International Journal of Engineering Research and Reviews ISSN 2348-697X (Online)
Vol. 13, Issue 4, pp: (38-54), Month: October - December 2025, Available at: www.researchpublish.com

Review on SUAV targets positioning and tracking with RTK GPS systems for LOS maintenance

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DOI: https://doi.org/10.5281/zenodo.17878900
Published Date: 10-December-2025

Abstract: **The use of Small Unmanned Aerial Vehicle (SUAV's) is rapidly increasing in civilian and military applications, but their cost, accessibility and easy usage make them potential tools for malicious activities. This review presents a comprehensive analysis of current SUAV detection and classification techniques. The SUAV detection methods include Radar Based Sensing, RF signal analysis, Acoustic signatures and Vision based systems. Findings show that single-sensor methods are insufficient, while hybrid approaches combining micro-Doppler, RF, and acoustic signatures offer higher detection accuracy. For precise SUAV navigation, this review discusses RTK GPS technology which uses carrier phase measurements and Integer ambiguity resolution by LAMBDA method for sub-centimetre accuracy. This paper also discusses IMU sensor integration with GPS sensor to provide high accuracy and real time positioning and navigation. The study also analyses Line of Sight (LOS) alignment strategies for air-to-ground and air-to-air communication, comparing gimbal-based alignment with monopulse tracking and FSOC based approaches. While gimbal mechanisms are reliable but slow, monopulse and EKF-based methods provide faster and more precise alignment. Overall, effective SUAV surveillance requires multi-sensor integration, advanced signal processing, and robust communication links. Future improvements in AI-driven fusion, swarm-based detection, GNSS alternatives, and autonomous FSO alignment can significantly enhance system reliability and performance.**

Keywords: **SUAV, Micro-Doppler, RTK GPS, NMEA, RTCM, LoRa, NTRIP.**

I. INTRODUCTION

Small Unmanned Aerial Vehicles have rapidly become popular technology across civilian and defence sector. Because of their light weight structure, ease of deployment, affordability and accessibility they are suitable for a wide range of applications such as precision farming, traffic and environmental monitoring, disaster response, surveillance etc. However, with great power comes great responsibility, but these advantages can be exploited for malicious purposes like illegal surveillance, smuggling operations, weaponised drone attacks etc. Thus, this paper highlights the urgent need for effective SUAV detection and classification techniques. Fig. 1 highlights the illegal activities that can be done by SUAV's [1].

Accurate Navigation and Positioning is an important aspect in Military and Civil applications of SUAV's. Standard GPS services provide meter level accuracy which becomes insufficient in critical tasks. Hence there is a need of a precise system which can provide sub-centimetre accuracy. To address this limitation RTK (Real Time Kinematic) GPS is used, it provides us high precision positioning using carrier phase measurements and real time corrections from fixed base station. To achieve reliable and smooth navigation RTK is paired with IMU and Kalman Filter.

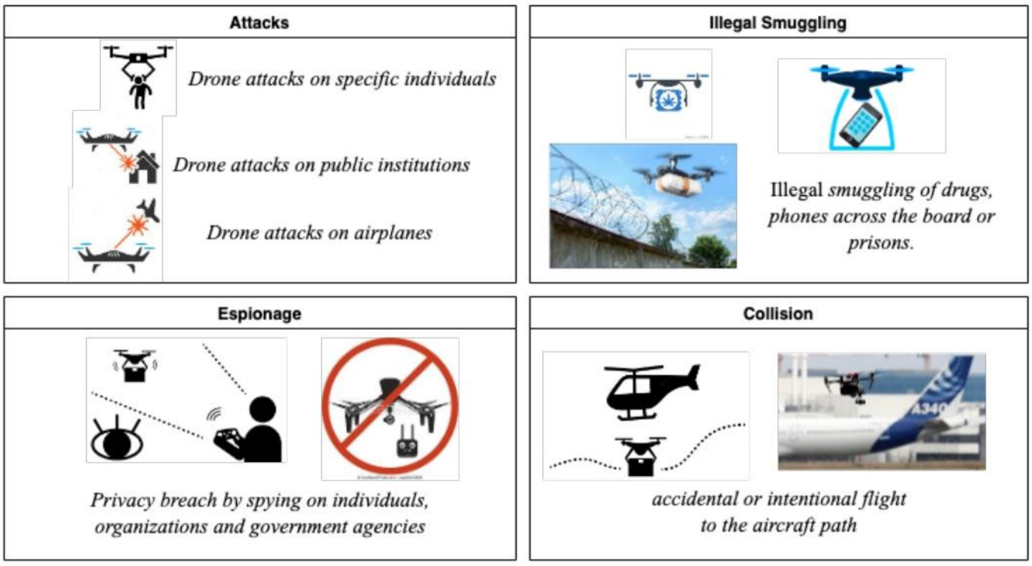

Fig. 1 Illegal use of SUAV

Additionally, this paper also discusses stable communication links for FSOC (Free Space Optical Communication). FSOC offers high speed and interference free data transfer, but it demands highly accurate LOS alignment. Various techniques for Air to Air and Air to Ground, LOS alignment techniques are discussed.

This report provides a comprehensive review of current strategies and technologies for SUAV detection and classification, high precision positioning and navigation using RTK GPS and LOS alignment techniques in SUAV systems. The aim is to clearly explain how different types of sensors, smart filtering algorithms, and strong communication systems work together to build SUAV monitoring solutions that are accurate, secure, and dependable for both civilian and defence use.

A. Key Literature Addressing Radar and FSO:

Recent literature reflects a wide and diverse set of advancements across radar sensing[129, 131], signal processing, and free-space optical communication. Work on photonic radar architectures has explored improved opto-electronic oscillator designs [102], while subsurface-scanning systems have benefited from SFCW-based GPR developments [103, 114] and enhanced clutter-suppression techniques for foliage-penetrating radar imaging [104]. Research efforts have also introduced digital architectures for real-time time–frequency imaging [105] and comprehensive reviews capturing the evolution of modern remote-sensing radar technologies [106, 116]. In the signal-processing domain, contributions include improved micro-Doppler classification through tuned R-PCA+SVM models [107], simplified receiver designs for OTFS-based SAR [108], interference-resilient OTFS waveform configurations [119], and empirical-wavelet–based approaches for posture and cadence-frequency imaging [109]. Additional progress has been demonstrated through X-band and C-band FMCW radar designs [110, 115, 128, 135], feature extraction methods for intrapulse LPI waveforms [111], CW-radar data-acquisition systems [112, 127], and UWB-based human-presence detection solutions [113].

Parallel developments in optical wireless communication highlight intelligent beam-steering approaches using fuzzy-logic controllers [117], OFDM-based radar system implementations [118], and detailed reviews on FSO-link security and modern fibreless-communication trends [120]. Surveys on acquisition, tracking, and pointing (ATP) mechanisms and beam-profile correction techniques further emphasize system-level challenges in FSO links [123, 130].

Foundational research also addresses atmospheric turbulence, proposing neural-based beam-wander mitigation [124, 125], turbulence-induced fading compensation [126], season-wise attenuation modeling [132], and weather-driven optical-attenuation formulations [133]. Complementary optical studies include adaptive beam-steering for terrestrial links [134], PID-based stabilization techniques [136], and AI-enabled approaches for improving FSO reliability [137].

Additional radar-focused contributions include detection algorithms for fast-moving FMCW targets [138], introductory frameworks for FSO communication fundamentals [139], foliage-target detection methodologies [121], and UAV-classification strategies using micro-Doppler signatures [122]. Altogether, these works collectively map the ongoing advancements shaping next-generation radar and optical-communication systems.

II. SUAV TARGET DETECTION AND CLASSIFICATION TECHNIQUES

Small Unmanned Aerial Vehicles (SUAVs) are emerging as one of the most influential technologies in today's rapidly evolving world. Their presence can be seen across a wide range of sectors, where they are revolutionizing operations and decision-making processes [1,15]. SUAVs play a vital role in both military and civilian applications, owing to the remarkable advantages they offer. Their compact size allows them to operate in confined or hard-to-reach areas, while their high durability ensures reliable performance even in challenging environmental conditions [26,30]. Because of these advantages, SUAV's are widely used for Traffic Monitoring, Agricultural Management, Forest Fire Detection, Civil Infrastructure monitoring, Disaster management, Marine environmental management and military applications [57-64].

