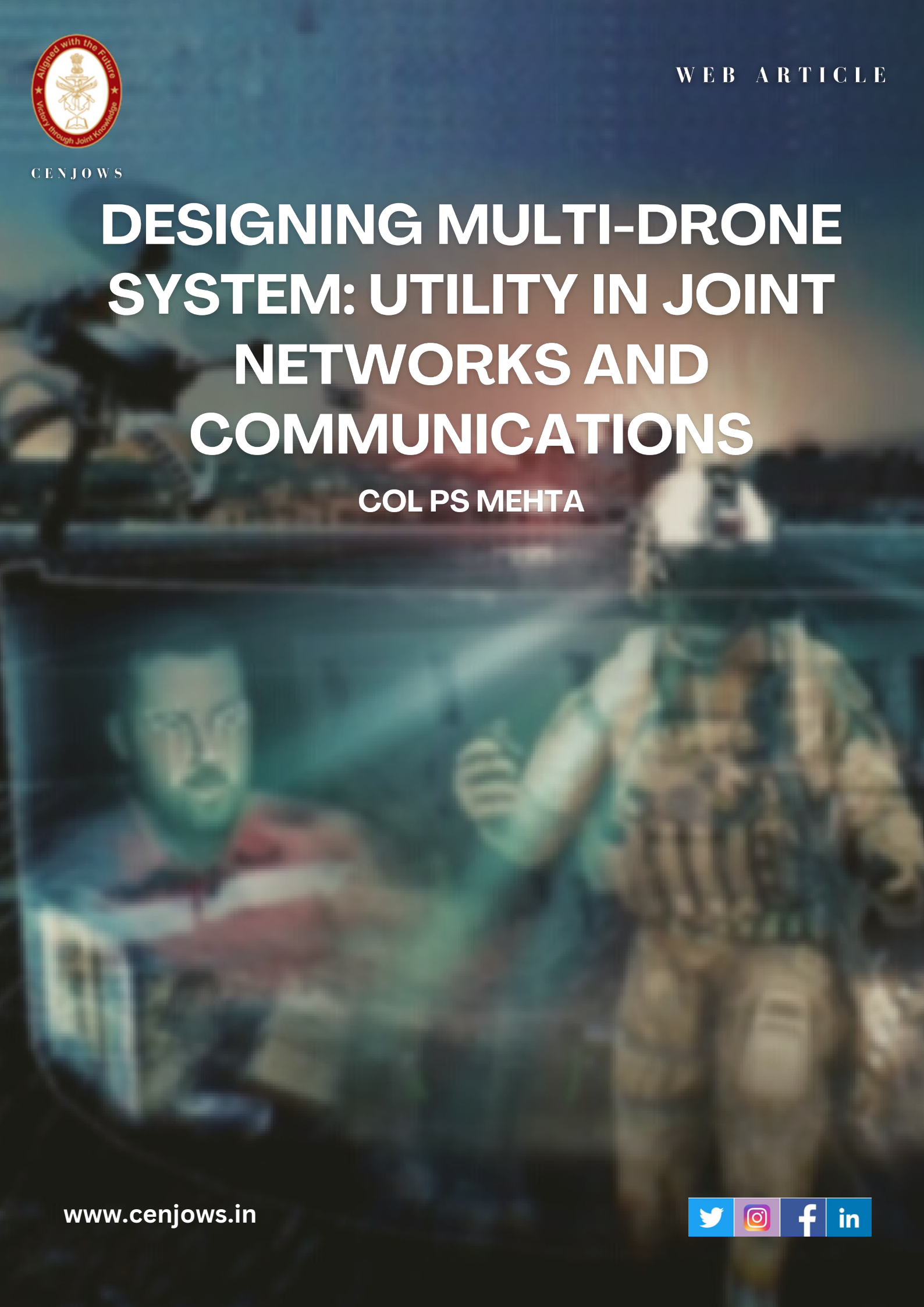

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DESIGNING MULTI-DRONE SYSTEM: UTILITY IN JOINT NETWORKS AND COMMUNICATIONS

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DESIGNING MULTI-DRONE SYSTEM: UTILITY IN JOINT NETWORKS AND COMMUNICATIONS

