

Management of Multiple Heterogeneous UAVs using Capability and Autonomy Visualisation: Theory, Experiment and Result

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Abstract—The interest in utilising multiple heterogeneous Unmanned Aerial Vehicles (UAVs) in close proximity is growing rapidly. As such, many challenges are presented in the effective coordination and management of these UAVs; converting the current *n-to-1* paradigm (*n* operators operating a single UAV) to the *1-to-n* paradigm (one operator managing *n* UAVs). This paper introduces an Information Abstraction methodology used to produce the functional capability framework initially proposed by Chen *et al.* and its Level Of Detail (LOD) indexing scale. This framework was validated through comparing the operator workload and Situation Awareness (SA) of three experiment scenarios involving multiple autonomously heterogeneous UAVs. The first scenario was set in a high LOD configuration with highly abstracted UAV functional information; the second scenario was set in a mixed LOD configuration; and the final scenario was set in a low LOD configuration with maximal UAV functional information. Results show that there is a significant statistical decrease in operator workload when a UAV's functional information is displayed at its physical form (low LOD - maximal information) when comparing to the mixed LOD configuration.

I. INTRODUCTION

Single UAVs for civilian applications such as urban/rural search and rescue, bushfire monitoring and pathogen sampling [1]–[3] are now being used worldwide. There is however a growing interest in using and investigating methods to effectively coordinate and manage multiple heterogeneous unmanned systems [4]–[9]. This paper describes a methodology to produce a functional capability and autonomy framework and to visually represent the UAVs' functional subsystems.

The aim of this study is to investigate the impact on an operator's workload and Situation Awareness (SA) based on the amount and type of information about the subsystem/functional autonomy of a UAV from a group of heterogeneous UAVs. The level of functional autonomy is reflected to the operator visually, without direct textual cues.

To support this aim, a functional capability framework was produced using an Information Abstraction (IA) method [10], [11], which recasts the five levels of abstraction proposed by Rasmussen [12], [13] into three Levels Of Details (LOD), to form a functional subsystems Abstraction Hierarchy (AH).

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II. LITERATURE REVIEW

A. Multiple UAV Management

Past research focused on different aspects of a single operator managing multiple UAVs such as human operators' mental resources in supervisory control of multiple UAVs [14]; establishing automation to assist with command and control [15]; and task-scheduling for managing current and future mission schedules [16]. Cummings and Guerlain [4], and Cummings and Mitchell [14] for instance studied the operator mental capacity and demonstrated that an operator had the mental capacity to supervise up to eight homogeneous UAVs. In their research, it was also identified that operator workload can be reduced [17] with assistance from automation [18].

Supervisory control of multiple UAVs through scheduling of tasks was investigated by Bertucelli *et al.* [19]. Their work explored task scheduling that involves managing the time and information, taking into account the different reaction and wait times of the human mental performance [14]. It also discusses the autonomous generation of schedules for the machines to perform tasks, thus reducing the operators' workload during a mission [19].

B. Level Of Autonomy (LOA)

Huang recognised that LOA does not only apply to a UAV system as a single entity [22], but also to its environment [23]. Chen *et al.* had also identified that LOA applies also to the UAV's functional subsystems [10]. A method or a taxonomy to quantify functional autonomy level was developed by exploring UAV levels.

Perhaps one of the most widely known LOA taxonomy was the Ten Levels of Automation, originally proposed by Sheridan and Verplanck, commonly known as the SV scale [20]. This taxonomy contained ten levels; level 1 represented the system has no portion of autonomous control and it is entirely manually operated, while level 10 represented the system has no portion of manual control and it is entirely automated. Table I illustrates the details of each of the levels in this ten-level taxonomy.

This taxonomy is linear and the attributes used to classify the levels are limited. The human machine interaction process is classified from a linear scale of 1 to 10 (table I), with only job descriptions relating to each level is available. No inclusion of solution generation, solution selection, information availability, decision-making, functional

TABLE I
TEN LEVELS OF AUTOMATION DEFINITION, REPRODUCED FROM [20], [21]

Levels	Description
1	Human does the whole job up to the point of turning it over to the computer to implement.
2	Computer helps by determining the options.
3	Computer helps determine options and suggests one, which human need not follow.
4	Computer selects action and human may or may not do it.
5	Computer selects action and implements it if human approves.
6	Computer selects action, informs human in plenty of time to stop it.
7	Computer does whole job and necessarily tells human what it did.
8	Computer does whole job and tells human what it did only if human explicitly asks.
9	Computer does whole job and tells human what it did and it, the computer, decides he should be told.
10	Computer does whole job if it decides it should be done, and if so tells human, if it decides he should be told.