There are various types of SUAV targets, some of the most commonly used classes of SUAV's are: - two-blade rotor, a three-short-blade rotor, a three-long-blade rotor, a quadcopter, a bionic bird and a two-blade-rotor [5]. Figure 2 shows various SUAV targets [4]

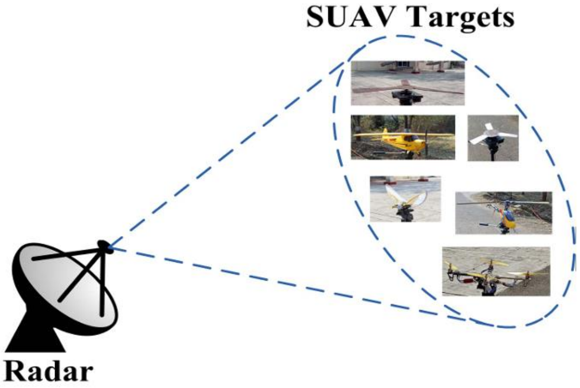

Fig. 2 Representation of SUAV targets

Due to all these benefits, they can be used for illicit purposes such as Drone Attacks (SUAV's carrying explosive and biological/chemical weapons), Illegal smuggling (Illegal Drugs, chemicals and weapons). Drone espionage (Privacy breaching). Drone collisions (Intentionally disturbing aerial appliances) [1]. That is why there is a rising demand in detection and classification techniques of SUAV's. There are multiple ways for the detection of the SUAV's, most commonly used techniques are:

A. Radar Based Detection

Radar is considered one of the most trust worthy technology used for detecting aerial vehicles as it measures their distance, direction, speed and size [13, 83, 87, 97]. It is used in military as well as civilian applications. Radar emits electromagnetic waves which gets reflected from surrounding objects. High frequency radars detect micro-doppler [17] signatures caused by small, fast and periodic motions of the small parts of the target SUAV. Examples include rotating of drone blades and flapping of wings of a bird [14].

These micro-doppler signatures [81,82,101] are different for varying SUAV's and multiple datasets are present for classification based on these specific signatures. *DIAT-μSAT* is a free access dataset consisting of 4849 micro-doppler spectrogram images of 5 SUAV's. It can be used to train various AI models to classify the SUAV's based on their specific micro-doppler signatures. When the data was collected, parameters of the SUAV targets such as rotor RPM and flapping frequency of wing was varied for higher number of data points [4]. One of the major drawbacks of Radar based detection is that birds and wildlife interfere in the echoes of SUAV's. This can lead to false alarms and operational inefficiency.

B. RF based Detection

RF based Detection is one of the most efficient ways of SUAV detection. As there are various RF based electronics components on the SUAV's like GPS receivers, radio link between controller and SUAV, live video transfer etc. Majority of the SUAV's operate within the 2.4 GHz ISM (Industrial, Scientific and Medical) frequency band. RF scanners passively detect the signals used by SUAV's and determines its location based on the strength of the detected signal [65]. Figure 3 shows a RF based detection system [1].

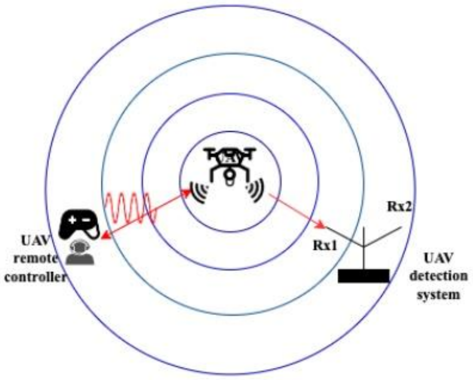

Fig. 3 RF based Detection System

In RF based SUAV detection the communication frequency spectrum is monitored and analysed. Some of the detection techniques are monitoring the frequency of data packet transmission at 2.4 GHz. If drone communication is via WiFi or other Access Point (AP) then the detection is done by monitoring the data packet length [66].

In this system there is a chance of frequency overlapping and signal jamming which causes interference which leads to the inability of our system to detect RF signals from SUAV's.

C. Acoustic based Detection

During the operation of SUAV's acoustic noise is generated by its rotor blades and motor. This noise can be detected by an array of microphones, which allows us to locate the aerial targets. Different SUAV's have their distinct acoustic noise signatures that allows us to classify them. These different signatures vary in frequency, amplitude etc [1].

There is pre-existing work on the acoustic based drone surveillance system by [68] in which the entire system consists of a spherical microphone array composed of 120 elements and a video camera. The issue with this setup is the distance to the object has to be known or calibrated manually due to its limited depth of acoustic focusing.

In [67] Zhiguo Shi *et al.* proposed a system which gives high accuracy and 24/7 availability. It uses an effective feature extraction method on which SVM is applied, to eliminate multiple paths in drone localization process they used TDOA (Time Delay of Arrival) algorithm.

In this system ambient noise, background noise and wind can create unwanted noises which can mask the acoustic signatures of target SUAV making it difficult to detect.

D. Vision based Detection

Vision based Detection uses cameras (IR, thermal, multi spectral) [8,10,27] and deep learning algorithms to detect and classify the SUAV's. It works on Optical Signature Detection like shape of the object, motion and appearance. This system is mainly used for identifying aerial objects with low RCS (Radar Cross Section) [69-70].

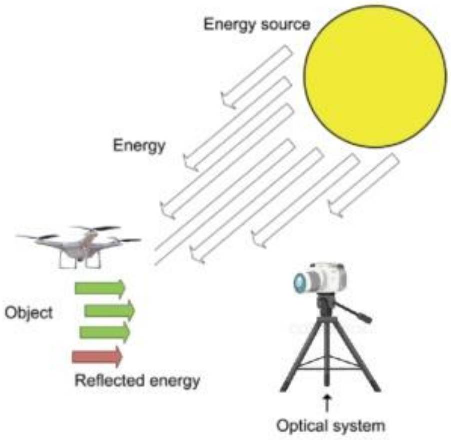

Fig. 4 Vision based Detection.

This detection technique has some limitations that leads to poor accuracy like low lighting, bad weather conditions, obstruction etc [71].

E. Sensor Fusion for detection

Detecting SUAV's is quite challenging as they are small, fast and often made with composite materials making them hard to detect using a single sensor. Hence there is a requirement to build a robust and fault proof detection system using sensor fusion [12]. Detection of SUAV's can be improved by collecting and combining data from multiple sensors. It used probabilistic data to increase detection of the SUAV's.

There are three types of fusion levels: -

1) Data level: - It includes integrating raw sensor signals like RADAR + LIDAR point clouds
2) Feature Level: - It includes integrating raw data which has been extracted by multiple sensors without any analysis or processing.
3) Decision level: - It processes the data that includes decisions or confidence scores from multiple sensors [1].

Overall, multi-modal sensing significantly enhances situational awareness by combining complementary sensor strengths, providing more reliable detection and tracking than any single sensor alone.

F. Classification of detected SUAV's

Ensuring protection against SUAV's is important for the national security. Thus, there is a need for advanced surveillance systems capable of automatically detecting and classifying low RCS aerial targets [5]. Radar Based Detection is the most popular method for detection of SUAV targets. Because it comes with various advantage such as operating in day/night, any weather condition, foliage environment, wide area coverage etc [4,6]. Deep Learning (DL) supported m-D (Micro Doppler) [33] and Machine Learning Algorithm are two primary classification techniques for low RCS aerial targets. But Machine Learning Algorithm requires manual feature extraction, which is difficult because it requires accurate listing, extracting multiple essential features, hence DL supported m-D based SUAV target classification is preferred [2,4,11].

III. RTK GPS FOR POSITIONING

Global Positioning System (GPS) is a satellite-based navigation system that provides us the coordinates and time information everywhere. GPS receiver can determine its position with the help of multiple satellites (GPS, GLONASS, Galileo, NavIC, BeiDou etc) [53] with an accuracy within a few meters, which is sufficient for general navigation but not enough for applications such as autonomous vehicles, land surveying, drone guidance etc. To overcome such limitations, Differential GPS (DGPS) is used, which improves accuracy by using a fixed base station that transmits correction data to nearby receiver. DGPS typically achieves 2–3-meter accuracy by compensating for satellite and ionospheric errors. However, this level of accuracy is not adequate for military applications. Thus, RTK (Real Time Kinematic)-GPS technology is employed which gives us sub-centimetre level accuracy [47,50,51].

A. Trilateration

Trilateration is a method which is used to determine the exact co-ordinates of any point on earth by measuring the distances from minimum 4 reference points and is thus useful in GNSS system.