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Abstract

Drone technology have reached an advanced stage and utility of drone-based applications have increased manifold in military and civil arena. A recent example of use of drone-based system in military arena is the use of modified Consumer First Person View (FPV) drones to carry and drop bombs, as they fly near the target area, in the ongoing Russia-Ukraine war. The drones are fitted with night vision cameras for surveillance and special bombs, which have caused considerable damage to the Russian forces. In this paper, we study the utility of multi-drone systems which includes establishment of high-speed communication links and efficient collaborative decision-making protocols which make them efficient, robust and reliable. There has been a growing impetus on coordinated communication recently to allow multi-drone systems to coordinate and communicate jointly for the completion of tasks in a short span of time with improved efficiency and reliability. It also gives an overview of the utility of individual drones and enhanced utility of multi-drone system in joint communication networks. Finally, design of a multi-drone system, its limitations and measures to overcome the limitations have been discussed.

Introduction

Multi-Drone systems are now a reality, as multiple drones communicate and collaborate seamlessly for a given role. The drones work in harmony to share information, coordinate activities and achieve a common aim. Shared and resilient communications networks and systems established by multi-drone systems have brought new realm of possibilities and advancement in military operations and humanitarian efforts. Connected and resilient communication networks established using multi-drone systems are transforming the telecommunications field. The multi-drone systems are connected in a continuous network, working together to provide a resilient and reliable communication network and exchange data in real time, plan their movements and perform tasks precisely to achieve the end goal. This synergy is made possible by shared networks that allow drones to work together, share information and act as a cohesive system. Individual drones serving as sole tracking devices have now given way to multi-drone systems which utilise the power of interconnectivity and collaborative networks to reach their full potential.

Shared networks enable drones to perform multifarious tasks such as aerial photography, scanning of large areas and efficient store deliveries in a commercial establishment, which leads to cost saving in terms of security manpower being employed for the task. Multi drone systems thus can collectively collect data and process it in real-time, which have a transformative impact on shared networks beyond the commercial realm. In military operations, drones are revolutionizing the way battles are fought. The combined drones can conduct coordinated surveillance, intelligence gathering and precision strikes without endangering forces on the ground. They increase situational awareness, providing the military with valuable intelligence while minimizing the risk of collateral damage. In addition, the use of multi-drone networks in humanitarian operations can save lives and enable rapid response in areas hit by natural disasters with drones equipped with advanced sensors and cameras collaborating to scan large inaccessible terrains to quickly and comprehensively assess damaged infrastructure, locate survivors in hard-to-reach areas, and provide urgent assistance. Constant communication between drones maximizes their effectiveness and allows them to act as first responders in critical situations.

However, effective communication in the case of a multi-drone system has lot of challenges such as dynamic nature of the flight environment creates obstacles in terms of limited bandwidth, restricted line of sight, interference and signal jamming. These challenges require the development of reliable communication systems that can overcome interference and stay connected even in the most adverse conditions. Some of the solutions include use of multiple communication channels, dynamic spectrum allocation, intelligent routing algorithms and satellite integration to ensure that the multi-drone systems have uninterrupted connectivity and reliability. Drones equipped with such flexible communication capabilities can navigate and overcome obstacles even in the toughest terrain and environmental conditions.

Key Areas for Utility of Multi-Drone System in Civil Arena

Multi-Drone Systems can be used in areas or applications where the task is to be accomplished in the minimum possible time and is of emergent nature. Here, the multi-drone systems can act as first responders to save on time. Utility of multi-drone systems in Civil arena[1] are given as under:-

Utility in Emergency Communication in Inaccessible Terrain. Multi-Drone systems can act as a saviour in inaccessible terrains where landline communication is not reliable or not working due to damage caused by natural disaster. In such conditions, Multi-drone System can establish critical communication links to enable reach in remote and inaccessible areas. Traditional landline communication infrastructure is the only source of communication in remote areas with difficult terrain or small population, which is erratic and prone to frequent faults and outage due to inhospitable terrain conditions and lack of skilled persons to maintain round the clock availability. Communication-equipped multi-drone systems can act as flying base stations, temporarily or permanently covering areas where ground infrastructure is inaccessible. This helps people in remote areas to access essential communication services during inclement weather and especially during emergencies. In case of natural disaster, multi-drone systems can be quickly deployed to establish communication links in a disaster area, facilitating real-time information sharing and thus providing a fillip to relief operations and succour to disaster- affected people. Their agility and flexibility allow for quick setup, instant connectivity and efficient coordination at critical moments. This capability greatly improves the effectiveness of disaster relief operations, leading to faster and more targeted relief efforts.

