無人機機群即時任務賦予及變更

Real-Time Tasking and Retasking of Multiple Coordinated UAVs

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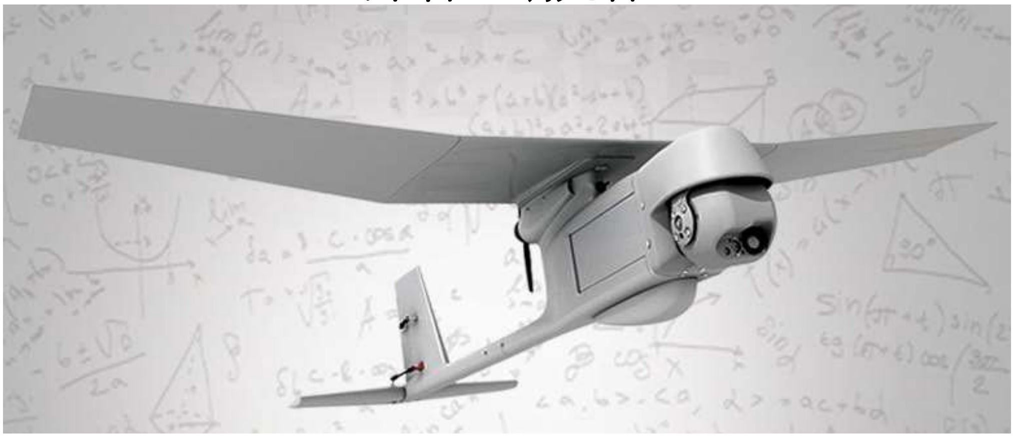

圖片說明：美國 RQ-11B 大鴉無人機（UAS: RQ-11B Raven® Courtesy AeroVironment)

INTRODUCTION

Both military missions and civilian applications have led to numerous investigations into using teams of collaborating unmanned aerial vehicles (UAVs) to accomplish a complex mission with strongly coupled tasks [1－26]. Given a team goal, these vehicles coordinate their activities to most efficiently and effectively accomplish an autonomous mission. For years, teams of UAVshave been proposed for various military applications, such as serving as wide area search munitions [4]; suppressing enemy air defense systems [8－10]; and conducting intelligence, surveillance, and reconnaissance (ISR) [15－18]. Researchers have also been suggesting UAV teams for civilian applications, such as tracking the shape of a contaminant cloud (e.g., to identify radioactive material release into the atmosphere) [22], monitoring biological threats to agriculture [23], conducting disaster management and civil security [24], and conducting traffic surveillance for sparse road networks [25].

前言

以無人機群應用在複雜任務的執行上，無論軍方或是民間都有為數眾多的討論 [1-26]。當賦予機群任務目標，經協調後各機採取最有效率的方式自主式分別執行。無人機在軍事上應用廣泛，例如大範圍偵蒐型彈藥 [4]、制壓敵防空系統 [8-10]，

及情監偵任務（ISR）[15-18]等。民間應用則包括，污染雲追踪（如大氣中放射性物質鑑識）[22]、農業生物威脅監測[23]、災害管理與民事安全[24]，及對偏遠道路網之交通監控[25]等。

Most current ground stations allow for the upload of waypoints, and by using autonomous controllers on the UAVs, these vehicles can fly a predetermined path without the intervention of a pilot. In most cases, ground stations can determine the correct smooth flight path between the waypoints based on the aircraft’s specifications. Thus, no additional flight planning is needed, only the ability to provide the ground station with waypoints.

目前大多數地面站可以將轉航點上傳至無人機，無需飛行員的介入無人機就可以其自主控制器按預定路徑飛行。在大多數情況下，地面站可根據飛機的性能決定各轉航點之間正確的平滑航線。因此，只需輸入轉航點即可，並不需要額外的飛行計劃。

Reduced reliance on human operators is the goal of autonomy. However, an alternative/complementary goal of autonomy is to allow the human operator to “work the mission” rather than “work the system”[27]. This statement means that autonomy must support, not take over the decision-making. The Intelligent Tasker software was developed to work alongside a ground stationto assist an operator in planning a complex mission using multiple vehicles. The user interface and back-end Genetic Algorithm Optimizer make planning and executing an optimized complex coordinated mission straightforward and uncomplicated for the user. The user designs the mission, and the software determines an optimized way to task the assets and provide the ground station with the waypoints needed to direct the UAVs to accomplish the mission. The software allows for the original tasking of multiple assets and then the retasking of assets in real-time if “pop-up” points of interest arise or an asset is lost. This work has been applied to small fixed-wing UAVs but can easily be applied to other types of aerial, terrestrial, or even marine vehicles, as well as heterogeneous teams[18].