TABLE II
COMPARISON TABLE FOR OODA [28], DYNAMIC DECISION
MAKING [29] AND ACL [22]

ACL	Dynamic Decision Making	OODA
Perception/SA	State of Environment	Observe
Analysis/Coordination	Situation Awareness	Orient
Decision Making	Decision	Decide
Capability	Performance of Actions	Act

TABLE III
MODERATOR, GENERATOR AND DECIDER SCALE OF
AUTOMATION [18], [25], [30]

Moderator/Generator/Decider Level	Who assumes the role?
1	Human
2	Mixed, but more human
3	Hybrid
4	Mixed, but more automation
5	Automation

subsystem representation or any other information processing flow attributes [10], [11], [21], [24], [25] are present. These additional attributes are crucial to model the functional LOA for the multiple heterogeneous UAV framework (further discussions in section III-C).

The fundamental question of how autonomous a system is and how could this autonomy be classified has been explored by a number of researchers at the Air Force Research Laboratory [22].

Autonomous Control Levels (ACL) for instance was developed to capture the idea of both, but not limited to the SV scale [20], [26] and the 3D intelligence space [27]. The resolution of the scale is increased to eleven levels, while it retains the multi-dimensional human-computer interaction feature presented in the 3D intelligence space [22].

The ACL taxonomy introduces the information process flow, where four common attributes are incorporated [22].

- Perception/Situational Awareness: The ability to acquire live information from the surroundings
- Analysis/Coordination: The ability to adapt and coordinate with the remainder of the UAV group using the acquired live information and health of the system
- Decision Making: The ability to make appropriate decisions based on the available data
- Capability: The ability to carry out tasks autonomously as required by the scenario based on the decision (autonomously or manually)

These four attributes were similar to Boyd's model of decision cycle; Observe, Orient, Decide and Act (OODA) [24], [28] and Endsley's dynamic decision making model [29]. Table II illustrates the equivalence between the three models

of information process flow. The ACL taxonomy is extensive and considers the information processing flow of each level of automation. However the ability to classify a UAV's functional systems and subsystems is not presented in ACL. The purpose of ACL is to classify autonomy in terms of human-computer interaction, and not in terms of UAV's onboard functional systems and subsystem LOA.

A recently proposed taxonomy is the Human Automation Collaboration Taxonomy (HACT) [18], [25], [30]. The attributes proposed in this taxonomy are completely independent from the existing taxonomies of LOA with some similarities shared amongst ACL [22]. HACT employs Parasuraman *et al.* [21] information processing flow model, and concentrates on the Decision-Making Process (DMP). This information process flow model also has similarities to Dynamic Decision making model [29] and the OODA model [28]. There are three basic roles in HACT; Moderator, Generator and Decider. The role of the moderator is to ensure the entire information processing flow carried forward at necessary rates and standards, these roles are classified into five levels and each level is defined by the responsible agent (table III). The roles of the generator and the decider have five levels (table ?? too).

HACT considered collaborative decision making, the roles, the levels, and the three primary characteristics; Functional Transparency, Information Transparency and Interactivity. These characteristics can assist in improving the SA of the human agent, as the levels that governs these characteristics indicated the opacity of the automation process, information feedback and the interactivity or between the

machine and the human agent. A secondary characteristic defined in HACT is the adaptability of each of the basic roles and their primary characteristics which is defined as the ability to manipulate the levels of a system without the human intervention [25].

C. Human Performance Metrics

Two metrics are commonly used to evaluate the effects of UAVs' functional capability and autonomy visualisation on human performance; Situation Awareness (SA), and workload.

SA is defined as a person's *perception of the elements of the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future* [31].

In this, Endsley's SA is considered in this work as a measure of operator performance, as it provided three levels of awareness that were potentially experienced by the operator. Each level is based on the assumption that the previous level is satisfied. The first level of SA is information perception; to satisfy this level, the operator needed to realise and acknowledge a change, or difference in the information presented. The second level is comprehension; to satisfy this level, the operator must not only acknowledge a difference, but must also be able to determine what the difference is prior to a change in the presentation of information. The third level is projection; where the operator must be aware of the change in information's implications on the near future.

