surrounding. The outcomes demonstrate that this calculation improves the quality and timeliness of the situating and direction monitoring up to 40cm. The control design of the direction following strategy is in Figure. 2. The likelihood of utilizing the direction/path tracking of the UAV as a visual contribution to the routing of the UAV in autonomous missions can be confirmed by the outcome of this study.

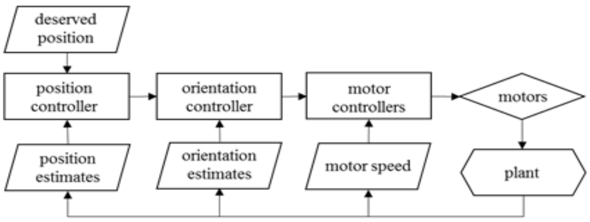

Figure 2.The nested control cycle of the quadcopter [8]

Wireless Sensor Network (WSN), a mini-UAV confinement unit is suggested by Cheng et al. [15]. The utilization of Sequential Probability Ratio (SPR) and Received Signal Strength (RSS) is utilized by the unit, in order to make a valuation of the scope of the WSN and to likewise handle the issue of signal vacillations or inconsistencies. The surrounding is a non-observable pathway or Non-Line of Sight (NLOS) comprising of limitations or impediments that obstruct signals from the signal guide to the WSN's objective that have a straightforward or direct trajectory. In view of the test outcomes, the confinement precision of such NLOS surrounding is enhanced by the unit.

In connection with the writing of autonomous flight appraisal, Durand et al. [14] did an appraisal of the autonomy of an UAV by estimating the stability and steadiness of its execution. In their evaluation, the origin of irregularities in the UAV is recognized; this is carried out by utilizing the estimations, physical parts and the algorithms. So as to evaluate the autonomy of UAVs, an Autonomous Control Level unit is brought up by Clough [20]. As indicated by Sellner et al. [21], the reaction speed of autonomous frameworks is influenced by the human reaction, which portrays a constraint, in contrast with different autonomous elements. Notwithstanding, the aid of people in independent frameworks that have vulnerabilities can't be belittled or overlooked, in light of the fact that the help of people empowers the effective execution of activities. In this manner, it evaluated the capacity of human administrators' controllability of robots utilizing sliding autonomy.

III. Materials and Methods

This study incorporates a UAV which is industrially known as AR.Drone version 2.0.; an independent multi-agent framework is utilized in operating the drone UAV [1], [17], while supervision and observation of the framework are done by a human director. [4]

A. AR. Drone

Four rotor fans that assist in hoisting the helicopter's primary body including different cargo or payloads by turning quickly are controlled by the AR.Drone [3]. The details or stipulations and properties of the UAV are examined in order to find out the settings of the undertakings that the drone independently carries out. Figure. 3 presents the AR.Drone 2.0 in an (a) in-door and (b) outdoor customs.

Figure 3.The AR. Drone 2.0.

Initially, the UAV is followed by a remote control programming which can be obtained from the site of the provider; the remote control is made available to an administrator for in controlling the UAV flight. Be that as it may, no autonomy is provided for the UAV except for essential controls, there is a requirement to program it to fulfill different needs. [3], [5] In this research, an autonomous UAV programming which can transmit remote control signals from a computer to the UAV is integrated; signals are transmitted to the UAV to carry out essential flight capacities and mobility. The whole framework is Dynamic Adjustable Autonomous

Drone (DAAD). More subtleties of the framework are shown in [1], [4] and [17].

The design or structure of the UAV's DAAD independent programming with peripheral programming is carried out in a computer in order to test it for successful usage of the remote independent applications of the UAV and the output Wi-Fi signals transmitted from the work-station. The fundamental testing of the drone is carried out in a predefined or prearranged surrounding so as to evaluate its autonomous capacities. The general tasks of the test UAV framework are illustrated in Figure. 4.