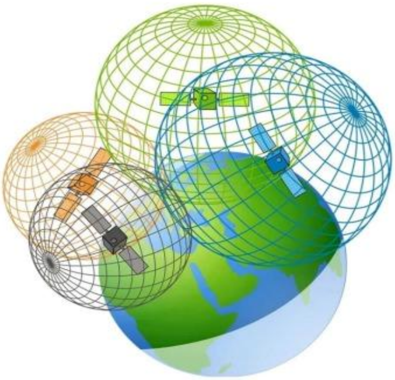

Fig. 5 Trilateration Methodology

If we generate an imaginary sphere around the satellite with radius equal to the distance between the satellite and the receiver, the intersection of these 4 spheres determines the precise location of the receiver. The GPS receiver quartz clocks are synchronized with atomic clock present in each satellite. Satellite sends an RF signal, which contains information about its origin time from the satellite. Then the receiver collects this signal and calculates its distance from the satellite by measuring the time difference between transmission and reception of the signal. DGPS is an enhanced version of GPS which uses a base station and a receiver to eliminate satellite and atmospheric errors. The base station is setup at a known location and it transmits correction data to the receiver via a Network or Radio link. This increases the accuracy of the GPS receiver.

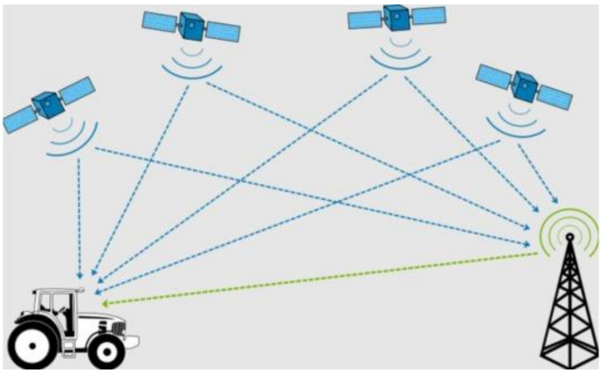

Fig. 6 DGPS Methodology

This enhancement in precision of location by DGPS makes it useful for applications like, marine navigation, land surveying, autonomous vehicle guidance systems etc. To overcome the drawbacks of Differential GPS, RTK-GPS technology is employed in military applications.

B. RTK (Real Time Kinematic)-GPS

In RTK-GPS Sinusoidal Carrier Waves play a crucial role in achieving centimetre level accuracy. The signal received by the RTK-GPS receiver is a Pseudo-Random Code modulated on a sinusoidal carrier wave, this code consists of information of approximate position with meter level accuracy. The high frequency sinusoidal carrier allows much finer distance measurement between satellite and the rover. The carrier wave frequency (1575.42 MHz, λ= 19cm) belongs to L-band frequency spectrum. RTK-GPS calculates its accurate distance with the given formula:

$$D = \lambda(N + \phi)$$

Where, D is the Distance between satellite and receiver, N is the total number of sinusoidal cycles, Φ is the fractional sine wave and λ is the wavelength of the sine wave. RTK-GPS receiver compares the phase (ϕ) of sinusoidal carrier wave received from the satellite with a wave of same frequency generated by its local oscillator (LO) [25]. This allows it to determine the fraction of the wavelength of the carrier wave [52]. Here, the total number of sinusoidal cycles are unknown and this creates Integer Ambiguity error which can be solved by using LAMBDA method. It is a mathematical model which applies integer transformation operations to the ambiguity vectors, thus reducing the correlations between different measurements. LAMBDA method uses different measurements from DGPS system to create multiple datasets which increases the accuracy of number of sinusoidal cycles [7,48].

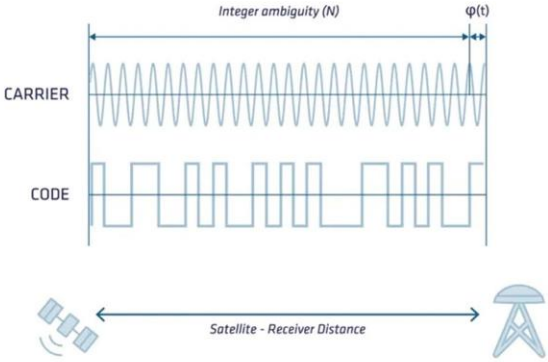

Fig. 7 Sinusoidal Carrier Phase Wave

Once the integer ambiguity is resolved, the system transitions from Float (Temporary Fix) to Fixed RTK solution providing us with sub-centimetre level accuracy. This makes RTK-GPS useful in certain applications requiring high precision such as, drone trajectory mapping, autonomous vehicle positioning and land surveying.

NMEA (National Marine Electronics Association) and RTCM (Radio Technical Commission for Maritime services) are two main data communication standards used in GNSS systems. NMEA is a standard format for transmitting GPS data in the form of ASCII text sentences like “$GPGGA”, “$GPRMC”, “GPGSV” which contains information like, Latitude, Longitude, Altitude, Time and Satellite Status. These messages are widely used in GPS receivers and external devices (Microcontrollers) for communication, which allows these systems to read real time data in a simple and human readable form. Whereas RTCM is a binary communication protocol specifically designed for transmitting correction data which used in high accuracy application systems such as RTK-GPS. RTCM messages are sent from the base station to the rover, which eliminates the satellite and atmospheric errors thereby increasing rover accuracy.

RTK-GPS has multiple civil as well as military applications such as, Land Surveying, Bridge mapping, Town planning, Robust Navigation for UAV’s, monitoring challenging environmental conditions, high yield agricultural practises, Measuring Vehicle Attitude and various Military applications [9, 34-46, 49].

In summary, RTK-enabled GNSS provides centimetre-level accuracy critical for SUAV navigation, though it must be supported by fallback systems to handle signal degradation or outages

C. Communication between Base Station and the Receiver

To transmit the correction data from the base station to the rover module we require a wireless communication link between them. Some of the most frequently used communication methods for RTK GPS are LORA and NTRIP [20, 21, 23, 24].

LoRa (Long Range): - LoRa is a low power, long range wireless communication technology. In RTK GPS system it is used to transmit the RTCM correction data form base station to the receiver without internet. It is majorly used in areas with less or no network availability.

NTRIP (Network Transport of RTCM via Internet Protocol): - It is the standard protocol used to transmit RTCM from Base station to the receiver via internet. NTRIP protocol has three layers which includes Client(rover), Server (base station) and the Caster (broker/gateway).

IV. DEAD RECKONING USING IMU INTEGRATION

Dead Reckoning is a navigation method that helps us in situations where GPS signal becomes weak. In such scenarios we don’t get satellite data and thus the system estimates the current position with the help of previous position, speed, motion and direction data collected from the IMU. The GNSS receiver gives current positional coordinates but when the signal is weak or lost it relies on IMU sensors [56] which consists of accelerometer, gyroscope and magnetometer, these sensors keep tracking motion and continues updating position. This allows smooth navigation without interruption.

The Kalman Filter is an algorithm which is used in RTK GPS for combining data from GNSS sensor and IMU [75-77], providing more accurate positioning [18, 19]. This entire system prevents position loss, maintains smooth trajectory and hence makes RTK system robust in real time applications [78, 79].

KALMAN Filter Working

In [75-77] we can see the application of integration of the extended Kalman filter, IMU sensor and the GPS sensor. The IMU has higher frequency data update than the GPS sensor but it does not have positional accuracy and is prone to drift. GPS sensor has higher positional accuracy than the IMU sensor, but low data updating rate.

We get advantages of both these methods collectively by implementing a Kalman Filter that estimates accurate position by estimating true value from noisy measurements.

To understand it more clearly let’s consider an example of a drone using integrated GPS+IMU sensors for navigation. In the first step, i.e. The Prediction Step the GPS provides the drones current position and the IMU sensor provides the estimated position for the next time interval (1 sec). In the second step, i.e. The Update Step we get the accurate position from GPS (Higher accuracy can be obtained from RTK GPS) after a certain time interval (1 sec). Hence, we now have 2 estimated positions of our drone’s current location. In the third step, i.e. Kalman Gain, the algorithm estimates uncertainty of both the sensors, then it calculates Kalman gain for each sensor which tells us which sensor to trust more. Finally, we obtain a high precise position by fusion of GPS and IMU sensor data with Kalman Filter.

V. TECHNIQUES FOR LOS ALIGNMENT

Reliable Line of Sight alignment is an important aspect in Free Space Optical Communication (FSOC) [80,85,86,88,89]. As the transmitter and the receiver move continuously on ground, in air and space, the pointing accuracy and the tracking bandwidth needs to be stabilized [91,92,96,98]. This stabilization and alignment is important to ensure high data transfer rate, reducing Bit Error Rate (BER) and preventing link failure.