Surveillance of Critical Assets. In telecommunication, energy, transportation and hazardous industries such as atomic research and pharmaceutical industries, infrastructure inspection and maintenance can be expensive, time consuming and potentially dangerous to the workers. Drones equipped with surveillance cameras and communications capabilities can be effectively utilized in these places, providing a safe and efficient way to inspect towers, power lines, pipelines and machinery without putting the lives of workers at stake by employing them in such tasks. The surveillance drone systems can transmit live video of critical machineries, equipment and their functioning to operators on the ground, enabling real-time assessment of the health of the infrastructure. The drone system increases inspection speed, accuracy, reduces operating costs and reduces the risks associated with manual testing which can be harmful to the workers.

Crowd Management. Large public gathering in sports competitions and political rallies often put a huge strain on existing communication networks due to the high concentration of users in a small space. Drones equipped with communication capabilities can reduce this burden by acting as temporary network nodes, reducing data traffic and providing participants with a reliable connection. By creating access

points to aerial communications, the drones increase network capacity, reduce congestion, and enable seamless communication and data sharing in congested environments.

Economy and Scalability. Multi-drone systems provide cost-effective and scalable solutions in communication, as it is easier to install, maintain and cheaper than the traditional communications infrastructure especially in remote or inaccessible areas. The drone systems offer the flexibility to scale up or down communication resources on requirement basis without the requirement of large investments in physical infrastructure. This scalability makes them an ideal choice for short-term events, emergencies or areas with rapidly changing communication requirements.

Utility of Drone for Defence Forces

Drones have been extensively utilised in military communications and operations and have revolutionized the way troops operate in the modern battlefield. Utilisation of drones with surveillance capability have enabled the commanders, by providing them critical information of the enemy without compromising the security of the friendly forces. A severe drawback in battlefield or operations is the availability of reliable communication. Drones fitted advanced communication system provide the troops with better situational awareness and operational readiness. The role of drones in military communications and surveillance has a significant impact on modern warfare as follows: -

Enabling Real-Time Surveillance and Reconnaissance. Drones equipped with high-resolution cameras, thermal imaging equipment and advanced sensors capture real-time aerial images, gather valuable intelligence, and transmit critical information to the commanders at Command Control centres who further decide on the next course of action based on analysis of the images. This real-time surveillance enables military commanders to track enemy movements and make informed tactical decisions quickly and efficiently, thus acting as a force multiplier that gives a decisive advantage over enemy forces. In addition, the drone detects movements of enemy patrols, which assists the commanders to lay ambush in time to eliminate the impending threat efficiently and in time. With the advent of advanced drone technology, their capabilities to support military operations, intelligence gathering, and surveillance efforts have increased substantially. Drones are also widely used in military communications to provide real-time information, relay high-resolution images and video feeds to commanders and troops in the battlefield, thus enabling them to make decisions based on precise and accurate information. The most significant benefit of using drones in battlefield is that it saves human life by reducing the requirement of physical presence of troops in challenging situations and unnecessarily putting their lives are in danger.

Improving Communications Networks. Traditional methods of communication, such as radio and satellite systems, can be susceptible to interference and disruption, especially in remote or hostile environments. However, drones can act as mobile

communication nodes, extending the range and reliability of military communication networks. This allows the military to maintain communication with command centres and with each other, even in the most difficult situations.

Relay Nodes in Military Communication. Drones serve as key nodes in military communications networks, filling gaps in communications coverage and extending the reach of existing infrastructure. They can be used as communication relays, providing continuous communication between ground forces, warships and air platforms. By transmitting voice, video and data signals, drones increase communication range and improve the efficiency of military operations, especially in remote or challenging terrain where infrastructure The traditional communication layer can be restricted or compromised, which have made drones and military communications increasingly interdependent in recent years.

Deployment in Risk-prone or Inaccessible Areas. Another benefit of integrating drones into military communications is their ability to operate in environments that might otherwise be inaccessible or dangerous for the operator. For example, drones can be deployed to gather intelligence in areas contaminated by chemical, biological or radioactive agents without endangering human life. This ability is especially valuable in time-sensitive situations, such as during a disaster response or after a terrorist attack.

Support for Intelligence, Surveillance and Reconnaissance (ISR) operations. Drones have revolutionized intelligence, surveillance and reconnaissance (ISR) operations with their ability to fly over large areas for long periods of time, unmanned and undetected due to their small form factor. Drones equipped with advanced ISR technology provide sustained surveillance and can scan targets of interest, gather intelligence and track potential threats, provide support invaluable aid to military commanders and decision makers. Real-time information gathered by these drones enhances situational awareness, enabling quick and effective response to changing threats.