There are different methods to determine SA [32], [33]. In this work, the operator's SA was acquired using SAGAT [31]; where a set of predesigned questionnaires based on the operator's first two level of SA is administered upon the conclusion of each experiment [31].

Workload is an important attribute as it is directly linked to the operator performance as suggested by a previous study [17], [21], [34]. This attribute is incorporated as a dependent variable during the experiments. Workload in this study is defined as the *stress experienced by a person attempting to comprehend all the information presented* [10]. It can also be considered as the mental workload that the operator experiences when he or she attempts to comprehend too much information simultaneously. The operator's workload can be captured using NASA-TLX [35], where the operator was given a set of attributes on a rating form, the operator is required to first assign a weight, then put a score to each of these attributes to achieve a normalised index score that is indicative of the workload experienced by the operator.

III. THEORY AND DESCRIPTION

Three concepts; Information Abstraction (IA), Level Of Detail (LOD) and Functional-LOA (F-LOA) are introduced as the foundation of the UAV capability and autonomy visualisation framework.

TABLE IV
UAV'S FUNCTIONAL LEVEL OF DETAILS MAPPED TO THE FIVE LEVELS OF INFORMATION ABSTRACTION

Levels of Abstraction	Levels of Detail (LOD)
Functional purpose level	High LOD
Abstract function	High LOD
Generalized functions level	Medium LOD
Physical function level	Low LOD
Physical form level	Low LOD

A. Information Abstraction (IA) and Capability Framework

IA, similar to Abstraction Hierarchy (AH) [13]; is a process that abstracts a UAV's functional system and subsystem information to form a functional capability framework.

Figure 2 illustrates the functional capability framework; the subsystem functions abstraction, and the information complexity layers. The subsystem functions abstraction dimension's primary systems has a hierarchical control loops for a single UAV [7]. Four main primary systems (branches) are derived 1 for visualisation purposes and defined as:

- **System Health:** The autonomy involved in (sub)system's self health monitoring capability.
- **Navigation:** The ability to self replan new paths given hazardous situations.
- **State/Autopilot:** That UAV's ability to self command to achieve specific altitude, speed and path.
- **Payload:** The searching capability onboard the UAV, the ability to perform searching operation during the experiment.

The information complexity layers (abstracted vertically) is a recast of the five levels of abstraction proposed by Rasmussen [12]. Table IV illustrates the mapping of the five levels of abstraction to the three levels of functional subsystem details.

An example of a generic UAV system capabilities abstracted into each of the four branches using the IA method is shown in figure 2. In each branch, further subsystems are abstracted into a more direct/raw informational level. For example, the left-most branch in figure 2 shows the overall health hierarchy of the UAV from the highest Level of Detail (LOD). The next level following is *UAV Data*, which describes more specifically the status of the UAV health. The lower the LOD is, the more direct and specific information are revealed.

This two dimensional framework (figure 2) is used to assess the operator's SA and evaluate their workload. The expectation is that during operation, the autonomy levels of multiple UAVs with heterogeneous autonomy can be reflected through the LOD representation.

B. Level Of Detail (LOD)

The LOD controls three levels of subsystem details as shown in Table IV, each level displays greater amount of information about the subsystems:

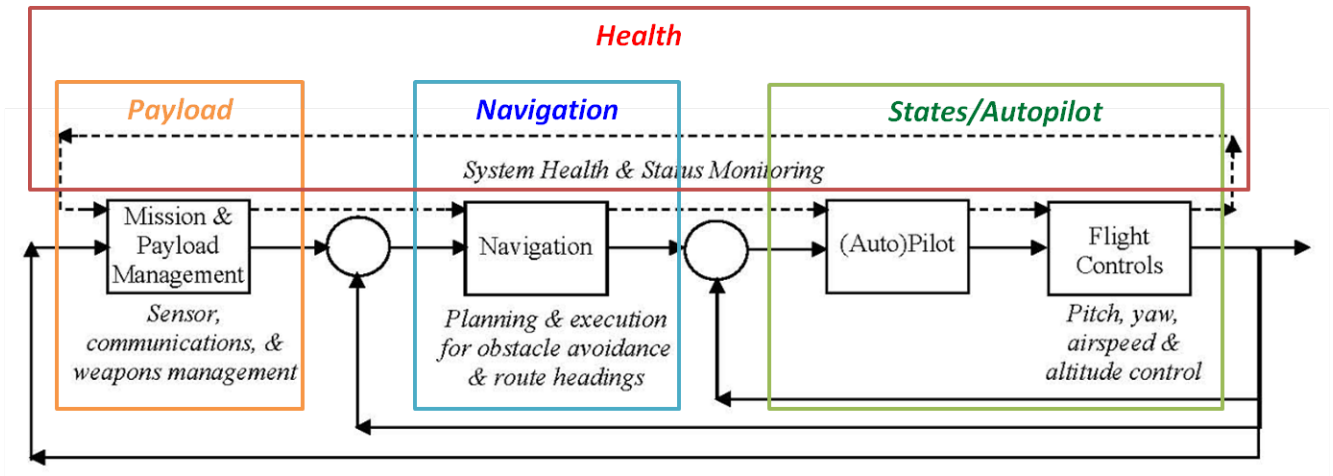


Fig. 1. Functional branches mapped to the hierarchical control loops for a single UAV [7].

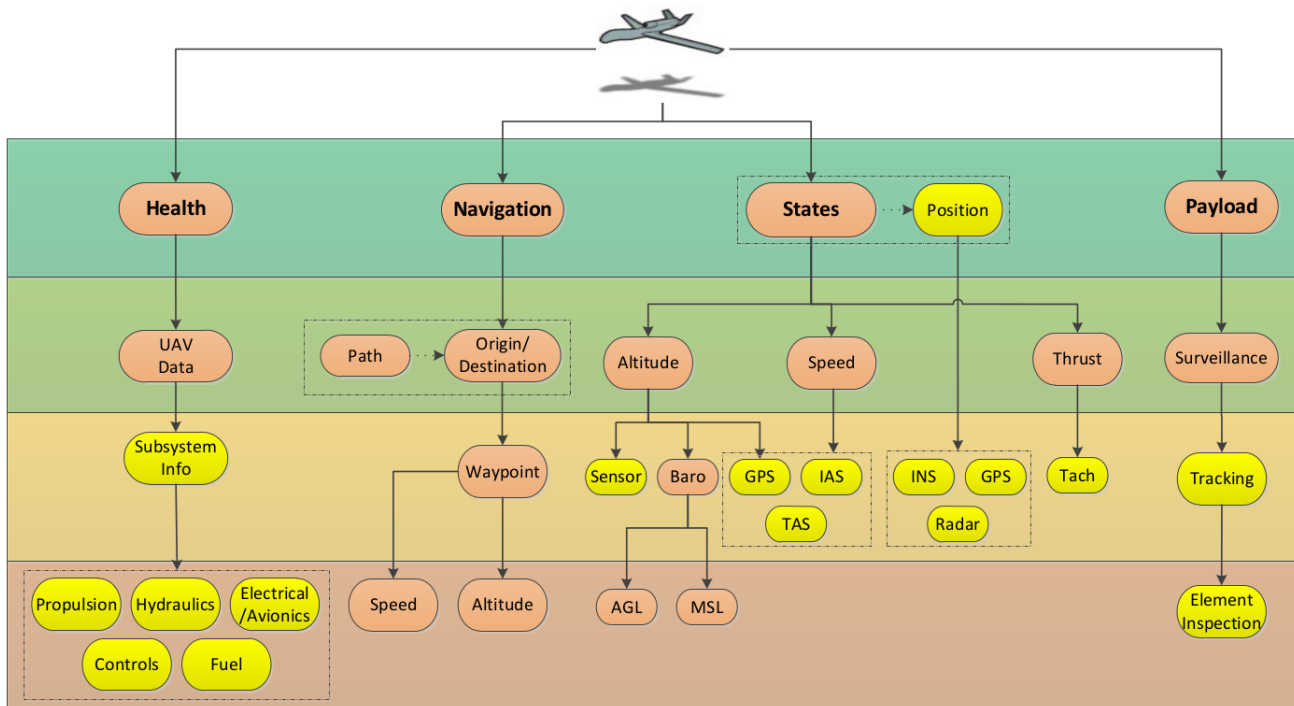


Fig. 2. UAV Functional Capability Framework.