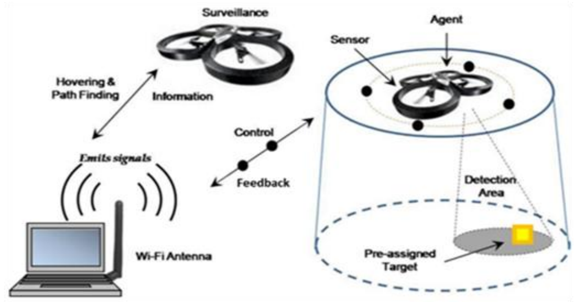

Figure. 4.The experimental UAV system

B. Trajectory Tracking Technique

Having the capacity to actively estimate the location of the drone for indoor autonomous flight, is the principal constraint of this study. As far as control is concerned, the test is helpful for the drone since it performs assignments inside a domain that lacks GPS [8], [15]. Gyrators and accelerometers are the installed in-flight (odometer) sensors of the drone. The outputs from the odometer indicate vulnerability or weakness for the location approximation of the drone, including autonomous routing. A case of the vulnerability of the drone location approximation for routing dependent on the perusing of its odometer is given in Figure. 5 as follows:

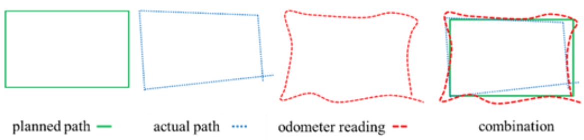

Figure 5.The navigation constraint of the AR. Drone

The direction tracking or optical stream which delivers very exact outcomes is a modest system for indoor limitation [18]. So as to accomplish the restriction of the drone utilizing this system, the drone's airborne downward-facing camera is employed. The camera catches a surge of poor-quality and small-sized pictures every now and again. A picture handling calculation and a location evaluation calculation are incorporated into the direction tracking method to separate the location information from the pictures. In addition, a drone that has UAV situating information is likewise utilized. This bolsters the evaluation of the location of the drone inside the surrounding. Figure 6 illustrates the general strides to direction or path following the procedure of UAVs.

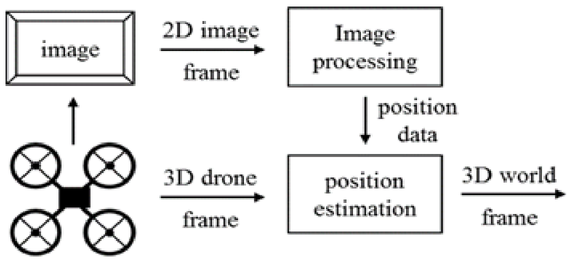

Figure 6.Schematic diagram of trajectory tracking

The calculation for evaluating location approximation relates to the projection of the world in a 3D outline by utilizing the 2D outline of the picture to facilitate the drone's 3D out-line [8]. Figure 7 demonstrates the directions and bearings of the three outlines.

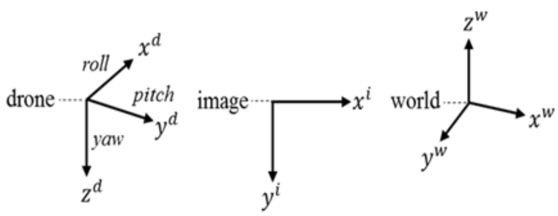

Figure 7.The coordinates of the frames

Using this orientation, a connection can be reached between a position and the world outlines as shown by Equation (1):

$$\begin{bmatrix} x_i^w \\ y_i^w \end{bmatrix} = \begin{bmatrix} x_i^w + \frac{r_i^1}{s^x} + \frac{r_i^2}{s^y} \\ y_i^w + \frac{r_i^3}{s^y} - \frac{r_i^4}{s^x} \end{bmatrix} \tag{1}$$

where $r_i^1 = z_i^w cos(\theta + yaw)(y_i^d - y_i^i)$, $r_i^2 = z_i^w sin(\theta + yaw)(x_i^d - x_i^i)$, $r_i^3 = z_i^w cos(\theta + yaw)(x_i^d - x_i^i)$, $r_i^4 = z_i^w sin(\theta + yaw)(y_i^d - y_i^i)$, s^x and s^y are the scaling proportions of a picture and θ is the angular compensate between the UAV outline and the picture outline.

Sets of poor-quality pictures are consistently handled by the picture handling calculation procedure or algorithm. The projection to the distinction between the location of 2 pictures at t and t+Δt times deduces the location data of the pictures. An underlying reference is given by the 1st picture, while the dissimilarity of the motion of the UAV between 2 pictures is given by the 2nd picture. The fundamental method of a 2D optical stream procedure is presented in the equation below.

$$P(x,y,t) = x + \Delta x, y + \Delta y, t + \Delta t \quad (2)$$

where P is a point of 2 bearings x and y in time t. Δ is the distinction between the estimation of 2 points.

Using the location estimation calculation, the vertical and horizontal movements of the drone are evaluated dependent on the distinction in the created points [8], [18]. However, this location evaluation procedure is increasingly proficient on environments with clear impressions or markings and cleaned surfaces.