Major advantages of FSO over RF communication are high data transfer rate, security and resistance to interference [71, 90, 94]. FSOC is used for high-speed, long-distance wireless data links in areas where laying fiber is difficult, such as remote or disaster-hit regions. It is widely used in satellite communication, inter-UAV links, last-mile connectivity, and secure military communication due to its high bandwidth and low interference. [100]

Techniques for LOS alignment between

a) Air to Ground

AG FSOC links are widely used transfer data (images/videos) from SUAV's to ground with capabilities such as more security and high data rate[93]. Because the SUAV's are moving continuously, maintaining an accurate LOS link requires robust pointing and tracking mechanism. Common AG LOS alignment techniques are: -

Gimbal based tracking physically steers its optical beam using servo motors in these cases [16, 28, 54, 94, 99]. Radar based detection is often used for locating SUAV's initially and hence pointing and directing the beam towards the SUAV. To improve the tracking accuracy the concept called multiple sensor fusion is integrated which includes: -

- GPS coordinates of SUAV [22, 31]
- IMU measurements
- Extended Kalman Filter (EKF)

This combination of sensors enhances system stability especially in long ranges of operations.

Monopulse based tracking technique estimates angular deviation by continuously measuring it from closely spaced array of antennas. This system forms sum and difference channels enabling real time calculation of target detection. It is highly resistant to noise and suitable in operations where signal fluctuation is a major issue [72, 73, 84].

b) Air to Air

Establishing FSOC link in AA system is complex because of the target noise and the receiver's own motion [3, 29]. To establish good communication link, we need to consider relative position, relative velocity and target acceleration [55]. To establish and maintain LOS, AA systems require precise estimation of relative position, velocity and orientation.

Relative Position estimation

In this GPS is used for determining each SUAV's position, but if higher accuracy is required, especially during tight beam alignment, RTK GPS is used to minimize positional error to centimeter level.

Relative Velocity and Attitude estimation

IMU (Gyroscopes and accelerometers) provides accurate measurements for predicting motion dynamics. Fusing IMU with GPS improves robustness during GPS droputs.

EKF based state estimation

Vinod K *et al.* [74] used 9 states extended Kalman filter (EKF) to estimate the state vector using the noisy radar measurements and own-ship inertial navigation system (INS). The EKF offered improved tracking accuracy and dynamic response, for getting stable AA FSOC, even under harsh conditions.

Existing AA and AG LOS alignment techniques still face major challenges such as different atmospheric conditions, temporary loss of GPS signal and vibration induced jitter. These issues make it difficult for dynamic operations in unpredictable environment. Future work should explore machine learning based prediction models that will help us to detect motion before it happens.

VI. CONCLUSION

Small unmanned aerial vehicles (SUAV's) are becoming popular for civilian and military applications, due to their low cost, ease of operation and high availability they can be used for malicious activities. Hence there is a need of surveillance systems that detect and classify SUAV's. This review presents a detailed analysis of multiple SUAV detection techniques such as Radar based detection, RF based signal analysis, acoustic sensing, vision-based systems and sensor fusion methods. This survey concludes that using a single sensor for SUAV detection is insufficient and hence hybrid systems which combines m-D (Micro Doppler), acoustic and RF spectral signatures provides more accuracy in aerial target detection.

Accuracy in navigation and positioning of SUAV's is important for robust surveillance systems. This review emphasizes on methodology of RTK GPS technology. It shows the role of carrier-phase measurements, integer ambiguity resolution, and the LAMBDA method in RTK GPS for achieving centimetre level accuracy. Since GPS systems are susceptible to outages and signal losses, IMU based dead reckoning and Kalman filter fusion were discussed for reliable for accurate SUAV positioning.

The paper also analysed Line of Sight (LOS) alignment strategies for air-to-ground and air-to-air communication. It discusses the advantages of FSOC over RF communication and methods of aligning such LOS in AA and AG systems. AG systems use Gimbal based alignment using data from GPS and IMU sensors placed on UAV whereas Mono-pulse method uses an array of antennas that detect reflected waves from target to accurately estimate range, azimuth and elevation angles. Although gimbal-based methods are mature and widely used, their mechanical nature limits response speed for highly dynamic UAV trajectories. In contrast, mono-pulse tracking and EKF-based fusion offer faster and more precise LOS estimation, but require high-quality sensors and powerful onboard computation.

Overall, this review highlights that effective SUAV detection and navigation require multi-sensor integration, advanced signal processing, and robust communication architectures. Future research should explore AI-driven sensor fusion models, swarm-based cooperative detection, resilient GNSS alternatives, and autonomous alignment systems for long-range FSO links. With these advancements, next-generation SUAV detection systems can achieve higher accuracy, reliability, and operational resilience across both civilian and defence scenarios.

REFERENCES

[1] Seidaliyeva, Ulzhalgas, et al. "Advances and challenges in drone detection and classification techniques: A state-of-the-art review." Sensors 24.1 (2023): 125. https://doi.org/10.3390/s24010125

[2] Dinesh, K. B., and AA Bazil Raj. "Drone detection and classification using deep learning." IEEE Inter., Conf.," Intelligent computing and control systems (ICICCS)". 2020. https://doi.org/10.1109/ICICCS48265.2020.9121150

[3] Khan, Mahmudur, and Murat Yuksel. "Autonomous alignment of free-space-optical links between UAVs." Proceedings of the 2nd international workshop on hot topics in wireless. 2015. https://doi.org/10.1145/2799650.2799656

[4] Kumawat, Harish Chandra, Mainak Chakraborty, and A. Arockia Bazil Raj. "DIAT-RadSATNet—A novel lightweight DCNN architecture for micro-Doppler-based small unmanned aerial vehicle (SUAV) targets' detection and classification." IEEE Transactions on Instrumentation and Measurement 71 (2022): 1-11. https://doi.org/10.1109/TIM.2022.3188050

[5] Kumawat, Harish C., et al. "DIAT-μSAT: Small aerial targets' micro-Doppler signatures and their classification using CNN." IEEE Geoscience and Remote Sensing Letters 19 (2021): 1-5. https://doi.org/10.1109/LGRS.2021.3102039

[6] Upadhyay, Madhusudan, Somanchi Krishna Murthy, and AA Bazil Raj. "Intelligent System for Real time detection and classification of Aerial Targets using CNN." *2021 5th International Conference on Intelligent Computing and Control Systems (ICICCS)*. IEEE, 2021.https://doi.org/10.1109/ICICCS51141.2021.9432136

[7] Takasu, Tomoji, and Akio Yasuda. "Development of the low-cost RTK-GPS receiver with an open source program package RTKLIB." International symposium on GPS/GNSS. Vol. 1. Seogwipo-si, Republic of Korea: International Convention Center Jeju Korea, 2009. https://gpspp.sakura.ne.jp/paper2005/isgps_2009_rklib.pdf

[8] Hao, Jingxuan, et al. "A review of target tracking algorithm based on UAV." 2018 IEEE International Conference on Cyborg and Bionic Systems (CBS). IEEE, 2018. https://doi.org/10.1109/CBS.2018.8612263

[9] Lee, In-Su, and Linlin Ge. "The performance of RTK-GPS for surveying under challenging environmental conditions." Earth, planets and space 58.5 (2006): 515-522. https://doi.org/10.1186/BF03351948

[10] Vaishnavi, Ravi, G. Unnikrishnan, and AA Bazil Raj. "Implementation of algorithms for Point target detection and tracking in Infrared image sequences." *2019 4th International Conference on Recent Trends on Electronics, Information, Communication & Technology (RTEICT)*. IEEE, 2019. https://doi.org/10.1109/RTEICT46194.2019.9016871

[11] Bamane, Vinaya, et al. "A Review on AI Based Target Classification Advanced Techniques." *vol* 10: 88-99. https://doi.org/10.5281/zenodo.7491584

[12] Latpate, Abhinav, et al. "A Review on Image Based classification for LSS Targets using Radar." *Int. J. Eng. Res. Rev* 10.4 (2022): 100-112. https://doi.org/10.5281/zenodo.7493827

[13] Kumawat, Harish Chandra, and Arockia Bazil Raj. "Moving target detection in foliage environment using FMCW radar." *2020 5th International Conference on Communication and Electronics Systems (ICCES)*. IEEE, 2020. https://doi.org/10.1109/ICCES48766.2020.9138095

[14] Mazumder, Joydeep, and Arockia Bazil Raj. "Detection and classification of UAV using propeller Doppler profiles for counter UAV systems." *2020 5th International Conference on Communication and Electronics Systems (ICCES)*. IEEE, 2020. https://doi.org/10.1109/ICCES48766.2020.9138077

[15] Pramod, Anjali, H. Shankaranarayanan, and A. Arockia Bazil Raj. "A precision airdrop system for cargo loads delivery applications." *2021 International Conference on System, Computation, Automation and Networking (ICSCAN)*. IEEE, 2021. https://doi.org/10.1109/ICSCAN53069.2021.9526453

[16] Raj, A. Arockia Bazil, and J. Arputha Vijay Selvi. "Lower-order adaptive beam steering system in terrestrial free space point-to-point laser communication using fine tracking sensor." *2011 International Conference on Signal Processing, Communication, Computing and Networking Technologies*. IEEE, 2011. https://doi.org/10.1109/ICSCCN.2011.6024641