減少對操控人員的依賴是自主的目的，而另一層目的則是讓操控人員「執行任務」而不需要「操作系統」[27]。此一表述意味著自主必須支持，而不是接管決策。智慧型任務軟體(Intelligent Tasker software)的開發是為了配合地面站，協助操控人員遂行多機、複雜任務之規劃。用戶介面與後端之「遺傳運算優化器」讓用戶在執行複雜任務時既有效率又簡單易行。用戶負責設計任務，軟體負責將任務資產管理最優化，並各機機完成任務所需的轉航點提供給地面站。該軟體可以進行多機分工，同時當瞬間目標出現或原訂目標消失，可以重新賦予新

任務。此一方式方已經適用於小型固定翼無人機，但可以很容易地運用於其他類型的空、天、陸、海上各種載具以及複合載具群 [18]。

MISSION SCENARIO

The mission example considered here is ISR. Conceivably, this mission could be to provide intelligence for securing the surroundings of an Army base or other specific area. This type of mission is also relevant for many civilian applications in which places or points of interest need to be monitored, such as for border patrol or forest fire detection. In this example, a three- plane scenario was chosen since the small AeroVironment Raven RQ-11 UAV (pictured in Figure 1) is currently deployed in sets of three [28]. The Raven is used by the U.S. Army, Air Force, Marine Corps, and Special Operations Command. Additionally, foreign customers include; Australia, Estonia, Italy, Denmark, Spain, and the Czech Republic. To date, more than 19,000 airframes have been delivered to customers worldwide, making the Raven one of the most widely adopted UAV systems inthe world. Even though Ravens are widely fielded in sets of three, there do not seem to be any examples in open literature specifically discussing the teaming of Ravens to complete a mission. The ideas in this article extend the usefulness of having three assets teamed to do a coordinated mission without the necessity for adding additional trained personnel.

任務想定

本想定以情監偵(ISR)為主。ISR 相關任務，包括提供陸軍基地或其他特定區域的維安情報，及邊境巡邏或森林火災偵測等民間用途。之所以採取以三機併用，是因為目前三軍及特戰部隊所使用 AeroVironment 公司生產的 RQ-11 渡鴨式無人機即採三機編制。外國部隊如澳洲、愛沙尼亞、意大利、丹麥、西班牙和捷克亦都採購本裝備，迄今已有 19,000 多架交付全球客戶，是全球採用最廣的無人機系統之一。雖然基本上均採三機編制，但在公開文獻中似乎尚無整個機隊同時執行任務的討論。本研究的想法在於如何在不必增加員額狀況下，三機同時執行任務之協調作業。

In this mission scenario, three planes are launched within minutes of each other (as pictured in Figure 2), to return within minutes of each other. The scenario does not require the fastest time to complete the mission but rather requires that the planes observe the area as long as needed to complete the mission and spend the maximum time over the area of interest (while not exceeding the battery life). In the scenario constructed for this exercise, it was assumed that there is a set of points of interest (POIs),$\{p_1, p_2, p_3, \cdots, p_n\}$, chosen from a map of the area of interest. These POIs would have priorities, {low, medium, high},assigned to them based on the threat that they may impose or the importance of the site. The priority level dictates how manytimes during the mission the site will be visited. Also, loiter times are chosen for the POIs that dictate the length of time the UAVshould circle, observing the site during each visit.

本想定以三架飛機分別間隔數分鐘投放（見圖二），返航時亦間隔數分鐘落地。想定要求不求快，但要以最長時間監控重要區域（在電池蓄電量所能維持之最長滯空時間）。該想定設定數個偵查要點（POI）{ p_1、p_2、p_3、...、p_n }，各點依其威脅性及重要性區分優先等級{低、中、高}。優先等級決定偵查的次數，以及在該區域盤旋的時長。

Figure 1: Raven RQ-11 Field Set.

圖一 RQ-11 渡鴨式無人機成套野戰裝備

Figure 2: Soldier Launching Raven UAV.

圖二　渡鴨式無人機投放

THE USER INTERFACE

The graphical user interface (GUI) allows a user to easily plan and execute a complex coordinated mission with three UAVs and up to 10 POIs. To begin, an operator chooses a set of POIs and a launch point. The user selects an area of interest from Bing Hybrid Map Provider and indicates how many points of interest in the area are to be visited. Clicking on the map then populates the latitude and longitude of the points and allows the user to specify priority level and loiter time for each (as pictured in Figure3). From the launch point, the maximum distance a UAV can fly and return within its safe battery life is calculated. Pointsoutside an acceptable range will not be allowed to remain in the list because doing so would result in a mission failure. Pointsclose together (able to be observed at the same time) are clustered for efficiency.