C. Experimental Environment

The exploratory situations are move, reconnaissance and rescue missions in which the drone is needed to move and search for various labels in a domain that is predetermined. So as to build up a suitable testing plan and guaranteeing that critical outcomes are gotten, different practices are exhibited by the structure of the missions. A portion of the practices of the missions is very unpredictable and complicated in light of the fact that they include activities and assignments that are proactively and resolutely arranged. Making a mission which can be utilized in testing the framework with a less number of preliminaries is a constraint in testing case. Along these lines, regardless of the equipment requirements, the mission can be effectively done by the framework.

The missions are explicitly custom-made for testing inside an indoor field of 30 x 25 x 20 meters (m) measurements. The field which is encompassed by dividers on 4 sides additionally has 4 columns and a shut rooftop. A top perspective on the testing field is shown in Figure 8.

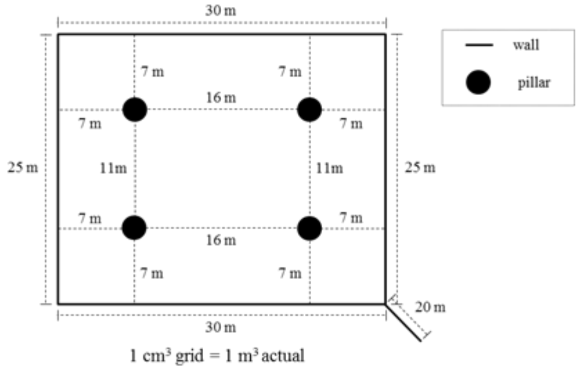

Figure 8.The blueprint of the testing arena

IV. The Assessment Model

Using Performance Visualized Assessment (PVA) for performance-based assessment gives a global perspective on the DAAD system execution. This archetype or model can be utilized in finding out the ability of the DAAD system when carrying out the dance move, surveillance and search missions inside uniquely changing conditions. The PVA centers on picturing and assessing the reaction of the system inside the surrounding by following the motion of the UAV drone. The reason for envisioning the reaction of the framework inside the surrounding is to reveal any irregularity/non-conformant between the expected execution and real execution. Essentially, the PVA is comprised of Visualized Mission Grid (VMG) map and a Chi-Square Inference (CSI) algorithm. A Chi-square and direction tracking calculations are controlled by the CSI algorithm. The area-explicit information of the field, including case or condition, is controlled by the VMG map. The field information is the trajectory needed by the drone and the positions of the items inside the field. Figure 9 shows an imagined or viewable case of the VMG map.

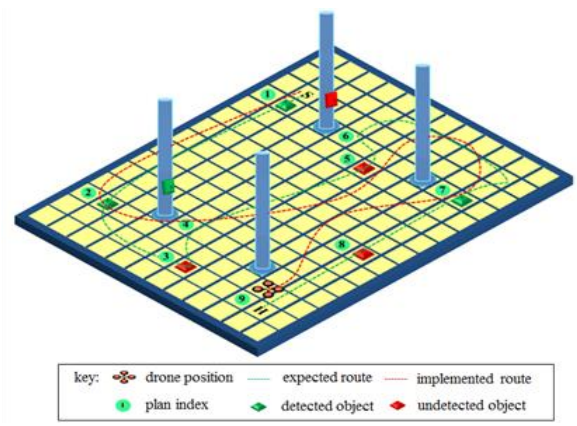

Figure 9.A 3D projection to the VMG map

The fundamental exercise carried out by the CSI is mapping out or drawing the locating and direction tracking information with the VMG map to estimate and produce the execution appraisal outcomes. In every 65 milliseconds, communication between the CSI and the VMG happens to update the drone's location inside the VMG map. The actualized trajectory of the drone is mapped out by the VMG, which likewise features the achievements accomplished by the DAAD system. The framework's conduct is approved by the CSI via a correlation of the executed trajectory with the intended trajectory and the items which have been identified including the encompassing dynamic items. The PVA is in Figure 10 below.