[17] Akella, A. S., and A. B. Raj. "DCNN based activity classification of ornithopter using radar micro-Doppler images." In 2021 5th International Conference on Intelligent Computing and Control Systems (ICICCS) 2021 May 6 (pp. 780-784)." https://doi.org/10.1109/ICICCS51141.2021.9432228

[18] Cahyadi, Mokhamad Nur, et al. "Performance of GPS and IMU sensor fusion using unscented Kalman filter for precise i-Boat navigation in infinite wide waters." Geodesy and Geodynamics 14.3 (2023): 265-274.https://doi.org/10.1016/j.geog.2022.11.005

[19] Cahyadi, M. N., et al. "Analysis of GNSS/IMU sensor fusion at UAV quadrotor for navigation." IOP conference series: earth and environmental science. Vol. 1276. No. 1. IOP Publishing, 2023. https://doi.org/10.1088/1755-1315/1276/1/012021

[20] Syetiawan, Agung, et al. "High Accuracy Rapid Mapping Using NTRIP-RTK on Unmanned Aerial Vehicle (UAV)." 2024 IEEE International Conference on Aerospace Electronics and Remote Sensing Technology (ICARES). IEEE, 2024. https://doi.org/10.1109/ICARES64249.2024.10768010

[21] Grigorov, Ivan, et al. "Implementing a High-Precision Boat Navigation System Using Raspberry Pi with RTK and GPS Integration via ESP32." 2024 International Conference Automatics and Informatics (ICAI). IEEE, 2024. https://doi.org/10.1109/ICAI63388.2024.10851704

[22] Epple, Bernhard. "Using a GPS-aided inertial system for coarse-pointing of free-space optical communication terminals." Free-Space Laser Communications VI. Vol. 6304. SPIE, 2006. https://doi.org/10.1117/12.680502

[23] Gamagedara, Kanishke, Taeyoung Lee, and Murray R. Snyder. "Real-time kinematics gps based telemetry system for airborne measurements of ship air wake." AIAA Scitech 2019 Forum. 2019. https://doi.org/10.2514/6.2019-2377

[24] Zhao, Biquan, et al. "assessing GPS sensor accuracy using real-time kinematic device for livestock tracking." Journal of Animal Science 102 (2024): skae253. https://doi.org/10.1093/jas/skae253

[25] Xie, Yang, et al. "Carrier phase tracking and positioning algorithm with additional system parameters based on Orbcomm signals." GPS Solutions 28.4 (2024): 184. https://doi.org/10.1007/s10291-024-01721-8

[26] Yoon, Jihwan, Ming Feng, and Hao Xu. "Skyshield: Detecting and tracking multiple small unmanned aerial vehicle in real-time." AIAA Scitech 2019 Forum. 2019. https://doi.org/10.2514/6.2019-2072

[27] Zhang, Yu, et al. "Design and training of deep CNN-based fast detector in infrared SUAV surveillance system." IEEE Access 7 (2019): 137365-137377. https://doi.org/10.1109/ACCESS.2019.2941509

[28] Miller, Rick, Greg Mooty, and J. M. Hilkert. "Gimbal system configurations and line-of-sight control techniques for small UAV applications." Airborne intelligence, surveillance, reconnaissance (ISR) systems and applications X. Vol. 8713. SPIE, 2013. https://doi.org/10.1117/12.2015777

[29] Kaymak, Yagiz, et al. "A survey on acquisition, tracking, and pointing mechanisms for mobile free-space optical communications." IEEE communications surveys & tutorials 20.2 (2018): 1104-1123.. https://doi.org/10.1109/COMST.2018.2804323

[30] Liu, Xuancen, et al. "Real-time visual tracking of moving targets using a low-cost unmanned aerial vehicle with a 3-axis stabilized gimbal system." Applied Sciences 10.15 (2020): 5064. https://doi.org/10.3390/app10155064

[31] Saw, Wee-Leong, Hazem H. Refai, and James J. Sluss Jr. "Free space optical alignment system using GPS." Free-Space Laser Communication Technologies XVII. Vol. 5712. SPIE, 2005. https://doi.org/10.1117/12.591226

[32] Cheung, Kar-Ming, and Charles Lee. "A trilateration scheme for relative positioning." 2017 IEEE Aerospace Conference. IEEE, 2017. https://doi.org/10.1109/AERO.2017.7943800

[33] Hasan, Mohammad M., Mainak Chakraborty, and A. Arockia Bazil Raj. "A hyper-parameters-tuned R-PCA+ SVM technique for sUAV targets classification using the range-/micro-Doppler signatures." IEEE Transactions on Radar Systems 1 (2023): 623-631. https://doi.org/10.1109/TRS.2023.3322607

[34] Pirti, Atınç. "Evaluating the repeatability of RTK GPS." *Survey Review* 43.320 (2011): 177-186. https://doi.org/10.1179/003962611X12894696204984

[35] Xu, Hongtao. "Application of GPS-RTK technology in the land change survey." *Procedia Engineering* 29 (2012): 3454-3459.https://doi.org/10.1016/j.proeng.2012.01.511

[36] Lin, Lao-Sheng. "Application of GPS RTK and total station system on dynamic monitoring land use." *Proceedings of the ISPRS Congress Istanbul, Turkey*. 2004. https://www.isprs.org/proceedings/XXXV/congress/comm7/papers/59.pdf

[37] Bouvet, Denis, and Gaetan Garcia. "Improving the accuracy of dynamic localization systems using RTK GPS by identifying the GPS latency." *Proceedings 2000 ICRA. Millennium Conference. IEEE International Conference on Robotics and Automation. Symposia Proceedings (Cat. No. 00CH37065)*. Vol. 3. IEEE, 2000. https://doi.org/10.1109/ROBOT.2000.846408

[38] Gryte, Kristoffer, et al. "Robust navigation of UAV using inertial sensors aided by UWB and RTK GPS." *AIAA guidance, navigation, and control conference*. 2017. https://doi.org/10.2514/6.2017-1035

[39] Ong, Richard B., Mark G. Petovello, and Gérard Lachapelle. "Assessment of GPS/GLONASS RTK under various operational conditions." *Proceedings of the 22nd International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS 2009)*. 2009. https://www.researchgate.net/profile/Gerard-Lachapelle2/publication/268357703_Assessment_of_GPSGLONASS_RTK_under_various_operational_conditions/links/55a548d808ae00cf99c9591b/Assessment-of-GPS-GLONASS-RTK-under-various-operational-conditions.pdf

[40] Lee, In-Su, and Linlin Ge. "The performance of RTK-GPS for surveying under challenging environmental conditions." *Earth, planets and space* 58.5 (2006): 515-522. https://doi.org/10.1186/BF03351948

[41] Um, Inseop, et al. "Configuring RTK-GPS architecture for system redundancy in multi-drone operations." *IEEE Access* 8 (2020): 76228-76242. https://doi.org/10.1109/ACCESS.2020.2989276

[42] Edwards, S. J., et al. "An examination of network RTK GPS services in Great Britain." *Survey Review* 42.316 (2010): 107-121. https://doi.org/10.1179/003962610X12572516251529

[43] Ortiz, Brenda V., et al. "Evaluation of agronomic and economic benefits of using RTK-GPS-based auto-steer guidance systems for peanut digging operations." Precision agriculture 14.4 (2013): 357-375.https://doi.org/10.1007/s11119-012-9297-y

[44] Morales, Yoichi, and Takashi Tsubouchi. "DGPS, RTK-GPS and StarFire DGPS performance under tree shading environments." 2007 IEEE International Conference on Integration Technology. IEEE, 2007. https://doi.org/10.1109/ICITECHNOLOGY.2007.4290370

[45] Elnabwy, Mohamed T., Mosbeh R. Kaloop, and Emad Elbeltagi. "Talkha steel highway bridge monitoring and movement identification using RTK-GPS technique." Measurement 46.10 (2013): 4282-4292. https://doi.org/10.1016/j.measurement.2013.08.014

[46] Pirti, Atınç. "Performance analysis of the real time kinematic GPS (RTK GPS) technique in a highway project (stake-out)." Survey Review 39.303 (2007): 43-53. https://doi.org/10.1179/003962607X164989

[47] Takasu, Tomoji, and Akio Yasuda. "Evaluation of RTK-GPS performance with low-cost single-frequency GPS receivers." Proceedings of international symposium on GPS/GNSS. 2008 https://gpspp.sakura.ne.jp/paper2005/ISGPSGNSS2008_abst.pdf