- **Higher Level (HL):** Highest level of abstraction of subsystem information, showing a generalised representation of the functional subsystems, using methods such as colour coding, or differential shape representation.
- **Medium Level (ML):** Enhanced abstraction of details, showing more specific functional subsystem information. These are also colour coded to aid the operator with data interpretation.
- **Lower Level (LL):** Least amount of abstraction of the subsystem information, showing detailed components in its physical (textual) form.

The capability framework shown in figure 2 illustrates four levels of subsystem details. As this is a framework in its earlier form, it should not be confused with the final/three levels of subsystem details presented in this section.

Figure 3 illustrates the visual representations to each system's LOD. This table is a 3 x 3 matrix divided by the LOD and the subsystems. A lower LOD level reveals more direct and raw information about the UAV system.

C. Functional Level Of Autonomy (F-LOA)

The concept of Level Of Autonomy (LOA) has been used as a scale to describe UAV autonomy [21]. However, through recent studies, it has been established that autonomy should










	High LOD	Medium LOD	Low LOD
Subsystem Health	Normal Icon 	Pie Chart Health 	Detailed Panel 
Navigation	No Path Display 	Waypoint Display 	Waypoint and Path Display 
States/ Autopilot	Position Only (via Icon) 	1 st Level Detailed Panel 	2 nd Level Highly Detailed Panel 
Payload/ Searching	<i>Relate to figure 4</i>		

Fig. 3. Visual representation chart of UAV's systems under a full range of LOD.

not be viewed as a feature of a UAV in isolation [22], as each UAV has several subsystems and functionalities [10]. Therefore, the concept of Functional LOA (F-LOA) was introduced by Chen *et al.* [10].

F-LOA was used to describe how autonomous a specific functional subsystem of a UAV was, rather than the entire UAV entity described by a single LOA scale [20]. In this study, the F-LOA of a UAV is characterised into three levels, each level requires an increase in the amount of manual input to each of the subsystems:

- **High Autonomy (HA):** No manual input is required, the UAV is able to make appropriate internal adjustments to perform the required task.
- **Part Autonomy (PA):** Part manual input is required by the operator, where the UAV also makes certain decisions based on the scenario.
- **Low Autonomy (LA):** Near full manual control of the UAV is required, with minimal to no decisions made by the UAV itself.

This LOA structure is similar to that of the Human Automation Collaboration Taxonomy (HACT) [30], where the LOA granularity is reduced for cross-application to the different UAV subsystems.

IV. EXPERIMENT SOFTWARE DESIGN

A graphical software representation is implemented and tested to verify the effect of the proposed frameworks. All the visible components are developed using the Java MT4J multi-touch framework with the gesture detection engine using DT-Ivy. The experiment is run on a multi-user touch-sensitive tabletop device (Circle Twelve Diamond-Touch DT104 [36]) to encourage a more intuitive way to interact with the UAVs and the environment. The design of the experimental elements is organised in a layered approach; where each layer above is of a higher level of abstraction from the lower layers. The functional LOA is represented through the different icons and the UAVs' functional capability visualisation. In general, a higher LOD indicates that the information about a specific branch is more concise.

A. UAV Functional Level of Autonomy Representation

Two methods of representing F-LOA of a UAV are presented; through its icons indicating the physical autonomy levels and one to show an alternate plan display suggesting its autonomy levels and capability to generate alternate plans during mission critical situations [11]; however, this paper will not cover the latter form of autonomy visualisation.

1) *Visualisation using Icons:* There are four subsystems in each UAV as outlined in section III-A. Each subsystem contains an F-LOA. Each LOA capability is represented by

TABLE V

VISUAL REPRESENTATIONS OF A UAV'S FUNCTIONAL LOA THROUGH ICONS

Visual Icon/Colour	F-LOA Description
Triangle	High Nav. Auto
Circle	Part Nav. Auto
Square	Low Nav. Auto
Green	High Health Monitoring Auto
Yellow	Part Health Monitoring Auto
Red	Low Health Monitoring Auto
No Direction Line	High State/Autopilot Auto
Dashed Direction Line	Part State/Autopilot Auto
Solid Direction Line	Low State/Autopilot Auto

a different configuration visually, either by shape, colour, or pattern as illustrated in figure 4 and Table V. These were combined with the situations of the experiment to present the autonomy of various functional subsystems, such as the example in figure 5a.