Facilitating Target Acquisition and Accurate Attacks. Equipped with targeting systems and guided munitions, drones have become a tool of modern warfare. Using real-time information and surveillance capabilities, these drones can identify and track targets with great accuracy. The integration of advanced communication systems allows for the seamless coordination of the drone with ground or air platforms, allowing for precise strikes on identified targets. This ability greatly reduces the risk to troops, minimizes side damage, and increases the overall effectiveness of military operations.

Improved Troop Protection and Situational Awareness. Drones increase soldier protection by providing military personnel with a long-range aerial perspective. They can be used for perimeter surveillance, monitoring for potential threats, and detecting unauthorized activity around military bases or facilities. This advanced situational awareness helps military detect and respond to security breaches while minimizing risk

to personnel and assets. The shortage of troops in units to be used for patrol activities can be easily overcome by deploying AI-assisted drones to keep an eye on sensitive areas that are not patrolled. Any intrusion attempt can be detected remotely using a camera built into the drone that relays images of the intruder to the base for quick action.

Although there are many benefits to using drones in military communications, there are also number of challenges. One such issue is the possibility of the drone being hacked or compromised by an adversary, resulting in the loss of sensitive information. To mitigate this risk, it is essential to have drones equipped with robust cybersecurity measures to protect the communication networks on which they rely. Drone system usage has also led to ethical implications in battlefield, especially when it comes to targeting and killing people, as although it can help reduce the risk to human life on the battlefield, it also raises questions about the accountability and transparency of these actions.

Concept of Multi-Drone System and Utility in Joint Networks

Multi-drone system have led to a paradigm shift in communication field, as drones equipped with advanced communication systems have proven revolutionary in filling the gap. communications, extend range, and improve connectivity in remote or difficult environments. Equipped with GPS and sensors such as accelerometers, gyroscopes and barometers, multi-drone system provide automatic stabilization and position spatially. In addition, some drones can bear additional weight of sensors such as imaging and infrared cameras. When covering large areas at conventional image resolutions with these small-scale drones, the overall picture often has to be created from dozens of individual images. Typically, multiple drones are used to deal with the time constraints of a dynamic environment and the limited flight time of a single drone. In such situations, several networked drones must fly at low altitudes and use specialized software to convert the resulting images into a single mosaic image. This process, known as image stitching, creates a large overview image of the target area from which the user can extract the desired information. At present, the application of drones in communication is not limited to point-to-point communication between the drone and the remote controller, but has reached the stage of tight integration with the mobile communication technology such as ultra-high bandwidth, low latency, high reliability and wide coverage[2]. Furthermore, the existing features of long-range endurance, security management and drone control technology are the driving force behind the emerging field of drone networking.

A multiple drone system is the deployment of multiple drones in a network, which is useful in missions covering a large geographical area where a single drone is insufficient to cover a large range due to its limited power and load bearing capacity.[3] A multiple drone system, consisting of several networked drones, would allow to cover a

wider geographical area. Networked drones cover a wide area from different vantage points which results in better fault tolerance.

Components of Multi-Drone System

Components of a multi-drone system are the communication, sensor, dispatch modules and drone platform. The key attributes of a networked drone system are durability, adaptability, scalability, collaboration, heterogeneity, and self-configuration made possible by integrating each drone and their navigation and communication capabilities. A networked drone works centrally or in a decentralized manner. Centralised networked drone collects information from the environment, takes decisions based on the data collected and carries out the mission centrally. In decentralised drone system, individual drones share and collate information at various stages to accomplish the final objective. Thus, designing a multiple drone system involves integration of individual drones to accomplish the final objective. The outputs of the individual drones must be collated to obtain a workable and desirable output, which requires seamless integration of physical control of individual drones and their capabilities. The first major requirement in collaborative drone design is choosing among the airship/ fixed wing drone. However, the important design aspect to consider here is that each of these drones differs in size, payload, or flight time, which affect network life, distances mobility and communication distance. The second aspect to consider is the area where many drone systems are used, which will further determine the final design, such as low- or high-level control and other aspects of orbital planning, networking and communications.