[48] Hu, G. R., et al. "Development and assessment of GPS virtual reference stations for RTK positioning." Journal of Geodesy 77.5 (2003): 292-302. https://doi.org/10.1007/s00190-003-0327-4

[49] Fukuba, Hitoshi, et al. "Measurement of vehicle attitude with RTK-GPS for analyzing the vehicle motion behavior." JSAE review 24.3 (2003): 313-320. https://doi.org/10.1016/S0389-4304(03)00036-5

[50] Skoglund, Martin, et al. "Static and dynamic performance evaluation of low-cost RTK GPS receivers." 2016 IEEE Intelligent Vehicles Symposium (IV). IEEE, 2016. https://doi.org/10.1109/IVS.2016.7535357

[51] Matias, Bruno, et al. "High-accuracy low-cost RTK-GPS for an unmannned surface vehicle." OCEANS 2015-Genova. IEEE, 2015. https://doi.org/10.1109/OCEANS-Genova.2015.7271673

[52] Zhang, Tisheng, et al. "Carrier-phase-based initial heading alignment for land vehicular MEMS GNSS/INS navigation system." IEEE Transactions on Instrumentation and Measurement 71 (2022): 1-13.https://doi.org/10.1109/TIM.2022.3208646

[53] Pan, Lin, et al. "Assessment of IRNSS-only data processing: availability, single-frequency SPP and short-baseline RTK." Remote Sensing 14.10 (2022): 2462. https://doi.org/10.3390/rs14102462

[54] Miller, Rick, Greg Mooty, and J. M. Hilkert. "Gimbal system configurations and line-of-sight control techniques for small UAV applications." Airborne intelligence, surveillance, reconnaissance (ISR) systems and applications X. Vol. 8713. SPIE, 2013. https://doi.org/10.1117/12.2015777

[55] Dhruv, and Hemani Kaushal. "A Review of Pointing Modules and Gimbal Systems for Free-Space Optical Communication in Non-Terrestrial Platforms." Photonics. Vol. 12. No. 10. MDPI, 2025. https://doi.org/10.3390/photonics12101001

[56] Gryte, Kristoffer, et al. "Robust navigation of UAV using inertial sensors aided by UWB and RTK GPS." AIAA guidance, navigation, and control conference. 2017. https://doi.org/10.2514/6.2017-1035

[57] Khan, Muhammad Asif, et al. "On the detection of unauthorized drones—Techniques and future perspectives: A review." IEEE Sensors Journal 22.12 (2022): 11439-11455. https://doi.org/10.1109/JSEN.2022.3171293

[58] Mohammed, Farhan, et al. "UAVs for smart cities: Opportunities and challenges." 2014 international conference on unmanned aircraft systems (ICUAS). IEEE, 2014. https://doi.org/10.1109/ICUAS.2014.6842265

[59] Chow, Joseph YJ. "Dynamic UAV-based traffic monitoring under uncertainty as a stochastic arc-inventory routing policy." International Journal of transportation science and technology 5.3 (2016): 167-185. https://doi.org/10.1016/j.ijtst.2016.11.002

[60] Huang, Yanbo, et al. "Development and prospect of unmanned aerial vehicle technologies for agricultural production management." International Journal of Agricultural and Biological Engineering 6.3 (2013): 1-10. https://www.ijabe.org/index.php/ijabe/article/view/900/pdf

[61] Cruz, Henry, et al. "Efficient forest fire detection index for application in unmanned aerial systems (UASs)." Sensors 16.6 (2016): 893. https://doi.org/10.3390/s16060893

[62] Ham, Youngjib, et al. "Visual monitoring of civil infrastructure systems via camera-equipped Unmanned Aerial Vehicles (UAVs): a review of related works." Visualization in Engineering 4.1 (2016): 1. https://doi.org/10.1186/s403 27-015-0029-z

[63] Erdelj, Milan, et al. "Help from the sky: Leveraging UAVs for disaster management." IEEE Pervasive Computing 16.1 (2017): 24-32. https://doi.org/10.1109/MPRV.2017.11

[64] Klemas, Victor V. "Coastal and environmental remote sensing from unmanned aerial vehicles: An overview." Journal of coastal research 31.5 (2015): 1260-1267. https://doi.org/10.2112/JCOASTRES-D-15-00005.1

[65] Al-Sa'd, Mohammad F., et al. "RF-based drone detection and identification using deep learning approaches: An initiative towards a large open-source drone database." Future Generation Computer Systems 100 (2019): 86-97. https://doi.org/10.1016/j.future.2019.05.007

[66] Basak, Sanjoy, et al. "Combined RF-based drone detection and classification." IEEE Transactions on Cognitive Communications and Networking 8.1 (2021): 111-120. https://doi.org/10.1109/TCCN.2021.3099114

[67] Shi, Zhiguo, et al. "An acoustic-based surveillance system for amateur drones detection and localization." IEEE transactions on vehicular technology 69.3 (2020): 2731-2739. https://doi.org/10.1109/TVT.2020.2964110

[68] Busset, Joël, et al. "Detection and tracking of drones using advanced acoustic cameras." Unmanned/Unattended Sensors and Sensor Networks XI; and Advanced Free-Space Optical Communication Techniques and Applications. Vol. 9647. SPIE, 2015. https://doi.org/10.1117/12.2194309

[69] Rozantsev, Artem. *Vision-based detection of aircrafts and UAVs*. Diss. EPFL, Switzerland, 2017. https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=Vision-based+detection+of+aircrafts+and+UAVs&btnG=

[70] Abdelsamad, Safa E., et al. "Vision-based support for the detection and recognition of drones with small radar cross sections." *Electronics* 12.10 (2023): 2235. https://doi.org/10.3390/electronics12102235

[71] King, Timothy I., et al. "Control system analysis for ground/air-to-air laser communications using simulation." 24th Digital Avionics Systems Conference. Vol. 1. IEEE, 2005. https://doi.org/10.1109/DASC.2005.1563301

[72] Kim, Jaesin, Jaemoon Lee, and Inkyu Lee. "Antenna tracking techniques for long range air-to-ground communication systems using a monopulse method." IEEE Access 8 (2020): 166442-166449. https://doi.org/10.1109/ACCESS.2020.3022932

[73] Harris, Alan, et al. "Alignment and tracking of a free-space optical communications link to a UAV." 24th Digital Avionics Systems Conference. Vol. 1. IEEE, 2005. https://doi.org/10.1109/DASC.2005.1563300

[74] Saini, Vinod K., and Hari B. Hablani. "Air-to-air tracking performance with inertial navigation and gimballed radar: a kinematic scenario." IFAC Proceedings Volumes 47.1 (2014): 234-241. https://doi.org/10.3182/20140313-3-IN-3024.00029

[75] Bistrovs, Vadims, and Ansis Kluga. "Combined information processing from GPS and IMU using Kalman filtering algorithm." Elektronika ir Elektrotechnika 93.5 (2009): 15-20. https://www.eejournal.ktu.lt/index.php/elt/article/view/10171

[76] Dhongade, Amol P., and M. A. Khandekar. "GPS and IMU Integration on an autonomous vehicle using Kalman filter (LabView Tool)." 2019 International Conference on Intelligent Computing and Control Systems (ICCS). IEEE, 2019. https://doi.org/10.1109/ICCS45141.2019.9065851

[77] Kaczmarek, Adrian, et al. "Experimental 2D extended Kalman filter sensor fusion for low-cost GNSS/IMU/Odometers precise positioning system." Measurement 193 (2022): 110963. https://doi.org/10.1016/j.measurement.2022.110963

[78] Toledo-Moreo, Rafael, et al. "Fusing GNSS, dead-reckoning, and enhanced maps for road vehicle lane-level navigation." *IEEE Journal of Selected Topics in Signal Processing* 3.5 (2009): 798-809. https://doi.org/10.1109/JSTSP.2009.2027803

[79] Mezentsev, Oleg, Gerard Lachapelle, and Jussi Collin. "Pedestrian dead reckoning—A solution to navigation in GPS signal degraded areas?." Geomatica 59.2 (2005): 175-182. https://doi.org/10.5623/geomat-2005-0023

[80] Raj, Arockia Bazil, and Arun K. Majumder. "Historical perspective of free space optical communications: from the early dates to today's developments." IET communications 13.16 (2019): 2405-2419. https://doi.org/10.1049/iet-com.2019.0051

[81] Kumawat, Harish C., and Arockia Bazil Raj. "Extraction of Doppler signature of micro-to-macro rotations/motions using continuous wave radar-assisted measurement system." IET Science, Measurement & Technology 14.7 (2020): 772-785. https://doi.org/10.1049/iet-smt.2018.5563

[82] Chakraborty, Mainak, et al. "DIAT-μ RadHAR (micro-Doppler signature dataset) & μ RadNet (a lightweight DCNN)—For human suspicious activity recognition." IEEE Sensors Journal 22.7 (2022): 6851-6858.. https://doi.org/10.1109/JSEN.2022.3151943