用戶介面

圖形用戶介面（graphical user interface, GUI）可以讓用戶同時操作三架無人機，計畫並執行複雜任務，轉航點最多設定 10 個。首先，操控員選擇一組 POI 及發射位置。先從「Bing 混合地圖產生器」(Bing Hybrid Map Provider)選擇若干重要偵測區，在地圖上點擊即出現該點的經緯度，並設定各點的優先等級和盤旋時間（見圖三）。計算從發射點無人機在其電池蓄電量範圍內可以安全返航的最大距離，若超過該距離之點即被剔除。相近各要點(如可同時實施偵查之不同點)加以串接，有利於提高偵查效率。

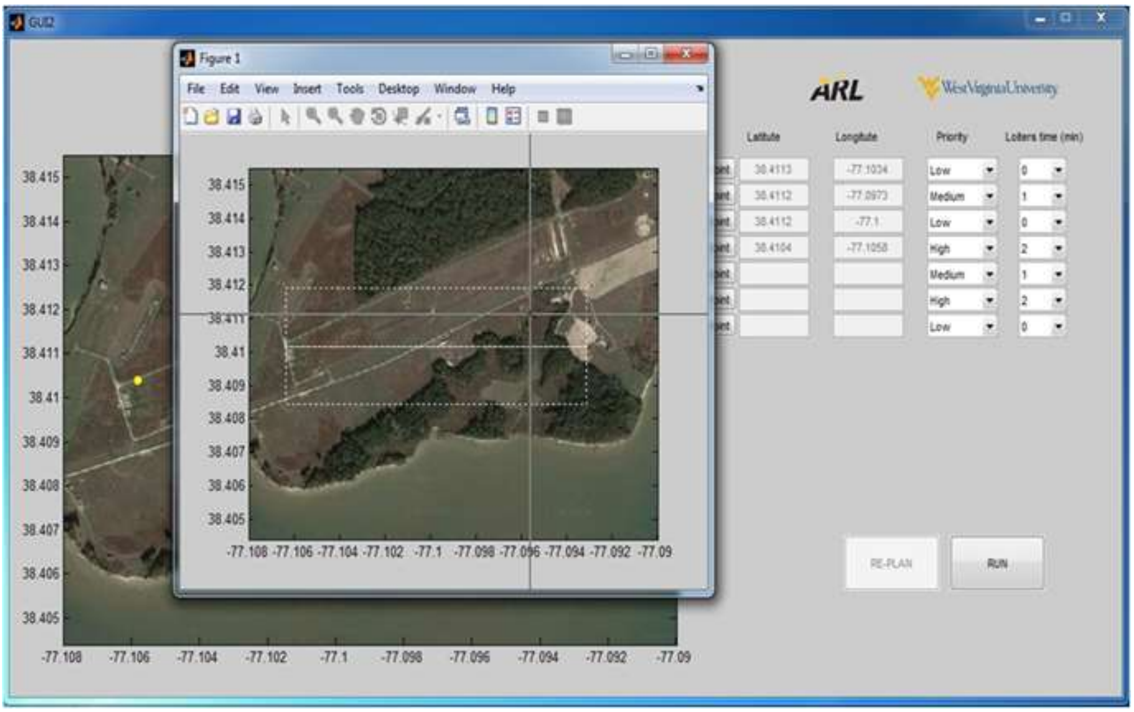

Figure 3: User Interface for Intelligent Tasker Software.

圖三 智慧型任務軟體之用戶介面

SYSTEM DESIGN

The Intelligent Tasker is designed to work with various ground stations that have autopilot capabilities (e.g., Ardupilot, APM Mission Planner, Corvid) (see Figure 4). The idea is to allow the ground station software to manage multiple autonomous vehicles to complete a coordinated operation. As illustrated in Figure 4, the operator communicates to the Intelligent Tasker to define the mission and runs the simulation to ensure the routes are acceptable. Once the operator determines that thesuggested coordinated solution is acceptable, then the plan is made available to the ground station. In the event that retasking is necessary, the ground station will relay information back to the Intelligent Tasker. This information will contain the UAV’ s current position, the points of interest that have been visited, and each vehicle’ s remaining battery life.