Function of Various components of Multi-Drone Systems

Designing a system of multiple drone system operating as a network to achieve the desired goal is complex due to the coordination requirements between the different subsystems. Multi-drone systems include multiple drones that sense the environment and communicate observations to other drones through a drone network by planning a path and share tasks to achieve the end result. The main challenges in developing multi-drone system are designing the hardware for detection, communication, networking, and further coordination among the hardware. In a multi-drone system, the drones must observe their surroundings, collate information and perform launch for the desired attack in the most effective way. The main components are[4]:-

Communication Subsystem. This subsystem carries out information exchange, and adapts efficiently to diverse communication networks. This block is responsible for coordinating between drones to transmit control information and exchange observations to accomplish the ultimate objective, for example, surveillance of a geographical area during a disaster in the minimum time.

Relay Block. In some cases of poor communication infrastructure, a relay block is required to provide connectivity between widely dispersed base stations. It is a known fact that drones have a very less range due to wireless connectivity and limited battery life to last for a limited period of time. The relay block ensures connection to earth stations even in poor connection situations.

Coordination Subsystem. This subsystem performs the coordination between the drones by calculating the trajectory of the drones and then distributing the tasks between the drones to get the final result. This involves having a rigid lineup or possibly a division of labour between the drones locally or globally. This subsystem of the multiple drone system manages the drones and the heterogeneous tasks. The main problems solved by this subsystem are:-

Task Allocation. Decision-making protocols must be embedded in this block to divide jobs among drone groups and ensure the ability to manage vague information and power tasks motion. This block is responsible to allocate mission to mission requirements based on drone capabilities.

Path Planning. Integrated three-way path planning, mission optimization, efficient data consolidation techniques from multiple heterogeneous sensors, data interpretation and feedback mechanisms, and possible effective collision and obstacle avoidance systems must be integrated in this block for path planning for an efficient multiple drone system.

Limitations of Multi-Drone System

Small-scale multi-drone system are resource-limited on multiple fronts[5]. The energy available on board a drone directly affects the total flight time, flight behaviour and stability of the flight, during inclement weather. Poor sensing and communication hinders sophisticated in-vehicle inference capabilities. Compensating for resource shortages in the one-way often compromises the other. Also, detected data of each drone is transmitted to base station to be collated and final command is given to the drones to accomplish the task. This approach works because ground control is more computationally capable than drones.

However, limitation is the transmission capability of the base station and drones. Planned routes must ensure that the drone are within communication range of the ground station or communication block, and the network connection must allow special mode operation.

Multi-hop routes between the drone and base station are an essential requirement. Fluctuation of the wireless channel leads to non-receipt of signal, even if the drones are within medium transmission range. Hence, it is not possible to guarantee a connection all the time in a multi-drone system.

Essential Requirements of Efficient Multi-Drone System

Design of Robust Subsystems of Multi-Drone System. Communication subsystem is responsible for efficient coordination of the drone, and thus success of the mission is hugely dependent on this subsystem[6]. Detected data will be forwarded to base station and mission requests will be passed to the drone. Wireless communication networks are inefficient and may not work in case of huge data to be transmitted which also affect task execution time. In addition, number of drones in a multi-drone system have to synchronize so that data is collected by multiple drones at almost the same time with different vantage points. Also, camera as a sensor in multi-drone system requires recording and stitching of images from number of drones, which is a big challenge.

Requirement of Test Beds. For testing efficacy of interdependence of various sub-systems of multi-drone systems, simulators can be used. The better proposition is the use of testbed to find out the full efficacy of the system, which can test the sensing, communication & networking parameters of the multi-drone systems which are difficult to create. The solution is design of realistic models to study the impact of inclement weather conditions on communication links, transmission of large amount of data and short flight times and low payload on the overall design of multi-drone systems.[7]

Independent User Interface. The applications inbuilt in multi-drone systems require a certain degree of independence in drone flight operations. With an efficient user interface, users are not concerned about managing individual drones, thus, an essential requirement to ensure low user engagement.

Conclusion

Multiple drone system has a wide range of applications, however, developing these systems have various challenges with respect to communication, control and joint decision-making. In this paper, potential and challenges of Multiple drone system have been highlighted and various key areas where the systems can be utilised to include tasks such as data collection and cooperative decisions that advance the multiple drone system's performance have been discussed. Advanced application of these systems in monitoring, surveillance, and management will soon be a reality. Once the shortcomings of multi-drone systems are overcome, they will offer a plethora of advanced applications in field of military and civil domains in the near future.

Endnotes

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