[83] U. Garg, A. A. Bazil Raj and K. P. Ray, "Cognitive Radar Assisted Target Tracking: A Study," 2018 3rd International Conference on Communication and Electronics Systems (ICCES), Coimbatore, India, 2018, pp. 427-430 https://doi.org/10.1109/CESYS.2018.8723894

[84] Raj, A. Arockia Bazil. "Mono-pulse tracking system for active free space optical communication." Optik 127.19 (2016): 7752-7761. https://doi.org/10.1016/j.ijleo.2016.05.143

[85] Raj, Arockia Bazil, and Arun K. Majumder. "Historical perspective of free space optical communications: from the early dates to today's developments." IET communications 13.16 (2019): 2405-2419. https://doi.org/10.1049/iet-com.2019.0051

[86] Raj Anthonisamy, Arockia Bazil, Padmavathi Durairaj, and Lancelot James Paul. "Performance analysis of free space optical communication in open-atmospheric turbulence conditions with beam wandering compensation control." IET Communications 10.9 (2016): 1096-1103. https://doi.org/10.1049/iet-com.2015.0717

[87] Raj, A. Arockia Bazil, et al. "Design of cognitive decision making controller for autonomous online adaptive beam steering in free space optical communication system." Wireless Personal Communications 84 (2015): 765-799. https://doi.org/10.1007/s11277-015-2660-3

[88] Garg, Upasana, AA Bazil Raj, and K. P. Ray. "Cognitive Radar Assisted Target Tracking: A Study." 2018 3rd International Conference on Communication and Electronics Systems (ICCES). IEEE, 2018. https://doi.org/10.1109/CESYS.2018.8723894

[89] Arockia Bazil Raj, A., et al. "A direct and neural controller performance study with beam wandering mitigation control in free space optical link." Optical Memory and Neural Networks 23 (2014): 111-129. https://doi.org/10.3103/S1060992X14030059

[90] Majumdar, Arun K., Zabih Ghassemlooy, and A. Arockia Bazil Raj. Principles and applications of free space optical communications. No. 78. The Institution of Engineering and Technology, 2019.

[91] ArockiaBazilRaj, A., and Ucuk Darusalam. "Performance improvement of terrestrial free-space optical communications by mitigating the focal-spot wandering." Journal of Modern optics 63.21 (2016): 2339-2347. https://doi.org/10.1080/09500340.2016.1200684

[92] Raj, A. Arockia Bazil, J. Arputha Vijaya Selvi, and S. Raghavan. "Terrestrial free space line of sight optical communication (tfslsoc) using adaptive control steering system with laser beam tracking, aligning and positioning (atp)." 2010 International Conference on Wireless Communication and Sensor Computing (ICWCSC). IEEE, 2010. https://doi.org/10.1109/ICWCSC.2010.5415900

[93] Raj, A. Arockia Bazil, and J. Arputha Vijaya Selvi. "Comparison of different models for ground-level atmospheric attenuation prediction with new models according to local weather data for FSO applications." Journal of optical communications. 36.2 (2015): 181. https://doi.org/10.1515/joc-2014-0054

[94] Raj, A. Arockia Bazil, and S. Padmavathi. "Quality metrics and reliability analysis of laser communication system." Defence Science Journal 66.2 (2016): 175-185. https://tinyurl.com/22zct4pn

[95] Raj, A. Arockia Bazil, et al. "Low cost beam steering system for FSOC to SMF coupling." IEEE-International Conference On Advances In Engineering, Science And Management (ICAESM-2012). IEEE, 2012. https://tinyurl.com/56p2csun

[96] Raj, A. Arockia Bazil, and J. Arputha Vijay Selvi. "Lower-order adaptive beam steering system in terrestrial free space point-to-point laser communication using fine tracking sensor." 2011 International Conference on Signal Processing, Communication, Computing and Networking Technologies. IEEE, 2011. https://doi.org/10.1109/ICSCCN.2011.6024641

[97] Garg, U., A. B. Raj, and K. P. Ray. "Cognitive Radar Assisted Target Tracking: A Study. In2018 3rd International Conference on Communication and Electronics Systems (ICCES) 2018 Oct 15 (pp. 427430)."https://doi.org/10.1109/CESYS.2018.8723894\

[98] A Arockia Bazil Raj (2019) "Principles and Applications of Free Space Optical Communications (Telecommunications)" The Institution of Engineering and Technology, ISBN number 978-1785614156

[99] A Arockia Bazil Raj "Steering Control system for Laser Beam Tracking" AICTE sponsored Nat. Level Conf. and Sem. Signals,Systems and Communication

[100] Kumar, Atul, et al. "A Review Paper on High Definition, Full Duplex Video Transmission for UAV to Ground Data Link."https://doi.org/10.5281/zenodo.10205450

[101] De, Sampurna, and AA Bazil Raj. "An X-Band Photonics Radar-Based Autonomous Technique for Parameter Measurement of sUAV Targets Using Micro-Doppler TF Images." IEEE Transactions on Aerospace and Electronic Systems (2025). https://doi.org/10.1109/TAES.2025.3586597

[102] N. Akhter, S. Sarkar, S. De and A. A. B. Raj, "OptoElectronic Oscillator Design for Photonic Radar System," 2023 IEEE Pune Section International Conference (PuneCon), Pune, India, 2023, pp. 1-6, https://doi.org/10.1109/PuneCon58714.2023.10450001

[103] A. Ingole, S. De and A. A. B. Raj, "Development of SFCW Based GPR for Sub-Surface Scanning," 2023 IEEE Pune Section International Conference (PuneCon), Pune, India, 2023, pp. 1-6 https://doi.org/10.1109/PuneCon58714.2023.10450139

[104] P. Tingare, S. De and A. A. Bazil Raj, "Hybrid Clutter Suppression Technique for FOPEN Target Imaging Radar," 2023 IEEE Pune Section International Conference (PuneCon), Pune, India, 2023, pp. 1-6 https://doi.org/10.1109/PuneCon58714.2023.10450055

[105] Vaishnavi D. Kanzarkar, Kshitija S. Kayat, Akanksha B. Jadhav, Pranavkumar Tingare, V.P. Patil, Sampurna DE, A ArockiaBazil Raj, "Design of Digital Architecture for Real-Time T-F Imaging with New Radar Waveform." International Research Journal of Modernization in Engineering Technology and Science, Nov. 2023. Crossref, https://doi.org/10.56726/irjmets46662

[106] S. S. Kari, A. A. B. Raj and B. K, "Evolutionary Developments of Today's Remote Sensing Radar Technology—Right From the Telemobiloscope: A review," in IEEE Geoscience and Remote Sensing Magazine, vol. 12, no. 1, pp. 67-107, March 2024, https://doi.org/10.1109/MGRS.2023.3329928

[107] M. M. Hasan, M. Chakraborty and A. A. B. Raj, "A Hyper-Parameters-Tuned R-PCA+SVM Technique for sUAV Targets Classification Using the Range-/Micro-Doppler Signatures," in IEEE Transactions on Radar Systems, vol. 1, pp. 623-631, 2023 https://doi.org/10.1109/TRS.2023.3322607

[108] G. Sharma and A. A. B. Raj, "OTFS Based SAR With Low Complexity Receiver," in IEEE Access, vol. 11, pp. 66194-66200, 2023, https://doi.org/10.1109/ACCESS.2023.3290322

[109] Akhter, N., Raj, A. A. B., & Prabu, K. Photonics radar based LSS targets' postures' m-D and cadence frequency imaging using empirical wavelet transform technique. The Imaging Science Journal, 72(6), 706– 722. https://doi.org/10.1080/13682199.2023.2221052

[110] S. Kumar and A. A. B. Raj, "Design of X-Band FMCW Radar Using Digital Doppler Processor," 2021 International Conference on System, Computation,Automation and Networking (ICSCAN), Puducherry, India, 2021, pp. 1-5, https://doi.org/10.1109/ICSCAN53069.2021.9526461

[111] Gupta, A., and A. B. Rai. "Feature extraction of intrapulse modulated LPI waveforms using STFT". In 2019 4th International Conference on Recent Trends onElectronics, Information, Communication & Technology(RTEICT) 2019 May 17 (pp. 742-746). https://doi.org/10.1109/RTEICT46194.2019.9016799

[112] Kumawat, Harish Chandra, and Arockia Bazil Raj. "Data acquisition and signal processing system for CW Radar." 2019 5th International Conference On Computing, Communication, Control And Automation (ICCUBEA). IEEE, 2019. https://doi.org/10.1109/ICCUBEA47591.2019.9128921