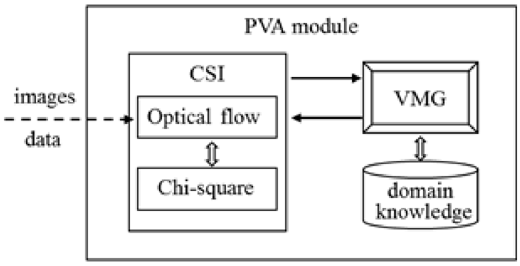

Figure 10.The PVA model

A Chi-square equation is utilized by the CSI to show the contrasts between various locations of the intended course bearings including the bearings of the travelled courses. A portrayal of the bearings and directions of the 2 is in a 2-dimensional cluster of intended, R^E, and travelled, R^T paths or courses alongside the time T. The setup of R^E is carried out after a few trials. The VMG guide of the area information is developed in the wake of acquiring the best test outcome. The Chi-square equation of precision and comparability coordinating is characterized by the accompanying expression below:

$$S_t = \sum_{i=0}^{r} \frac{(v1_i - v2_i)^2 * (t1_i - t2_i)^2}{(v1_i + v2_i) * (t1_i + t2_i)} \quad (3)$$

where S signifies the total comparability in time t, $v1$ is the bearing estimates of the intended route in the intended time $t1$ and $v2$ is the bearing estimate of the travelled or the navigated course in the travelled time $t2$ and r is the quantity of bearings that the optical stream calculation delivers altogether.

Equation (3) is utilized for X, and Y, bearings independently and the acquired outcomes are S^x and S^y, r, separately. The nature of the test which is performed is portrayed by the S value. On the off chance that a small value is controlled by S for every S^x and S^y, it indicates that the travelled course and intended course are the same, hence, superior-execution precision. Conversely, if S has a large value for every S^x and S^y, it infers that the likeness between the courses is low and thus suggesting low-execution precision.

V. IMPLEMENTATION AND RESULTS

The programming paradigm utilized for the execution of the PVA is Java, while the Java Agent DEvelopment (JADE) is the operating environment. The execution additionally includes the utilization of open source libraries. Using CSI and DAAD system metrics, the exercises of the drone are delineated for each 16ms and the VMG is refreshed. The model has a test instrument which empowers the manual perception and following of the intended exercises dependent on duplicates of VMG. Every duplicate of the VMG is depicted in a picture size of 700x500 pixels. The execution of the VMG includes the utilization of a lattice and picture preparing/handling calculations. Figure 11 shows the execution of the PVA with the VMG map inside the DAAD system.

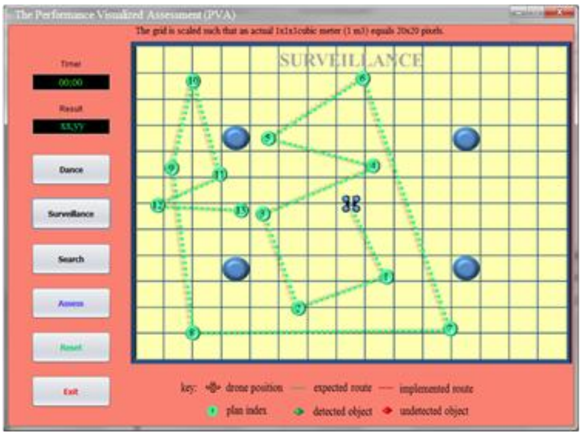

Figure 11.The GUI of the PVA model

The UAV is constrained by the DAAD system utilizing an independent agent [1], [19], [22], [23]. The DAAD system does the move/dance, observation and scan/search objectives for 4 successful trials. Here, when the test is carried out in the absence of disruption or stoppage, it is viewed as effective, and if interference or unforeseen occurrence which is outside the controllability of the framework happens amid testing, the test is seen as ineffective; unforeseen episodes can be abrupt ecological alterations or equipment breakdown. The accomplishment of the test is resolved using the human manager perception of the reported mission. The consequences of the execution precision of the DAAD system as indicated by the PVA are contained in Table 1.

Table 1. Results of performance assessment

No.	test	time	S_t^x	S_t^y	accuracy
1	dance	2.01	0.4079	0.3070	0.1252
2	dance	2.14	0.4768	0.5147	0.2454
3	dance	2.07	0.4310	0.6115	0.2636
4	dance	2.03	0.3896	0.2945	0.1147
5	surveillance	3.19	1.2398	1.4411	1.7867
6	surveillance	3.10	1.0130	0.8247	0.8355
7	surveillance	3.13	1.1207	1.7123	1.9190
8	surveillance	3.11	1.0605	0.8597	0.9117
9	search	4.05	0.8158	0.6141	0.5009
10	search	4.00	0.9537	1.0294	0.9817
11	search	4.22	0.8621	1.2231	1.0544
12	search	4.03	0.7793	0.5891	0.4590

In light of the estimation of the separation between the intended course and the travelled course, the execution is precise, with medium to the high likeness between the two courses or paths. The consequence of the dance objective test demonstrates the most precision execution generally proceeded by search and surveillance missions. The execution of the framework in the 3 objectives is evaluated and envisioned by the PVA. The direction map of the VMG to the drone motion for the 4 trials of the 3 objectives or missions is depicted in Figure 12.