系統設計

智慧型任務電腦可以用於所有具有自動駕駛功能的地面站（例如 Ardupilot，APM Mission Planner，Corvid）（見圖四）。運用該軟體可以讓地面站同時管理多架自主式無人機。如圖四所示，操控員與智慧型任務電腦鏈接，確定任務後加以模擬，確認飛行路線可行。當操控員確定方案可行，就將計劃傳送地面站。若需要變更任務，地面站可回傳智慧型任務電腦。內容包含無人機的當前位置，已偵查之要點以及各機之電池電量。

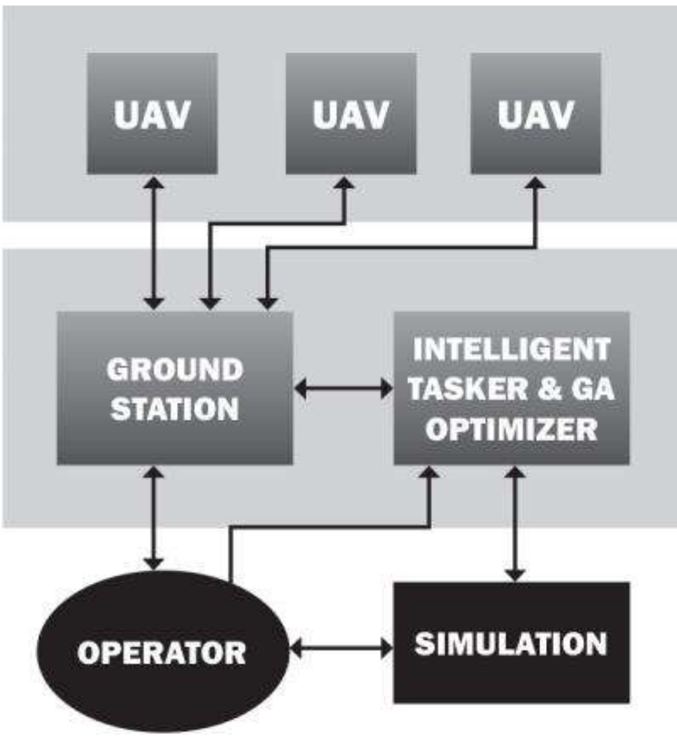

Figure 4: Intelligent Tasker as Part of the UAV System.

圖四 無人機系統之智慧型電腦

Ground stations may have multiple channels to communicate with multiple vehicles. In this case, the ground station will be given an ordered list of coordinates to visit for each of the UAVs. For a ground station with multiple channels, it is possible for one pilot to handle all UAVs during the mission, as demonstrated in Darrah et al. [17]. If the ground station only has onechannel to communicate with a UAV, then multiple instances of the ground station may need to be running, one for each vehicle, and the Intelligent Tasker will provide the ordered list of points to visit to the appropriate instances of the ground station.

地面站可以數個不同波道分別與數架無人機通連。在本想定中，地面站有一個協調順序。由於地面站有數個波道，故一位飛行操控員可以在任務期間同時操控數架無人機，正如在 Darrah(編輯論文集)所採用的狀況。[17] 若地面站只有單一個波道，則需要數個地面站各自操控一架無人機，透過智慧型任務電腦提供偵查各點之序列。

The UAVs as part of this system only communicate with the ground station. The UAVs are launched and put in a holding pattern over the launch site until the coordinated tasking received from the Intelligent Tasker is uploaded from the ground station to each UAV. To ensure vehicles do not collide, the planes are flown with a vertical separation. When retasking takes place forthe purpose of either adding an additional point of interest or continuing the mission after one asset has been lost, the UAVs are given the command to again enter the holding pattern where they are located, send their position to the ground station, communicate battery life remaining, and indicate waypoints they have left to visit. The new plan will take into account all taskings that still need to be completed, as well as the new positions of the vehicles.

無人機屬於整個系統的一部分，僅與地面站通連。無人機投放後進入待命狀態，等候地面站智慧型任務電腦上傳各機任務。為了確保無人機不發生碰撞，各機以高度區隔飛行。當增加偵查點或目標消失而重新賦予任務時，無人機飛回指定位置先進入待命狀態，剩餘電量及尚未完成之轉航點傳送給地面站，新的任務計畫必須考量尚未完成之任務及無人機的最新位置。

GENETIC ALGORITHM OPTIMIZER

A genetic algorithm (GA) is a search algorithm based on the mechanics of natural selection and natural genetics [29]. In our software, the GA Optimizer is used to look for the optimal task assignment of UAVs during the mission. The GA Optimizer employees the usual components of a GA, such as a fitness function developed for a particular scenario, chromosomes that represent the solutions to the problem, crossover that is used to develop new solutions from existing solutions, mutationto ensure that the GA does not get struck in a local optimum, and elitism to ensure the solution never degrades. These components work together to quickly provide an optimized solution in the form of a task list for each UAV. Other methods have been employed for the tasking problem [5-9]; however, the GA has proven to be the most versatile and scalable type of solution. A fitness function can be developed for individual mission scenario, and the solution space for each individual type of problem can be encoded as a set of chromosomes. For complete details on how the GA works, as well as various examples, see Darrahet al. [16, 17] and Eun and Bang [18].