Fig. 5. (a) UAV with low navigation, high health monitoring, and high state/autopilot autonomy. (b) Icon of fuel station used for UAV refueling. (c) Search target (red) and search zone (yellow)

Figure 5 a shows a green, square icon with a numerical number attached, the numerical value denotes the UAV number/code. In the example shown in figure 5, the numerical value 3 denotes that this unit UAV_3 , which contains with low autonomy on the navigation functionality (denoted by the square icon) and a high autonomy on the health monitoring/reporting functionality (denoted by the green icon). It also has a high autonomy on its state/autopilot functionality (denoted by no direction line of any type).

B. Event/Hazard Representation

The experiment was designed to have some hazardous events that require the participants to acknowledge and overcome by manipulating the UAVs. These events are represented using either grey or red elliptical patches, denoting hazardous clouds or zones (figure 6).

There are two conditions of hazardous events:

- **Grey zones:** If a UAV enters the marked grey regions/events, there may be the possibility of severe damage to the UAV. In this situation, the UAV can no longer carry out its task. On the other hand, the UAV may also vacate the event without any consequences. The possibility of this is set to 50%, therefore all the participants experience the same level of possibility of a UAV failure.



Fig. 6. Event or hazard area visual representation.

- **Red zones:** If a UAV enters a marked red region/event, a failure of UAV systems was imminent. That is, the failure rate is now set to 100%; the UAV (if decided by the operator to go through) can not exit the hazardous zone and carry on normal operations.

C. Refuel Station

Figure 5b indicates the area where the UAV could reach to refuel. It requires no special controls, and it is used only once during the first segment of the experiment. When the UAV approaches and enters the vicinity of the icon, the refuelling process automatically begins. The entire process takes approximately eight seconds to complete (indicated by the blue progress bar above the icon). During this time, the UAV fuel tanks are filled to approximately 80%, and the UAV continues to its designated search zone.

D. Search Zone

There are 12 search zones in total throughout the experiment. In each search zone, there are a designated number of person objects which the operator must differentiate from the decoys objects and select, and the zones are represented as seen in figure 5 (right). However, if a UAV was lost (due to various reasons) during the course of the experiment, the subsequent target search zones will not be searched. Search paths are automatically deployed the UAVs to carry out its search operations once they reach the search zone. And depending on the navigation LOD for the specific segment of the experiment, this pattern may or may not be visible to the operator.

V. EXPERIMENT SET-UP AND PROCEDURE

The mission for the operator (participant) is to manage four rotary wing UAV as well as their system health levels, flight paths and flight profiles, while identifying a number of items of interest from a number of decoys in each of the 12 search areas.

This experiment is broken into three segments, each segment lasts for approximately 10 minutes with no extended breaks in between segments.

There are two sets of questionnaires for each segment. Each round consists of a situation awareness and a mental











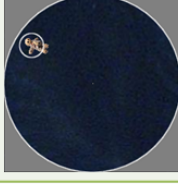
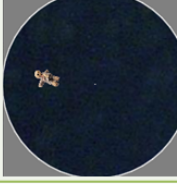
	High Autonomy	Part Autonomy	Low Autonomy
Subsystem Health	Green Icon 	Yellow Icon 	Red Icon 
Navigation	Triangle Icon 	Circle Icon 	Rectangle Icon 
States/ Autopilot	No Direction Line 	Dotted Direction Line 	Solid Direction Line 
Payload/ Searching	No Image Popup 	Image Popup 	Image Always Visible 

Fig. 4. F-LOA level visualisation for all main systems of a UAV

TABLE VI

FUNCTIONAL LOA ASSIGNMENT FOR EACH UAV IN SEGMENT 1 (HA: HIGH LOA, PA: PART LOA, LA: LOW LOA).

Callsign	Health	Nav.	State	Payload
UAV ₁	HA	HA	HA	PA
UAV ₂	LA	HA	HA	PA
UAV ₃	HA	PA	HA	PA
UAV ₄	HA	HA	HA	HA

TABLE VII

LOD ALLOCATION FOR EACH UAV IN SEGMENT 1 (HL: HIGH LOD, ML: MEDIUM LOD, LL: LOW LOD).