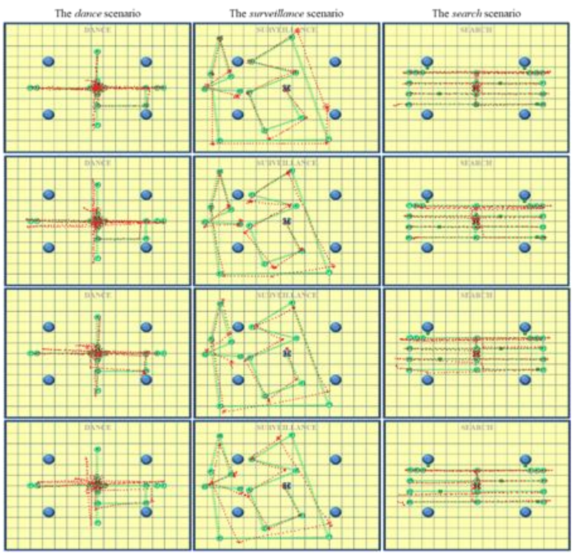

Figure 12.The VMG results from o the three missions

The most precise execution of the moving objects is in the 4th trial which is 0.1147, the most precise execution of the reconnaissance mission is in the 2nd trial which is 0.8355, and the most accurate execution of the search objective is in the 4th trial with a value of 0.4590. The mean time for move objective fulfilment is 2.06 minutes, 3.13 minutes for the reconnaissance is and 4.08 minutes for search. Figure 13 demonstrates the connection or relationship between time and precision of the trials.

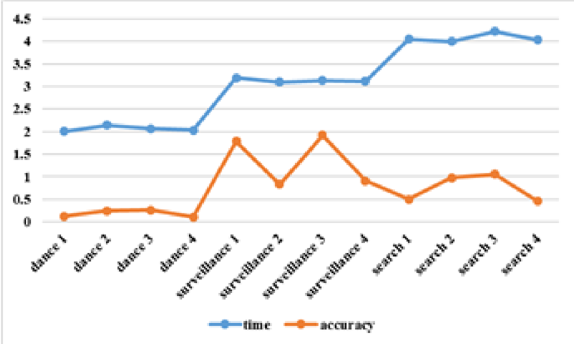

Figure 13.The relationship between time and accuracy

In view of Table 1 and Figure 13, discoveries of the tests demonstrated that in the 3 objectives for the 4 endeavours that were fruitful, the execution of the DAAD system is sufficient and reliable. Objectively, the execution of the DAAD amid the usage of the 3 missions of dance, surveillance and search objectives, the UAV system's execution is stable, persistent and precise. At the point when the human perception is contrasted with the execution of the drone and VMG outcomes, it very well may be inferred that the PVA is an auspicious method that can be utilized in the appraisal of the nature of mobility of autonomous UAV frameworks in indoor environments that are enclosed. Besides, the framework can be back-fed with the appraisal information in order to improve the execution of the frameworks. Some conceivable new study commitments based on this work such as; advance innovations of insects' or birds' standard or criterion and conduct setup absorption and investigation as in [18]-[20] by utilizing autonomous drones of multi-agent frameworks.

VI. Conclusion

In this research, a Performance Visualized Assessment (PVA) is suggested for the evaluation of the execution nature of the independent quadcopter UAV or drone UAV framework in an indoor surrounding. The PVA is comprised of a Visualized Mission Grid (VMG) guide and Chi-square Inference unit; an envisioned direction following and restriction of the UAV objectives is performed by the planned prototype. Also, an all-encompassing perspective on the UAV route direction and conduct when performing move or dance operation, observation and search are obtainable using the PVA. The consequences or outcomes of the trial reveal that the needed metrics for an exhaustive appraisal are limited by the PVA usage. It likewise lessens the remaining task at hand of a human administrator who is observing the execution of the framework. In view of the outcomes of missions carried out, are done with high precision. Later on, the UAV framework ought to be tried in a genuine mission and under various situations.

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