遺傳運算優化器

遺傳運算法（GA）是一種以自然天擇和遺傳學為機制的搜尋運算法 [29]。我們的遺傳式運算優化器的軟體中，主在尋找無人機的最佳任務分配。遺傳運算法優化器是遺傳運算的基本組件，當針對某一特定想定擬定最優解決方案時，是以所有可能方案作為染色體，經由染色體互換過程產生新方案，突變確保遺傳運算法不會受到局部優化而產生進化阻礙，精英主義可確保解決方案永不退化。在各部門合作下，迅速根據最優方案列出各機的任務。任務分配有很多方式[5-9]，但遺傳運算已證明最通用，且具擴充性的方法，可以針對個別任務想定開發出適應度功能。各類型問題的解決空間被編碼成為一組染色體。有關遺傳運算的完整細節以及各種範例，請參考 Darrah et al。[16,17]和 Eun 和 Bang[18]。

FLIGHT TESTING

Testing of this technology was performed at the U.S. Army Research Laboratory (ARL) Blossom Point Research Facility, near La Plata, MD. This 1,600-acre site offers a UAV test area that is 2 miles long by ½ mile wide. The facility is classified as a range and as such is closed to the public. The location also maintains a runway and a command-and-control area, which facilitates take-off and landing as well as UAV observation during the experiments.

飛行測試

技術測試在位於馬里蘭州 Blossom Point 附近的美國陸軍研究實驗室（ARL）實施。該場地占地 1600 英畝，其中 2 英里長，半英里寬的區域劃為無人機測試區，設有跑道和指揮管制區，便於實驗期間無人機起降與觀測。列為機密區域，不對大眾公開。

During the flight demonstration phase, the three planes were launched one at a time using manual control to take them to desired altitude and then switched to autonomous mode, where they began to circle at their home loiter position. The team could not acquire a set of Raven RQ-11 UAVs (which cost approximately $300,000) for testing, so planes of similar size, shape, and payload capability as the Raven were used. Three PROJET RQ-11 model airframes (pictured in Figure 5) were outfitted with the necessary radios, sensors, and control computers to fly autonomously. For command-and-control functions, a FreeWave MM2 900-MHz was installed in each aircraft as well as the ground control station (GCS). Video was captured from each plane by a HackHD camera mounted inside the fuselage with the lens flush with the airframe. Video was transmitted in real-timeto the ground using a Stinger Pro 5.8-GHz transmitter. The video was received on the ground via a YellowJacket Pro 5.8-GHz receiver integrated with the GCS. Each aircraft also had a MediaTek GPS module integrated for position sensing.

在示範飛行階段，三架無人機分別手動投放，到達所需的高度後，切換為自主模式，在上空盤旋待命。展示團隊無法採購渡鴨無人機(Raven RQ-11)作為測試之用（一套約 300,000 美元），因此採用三架與渡鴨無人機尺寸、形狀和有效載荷能力相似的 PROJET RQ-11 模型機。（見圖五）各機均配備必要之無線電、偵感器和可以自主飛行的操控電腦。每架無人機和地面控制站(GCS)以 FreeWave MM2 900 MHz 執行操控指令。裝置在機身內 HackHD 錄影機之鏡頭擷取視訊。即時視訊以 Stinger Pro 5.8-GHz 發射器傳輸至地面。地面站以 YellowJacket Pro 5.8-GHz 接收器接收並整合視訊。每架無人機均裝置 MediaTek GPS 模組感應位置訊號。

Figure 5: Model Planes Used as Surrogate for Raven RQ-11.
圖五 替代渡鴨無人機之模型飛機

The GCS employed for testing demonstrated consisted of a Futaba 9C remote controller and a Linux-based laptop. The Futaba was used by the pilot to directly command the UAVs during takeoff, landing, and any contingency operations. Additionally, it acted as the main communication node between the planes and the ground, except for video. The Linux-based laptop wasused for telemetry monitoring, situational awareness, and mission status observation. The Linux laptop communicated with the GA laptop used to calculate new mission plans. Once the mission plan was determined by the Intelligent Tasker, this plan was transmitted via Ethernet from the GA-based system laptop to the Linux-based laptop for review, and then transmitted via WiFi to the Futaba 9C communications package for final transmittal to the in-flight UAV team.