[113] B. B. Bhagat and A. B. Raj, "Detection of Human Presence Using UWB Radar," 2021 International Conference on System, Computation, Automation and Networking (ICSCAN), Puducherry, India, 2021, pp. 16, http://doi.org/ 10.1109/ICSCAN53069.2021.9526437

[114] A. Ingole, S. De and A. A. B. Raj, "Development of SFCW Based GPR for Sub-Surface Scanning," 2023 IEEE Pune Section International Conference (PuneCon), Pune, India, 2023, pp. 1-6, https://doi.org/10.1109/PuneCon58714.2023.10450139

[115] S. Kumar and A. A. B. Raj, "Design of X-Band FMCW Radar Using Digital Doppler Processor," 2021 International Conference on System, Computation,Automation and Networking (ICSCAN), Puducherry, India, 2021, pp. 1-5, https://doi.org/10.1109/ICSCAN53069.2021.9526461

[116] S. S. Kari, A. A. B. Raj and B. K, "Evolutionary Developments of Today’s Remote Sensing Radar Technology—Right From the Telemobiloscope: A review," in IEEE Geoscience and Remote Sensing Magazine, vol. 12, no. 1, pp. 67-107, March 2024, https://doi.org/10.1109/MGRS.2023.3329928

[117] S. H and A. B. R. A, "Digital Design of Fuzzy Logic Controller for Optical Beam Steering in Free Space Optical Communication," 2021 International Conference on System, Computation, Automation and Networking (ICSCAN), Puducherry, India, 2021, pp. 1-5, http://doi.org/10.1109/ICSCAN53069.2021.9526382

[118] N. Yadav and A. Rockia Bazil Raj, "Orthogonal Frequency Division Multiplexing Waveform Based Radar System," 2021 International Conference on System, Computation, Automation and Networking (ICSCAN), Puducherry, India, 2021, pp. 1-4, http://doi.org/10.1109/ICSCAN53069.2021.9526501

[119] Patil, S. S., Joseph, C., Varpe, D. T., & Raj, A. B. (2024). A comprehensive review on security in free-space optical communication. Int. J. Eng. Res. Rev., 12(3), 150-180. https://doi.org/10.5281/zenodo.13851700

[120] Sharma, Gaurav, and A. Arockia Bazil Raj. "Waveform and Receiver Design for OTFS-Based SAR Under Interference and Low SNR Conditions." IEEE Geoscience and Remote Sensing Letters (2024). https://doi.org/ 10.1109/LGRS.2024.3449898

[121] Patle, Nidhi, Raj, Arockia Bazil, Joseph, Chinchu and Sharma, Nishant. "Review of fibreless optical communication technology: history, evolution, and emerging trends" Journal of Optical Communications, vol. 45, no. 3, 2024, pp. 679-702. https://doi.org/10.1515/joc-2021-0190

[122] Bhavsar, N., Tayade, A., Ghodmare, H., Wagdharikar, N., De, S., & Raj, A. B. (2022). A review on image processing algorithm for foliage target detection and classification. Research Publish Journals, 10, 52-61. https://doi.org/ 10.5281/zenodo.7486512

[123] Hasan, Mohammad Mahmud, Ananjav Pandey, and AA Bazil Raj. "UAV Classification from Micro-Doppler Signature-based Time Frequency Images using SVM." 2022 International Conference on Augmented Intelligence and Sustainable Systems (ICAISS). IEEE, 2022. https://doi.org/10.1109/ICAISS55157.2022.10010898

[124] Eguri, Samson Vineeth Kumar, Raj A, Arockia Bazil and Sharma, Nishant. "Survey on acquisition, tracking and pointing (ATP) systems and beam profile correction techniques in FSO communication systems" Journal of Optical Communications, vol. 45, no. 4, 2024, pp. 881-904. https://doi.org/10.1515/joc-2021-0222

[125] Raj, A. Arockia Bazil, et al. "Mitigation of beam fluctuation due to atmospheric turbulence and prediction of control quality using intelligent decision-making tools." Applied optics 53.17 (2014): 3796-3806.https://opg.optica.org/ao/ abstract.cfm?URI=ao-53-17-3796

[126] Bazil Raj, Arockia A., et al. "Intensity feedback-based beam wandering mitigation in free-space optical communication using neural control technique." EURASIP Journal on Wireless Communications and Networking 2014 (2014): 1-18. Networking. 2014 Dec;2014:1-8. https://doi.org/10.1186/1687-1499-2014-160

[127] Raj Anthonisamy, Arockia Bazil, Padmavathi Durairaj, and Lancelot James Paul. "Performance analysis of free space optical communication in open-atmospheric turbulence conditions with beam wandering compensation control." IET Communications 10.9 (2016): 1096-1103. https://doi.org/10.1049/iet-com.2015.0717

[128] Kumawat, Harish Chandra, and Arockia Bazil Raj. "Data acquisition and signal processing system for CW Radar." 2019 5th International Conference On Computing, Communication, Control And Automation (ICCUBEA). IEEE, 2019. https://doi.org/10.1109/ICCUBEA47591.2019.9128921

[129] Gite, Tushar Yuvaraj, Pranav G. Pradeep, and AA Bazil Raj. "Design and evaluation of c-band FMCW radar system." 2018 2nd International Conference on Trends in Electronics and Informatics (ICOEI). IEEE, 2018.https://doi.org/10.1109/ICOEI.2018.8553838

[130] Gupta, Deeksha, AA Bazil Raj, and Abhijit Kulkarni. "Multi-Bit Digital Receiver Design For Radar Signature Estimation." 2018 3rd IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT). IEEE, 2018. https://doi.org/10.1109/RTEICT42901.2018.9012283

[131] Raj, A. Arockia Bazil, J. Arputha Vijaya Selvi, and S. Raghavan. "Terrestrial free space line of sight optical communication (tfslsoc) using adaptive control steering system with laser beam tracking, aligning and positioning (atp)." 2010 International Conference on Wireless Communication and Sensor Computing (ICWCSC). IEEE, 2010. https://doi.org/10.1109/ICWCSC.2010.5415900

[132] Rajkumar, Chennuru, and AA Bazil Raj. "Design and Development of DSP Interfaces and Algorithm for FMCW Radar Altimeter." 2019 4th International Conference on Recent Trends on Electronics, Information, Communication & Technology (RTEICT). IEEE, 2019.https://doi.org/10.1109/RTEICT46194.2019.9016960

[133] Arockia Bazil Raj, A., and S. Padmavathi. "Statistical analysis of accurate prediction of local atmospheric optical attenuation with a new model according to weather together with beam wandering compensation system: a season-wise experimental investigation." Journal of Modern Optics 63.13 (2016): 1286-1296.https://doi.org/ 10.1080/09500340.2016.1140840

[134] Anthonisamy, Arockia Bazil Raj, and Arputha Vijaya Selvi James. "Formulation of atmospheric optical attenuation model in terms of weather data." Journal of Optics 45 (2016): 120-135. https://doi.org/10.1007/s12596-016-0325-6

[135] Raj, A. Arockia Bazil, and J. Arputha Vijay Selvi. "Lower-order adaptive beam steering system in terrestrial free space point-to-point laser communication using fine tracking sensor." 2011 International Conference on Signal Processing, Communication, Computing and Networking Technologies. IEEE, 2011. https://doi.org/10.1109/ICSCCN.2011.6024641

[136] Gite, Tushar Yuvaraj, Pranav G. Pradeep, and AA Bazil Raj. "Design and evaluation of c-band FMCW radar system." 2018 2nd International Conference on Trends in Electronics and Informatics (ICOEI). IEEE, 2018. https://doi.org/10.1109/ICOEI.2018.8553838

[137] Baro, Dhrubajyoti, Sanjay K. Sharma, and AA Bazil Raj. "Study of a PID controller for laser beam stabilization system." 2021 International Conference on System, Computation, Automation and Networking (ICSCAN). IEEE, 2021. https://doi.org/10.1109/ICSCAN53069.2021.9526445

[138] Singh, Ranveer, et al. "A Review on Integration of Artificial Intelligence in Free Space Optical Communication." https://doi.org/10.46610/JIIS.2024.v09i03.005

[139] Rashmika, Thota, et al. "Detection Algorithms for Fast Moving Targets in FMCW Based Radar." International Conference on Paradigm Shifts in Communication, Embedded Systems, Machine Learning and Signal Processing. Cham: Springer Nature Switzerland, 2024. https://doi.org/10.1007/978-3-031-90580-3_11

[140] Ghassemlooy, Zabih, Arun Majumdar, and Arockia Bazil Raj. "Introduction to free space optical (FSO) communications." 2019. 1-26. https://doi.org/10.1049/PBTE078E_ch1