測試地面站裝置 Futaba 9C 遙控器及 Linux 膝上型電腦。起飛、著陸與發生應急狀況時，操控員使用 Futaba 直接操控無人機。除視訊外，該遙控器也是陸空之間的主要通信節點。Linux 膝上型電腦用於遙測、姿態感知和任務狀態觀察。與 Linux 與 GA 膝上型電腦互聯後用於計算新的任務計劃。一旦智慧型任務電腦完成任務規劃後，通過乙太網經由 GA 膝上型電腦傳輸到 Linux 膝上型電腦檢查，再經由 WiFi 將封包傳輸到 Futaba 9C，最終傳輸給無人機隊。

As the three planes were being launched, one of the Army personnel assembled to observe the demonstration was chosento enter a set of POIs and associated priorities into the Intelligent Tasker, and an optimized coordinated mission was devised and communicated to the ground station. Once all three planes were in autonomous mode circling at the home loiter position, they were given their mission assignments from the ground station. At this point, the UAVs all flew off in autonomous mode in different directions to complete their part of the mission. After completion of their task list (visiting specific POIs in a specified order), they returned to the home loiter position to await further tasking or to be taken over and manually landed. The flights were observed on monitors that were used to track the movements of the UAVs and also view the video feeds that were being sent back from the UAVs' onboard cameras. This monitoring verified that the UAVs found the designated POIs.

三架無人機投放時，選派了一名陸軍人員在智慧型任務電腦輸入一組 POI，及優先順序，經優化協調後的任務傳輸給地面站。無人機升空，進入自主模式並在地面站附近盤旋後，即可從地面站接收任務。此時，無人機全部以自主模式飛向不同方向完成賦予之任務。完成任務清單後（以特定的順序偵查特定的 POI），即自行返航至原盤旋位置，等待次一任務賦予或被接管，或以手控方式降落。在飛行及視訊傳輸監控過程中，證實無人機都找到了指定的偵查點。

CONCLUSIONS

Many complex military and civilian applications necessitate the use of teams of unmanned assets to accomplish diverse tasks. The goal for using a team of assets should be to allow the human operator to "work the mission" and not have to be concerned about the details of how to choose an optimal way to accomplish all the tasks. This means that intelligent algorithms and autonomy must support, not take over the decision-making. The Intelligent Tasker user interface makes it easy for a single operator or small group of operators to plan and execute a sophisticated mission with little effort. The GA Optimizer finds an optimal way to assign tasks to assets. The Intelligent Tasker is an add-on, not a replacement, to existing systems that uses existing autonomous controllers and ground stations to allow a complex mission to be carried out by one operator or a few operators in a supervisory capacity. This technology can provide a new way to maximize the use of UAVs in the field and is flexible enough to be applied to many diverse mission scenarios and types of assets (ground, aerial, terrestrial, or even marine vehicles, as well as heterogeneous teams). It can also reduce the number of required trained personnel, thus saving time, money, and possibly lives.

結語

無論軍、民用途，都有採用多機機隊執行各種任務的需要。採用多機機隊執行任務，可以讓操控人員專注於任務之執行，而不必分心思考如何以最佳方式來完成所有任務的細節。如此意味著智慧型運算及自主功能足以支持，卻非取代決策。智慧型任務電腦用戶界面使各別操控員或小型操作組能輕鬆計劃並執行複雜任務。遺傳運算優化器找出無人機任務分配的最佳方式。智慧型任務電腦是額外增加，而非取代現有地面站及操控器之自主系統，讓單一操控員或操控組有監控及執行複雜任務的能力。這項技術提供無人機的另一種運用方式，可應用於許多不同的任務想定與資產類型（地面，空中，陸地，甚至海上載具以及複合載具群），具有充分的靈活度，又不必增加員額，固可節省時間、金錢，甚至人員可能的傷亡。

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參考資料：

1. Richards, A., J. Bellingham, M. Tillerso, and J. P. How. “Coordination and Control of Multiple UAVs.無人機對之多機協調與操控” *Proceedings of AIAA Guidance, Navigation and Control Conference,* Washington, DC, 2002.
2. Chandler, P. R., M. Pachter, S. J. Rasmussen, and C. Schumacher. “Multiple Task Assignment for a UAV Team.無人機隊之多重任務賦予” *Proceedings of the AIAA Guidance*, Navigation and Control Conference, AIAA 2002-4587, Monterey, CA, 2002.

3. Flint, M., M. Polycarpou, and E. Fernandez-Gaucherand. “Cooperative Path Planning for Autonomous Vehicles UsingDynamic Programming.以動態程式規劃自主載具飛行路徑” *Proceedings of the 15th Triennial IFAC World Congress*, Barcelona, Spain, pp. 481 – 487, 2002.
4. Schumacher, C., P. Chandler, and S. Rasmussen. “Task Allocation for Wide Area Search Munitions with Variable PathLengths.以可變路徑廣域搜索彈藥之任務分配” *Proceedings of the American Control Conference*, Denver, CO, June 2003.
5. Schumacher, C. J., P. R. Chandler, M. Pachter, and L. Pachter. “Constrained Optimization for UAV Task Assignments.無人機任務賦予優化之限制” *Proceedings of the AIAA Guidance,Navigation and Control Conference,*Washington, DC, 2004.
6. Shima, T. S., S. J. Rasmussen, and A. G. Sparks. “UAV Cooperative Control Multiple Task Assignments Using GeneticAlgorithms.遺傳運算無人機隊多重任務賦予” *Proceedings of the American Control Conference*, Portland, OR, 2005.
7. Shima, T. S., and C. J. Schumacher. “Assignment of Cooperating UAVs to Simultaneous Tasks Using Genetic Algorithms.遺傳運算無人機隊同時任務賦予” *Proceedings of the AIAA Guidance,Navigation, and Control Conference and Exhibit*, San Francisco, CA, 2005.
8. Darrah, M. A., W. Niland, and B. Stolarik. “Multiple UAV Dynamic Task Allocation Using Mixed Integer Linear Programming in a SEAD Mission.以混合線性程式進行機隊多任務分配” *Proceedings of AIAA Infotech@Aerospace Conference*, Alexandria, VA, 2005.
9. Darrah, M., W. Niland, and B. Stolarik. “Multiple UAV Task Allocation for an Electronic Warfare Mission Comparing GeneticAlgorithms and Simulated Annealing.採取遺傳運算與模擬退火運算實施無人機隊電子戰分工之比較” DTIC Online Information for the Defense Community, ADA462016, 2006.
10. Darrah, M., W. Niland, B. Stolarik and L. Walp. “UAV Cooperative Task Assignments for a SEAD Mission Using GeneticAlgorithms.以遺傳運算實施無人機隊制壓敵防空之任務分配” *Proceedings of Guidance, Navigation and Control Conference*, Keystone, CO, August 2006.
11. Darrah, M., and W. Niland. “Increasing UAV Task Assignment Performance Through Parallelized Genetic Algorithms.以平行遺傳運算提升無人機隊任務分配功能” *Proceedings of Infotech@Aerospace Conference*, Rohnert Park, CA, 2007.

12. Shima, T., S. J. Rasmussen, A. G. Sparks, and K. M. Passino. “Multiple Task Assignments for Cooperating UninhabitedAerial Vehicles Using Genetic Algorithms. 無人機隊多任務賦予之遺傳運算” *Computers & Operations Research*, vol. 33, pp. 3252 – 3269, 2006.
13. Beard, R. W., T. W. McLain, D. B. Nelson, D. Kingston, and D. Johanson. “Decentralized Cooperative Aerial SurveillanceUsing Fixed-Wing Miniature UAVs. 定翼無人機分權式空中監視” *Proceedings of the IEEE*, vol. 94, issue 7, 2006.
14. Matlock, A., R. Holsapple, C. Schumacher, J. Hansen, and A. Girard. “Cooperative Defensive Surveillance Using UnmannedAerial Vehicles.無人機隊之空中防衛監視” *Proceedings of the American Control Conference*, St. Louis, MO, 2009.
15. Darrah, M., E. Fuller, T. Munasinghe, K. Duling, M. Gautam, and M. Wathen. “Using Genetic Algorithms for Tasking Teams of Raven UAVs.以遺傳運算進行渡鴨無人機隊之任務分工” *Journal of Intelligent & Robotic Systems*, vol. 70, issue 1, pp. 361 – 371, 2013.
16. Darrah, M., J. Wilhelm, T. Munasinghe, K. Duling, E. Sorton, S. Yokum, M. Wathen, and J. Rojas. “A Flexible GeneticAlgorithm System for Multi UAV Surveillance: Algorithm and Flight Testing.無人機隊運用彈性遺傳運算實施監視任務之運算與飛試” *Unmanned Systems*, vol. 3, no. 1, pp. 1 – 14, 2015.
17. Darrah, M., L. Pullum, S. Beck Roth, B. Gilkerson, and E. Taipale. “Using Genetic Algorithms for Robust Tasking of MultipleUAVs with Diverse Sensors.運用遺傳運算進行無人機隊個真敢器使用分工” *Proceedings of AIAA Infotech@Aerospace Conference*, Seattle, WA, April 2009.
18. Eun, Y., and H. Bang. “Cooperative Task Assignment/Path Planning of Multiple Unmanned Aerial Vehicles Using GeneticAlgorithms.運用遺傳運算無人機隊多重任務即飛行路線規劃” *Journal of Aircraft*, vol. 46, no. 1, pp. 338 – 343, 2009.
19. Karaman, S., T. Shima and E. Frazzoli. “Task Assignment for Complex UAV Operations Using Genetic Algorithms.運用遺傳運算作無人機多重任務賦予” *Proceedings of the AIAA Guidance, Navigation, and Control Conference*, Chicago, IL, 2009.
20. Zuo, Y., Z. Peng and X. Liu. “Task Allocation of Multiple UAVs and Targets Using Improved Genetic Algorithm.以改良式遺傳運算進行無人機隊多目標分工” *Proceedings of the 2nd International Conference on Intelligent Control and Information Processing*, pp. 1030 – 1034, 2011.

21. Edison, E., and T. Shima. "Integrated Task Assignment and Path Optimization for Cooperating Uninhabited Aerial VehiclesUsing Genetic Algorithms.無人機隊任務分工及飛行路線優化之遺傳運算" *Computers & Operations Research*, vol. 3, no. 8, pp. 340–356, 2011.
22. Sinha, A., A. Tsourdow, and B. White. "Multi UAV Coordination for Tracking the Dispersion of a Contaminant Cloud in anUrban Region.無人機隊之城鎮汙染雲擴散追蹤" *European Journal of Control*, vol. 15, issues 3–4, pp. pp. 441–448, 2009.
23. Techy, L., C. A. Woolsey, and D. G. Schmale III. "Path Planning for Efficient UAV Coordination in Aerobiological SamplingMissions.無人機隊實施生化樣品蒐集之飛行路線規劃" *Proceedings of the 47th IEEE Conference on Decision and Control*, Cancun, Mexico, December, 2008.
24. Maza, I., F. Caballero, J. Capitan, J. R. Martinez-de-Dios, and A. Ollero. "Experimental Results in Multi-UAV Coordination forDisaster Management and Civilian Security Applications.無人機隊實施災害管理與民視安全運用實驗結果" *Journal of Intelligent & Robotic Systems*, vol. 61, issue 1, pp. 563–585, 2011.
25. Liu, X. F., Y. Q. Song, Z. W. Guang, and L. M. Gao. "A UAV Allocation Method for Traffic Surveillance in Sparse RoadNetwork.無人機隊偏鄉道路網交統監控" *Journal of Highway and Transportation Research and Development*, vol. 7, issue 2, pp. 81–87, 2013.
26. Girard, A. R., A. S. Howell, and J. K. Hedrick. "Border Patrol and Surveillance Missions Using Multiple Unmanned AirVehicles.無人機隊之邊境巡邏與監控" *Proceedings of the 43rd IEEE Conference on Decision and Control*, Paradise Island, Bahamas, 2004.
27. U.S. Department of Defense. "Unmanned Systems Integrated Roadmap 2011–2036.無人機系統整合路徑圖" Reference Number 11-S-3613, http://www.acq.osd.mil/sts/docs/Unmanned%20Systems%20Integrated%20Roadma..., accessed August2016.
28. Airforce-technology.com. "RQ-11B Raven Unmanned Air Vehicle (UAV), United States of America." http://www.airforce-technology.com/projects/rq11braven/, accessed August 2016.
29. Goldberg, D. E.*Genetic Algorithms in Search, Optimization, and Machine Learning*. Reading, MA:*Addison-Wesley, 1989.*

本文專有名辭翻譯對照表

ground stations 地面站

autonomous controllers 自主控制器

Intelligent Tasker software 智慧型任務軟體

user interface 用戶介面

Genetic Algorithm Optimizer 遺傳運算優化器

heterogeneous teams 複合載具群

points of interest（POI） 偵察要點

graphical user interface,(GUI) 圖形用戶介面

Bing Hybrid Map Provider Bing 混合地圖產生器

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