Callsign	Health	Nav.	State	Payload
UAV ₁	HL	HL	HL	HL
UAV ₂	LL	HL	HL	HL
UAV ₃	HL	HL	HL	HL
UAV ₄	HL	HL	HL	HL

workload questionnaire. These questionnaires are designed to capture the operator's SA and mental stress at different stages of the experiment. Their overall performance is also logged via internal logging system implemented in the experiment itself.

A. Segment 1 - High LOD (Minimal Information), Mixed LOA

The first segment was designed with the specification illustrated in Tables VI and VII.

The segment has a mix of autonomy levels throughout the four subsystems of a UAV in this segment. An overall of high LOD is set as the baseline level of operator performance and response.

Two UAVs experience events during this segment:

- UAV₂: This UAV is deployed with a low fuel level. It

is programmed to encounter a hazardous zone, which would cause further impact to the fuel level. However, due to the autonomy settings for this segment, auto-replanning flight path is available and thus a new route is generated autonomously to direct the UAV to the refuelling point.

- UAV₃: This UAV has a lower F-LOA in the navigation subsystem. Due to a hazardous event, new routes are proposed as a resolution. The participant must act on this new route by selecting one of the two options prior to entering the hazard. Once the UAV enters the hazard, there is a 50% possibility that this UAV will be lost during or after the hazard.

TABLE VIII

F-LOA ASSIGNMENT FOR EACH UAV IN SEGMENT 2 (HA: HIGH LOA, PA: PART LOA, LA: LOW LOA).

Callsign	Health	Nav.	State	Payload
UAV ₁	HA	PA	HA	PA
UAV ₂	HA	HA	PA	PA
UAV ₃	HA	HA	HA	HA
UAV ₄	PA	HA	HA	HA

TABLE IX

LOD ALLOCATION FOR EACH UAV IN SEGMENT 2 (HL: HIGH LOD, ML: MEDIUM LOD, LL: LOW LOD).

Callsign	Health	Nav.	State	Payload
UAV ₁	HL	ML	HL	ML
UAV ₂	LL	HL	ML	ML
UAV ₃	ML	ML	HL	ML
UAV ₄	ML	HL	HL	HL

TABLE X

F-LOA ASSIGNMENT FOR EACH UAV IN SEGMENT 3 (HA: HIGH LOA, PA: PART LOA, LA: LOW LOA).

Callsign	Health	Nav.	State	Payload
UAV ₁	HA	PA	PA	PA
UAV ₂	HA	PA	HA	PA
UAV ₃	PA	PA	HA	PA
UAV ₄	LA	HA	LA	HA

B. Segment 2 - Mixed LOD (Hybrid Information), Mixed LOA

The second segment is designed with the following specification:

Similar to segment one, there is a mix of autonomy levels in this segment. It is designed to display the appropriate LODs for each UAV depending on the situation, and consequently enables the experimenter to capture the operators' mental, situational, and mission performance for this configuration. The hypothesis is that there is a positive impact on the operator's performance.

Two UAV events occur during this segment:

- **UAV₂**: This UAV experiences a sudden drop of F-LOA of the *States* subsystem from full to part autonomy, thus requiring operator's manual command of UAV's speed and altitude.
- **UAV₄**: There is a change with the UAV health. The operator is expected to keep close monitor of the health status and acknowledge that there is an increased rate of fuel burn.

1) *Segment 3 - Low LOD (Maximal Information), Mixed LOA*: The third and final segment is designed with the following specification:

This segment also has a mixed F-LOA. However, the UAVs displayed all its information systems (lowest LOD), which allows the participant access to the most complete and

TABLE XI

LOD ALLOCATION FOR EACH UAV IN SEGMENT 3 (HL: HIGH LOD, ML: MEDIUM LOD, LL: LOW LOD).

Callsign	Health	Nav.	State	Payload
UAV ₁	HL	HL	ML	ML
UAV ₂	HL	HL	HL	ML
UAV ₃	ML	ML	HL	ML
UAV ₄	LL	HL	LL	ML

raw set of subsystem status.

There are two events occurring for two UAVs during this segment:

- **UAV₁**: The automated flight subsystem and health subsystem are reporting malfunctions due to atmospheric conditions, thus requiring manual monitoring and partial adjustment of the UAV's state/piloting functions.
- **UAV₄**: There are some onboard failures for this UAV, which results in the participants being required to manually operate this UAV by managing its speed, altitude and direction. However, due to severe failures, most participants are not able to perform basic manipulations to the UAV, thus the participants are required to acknowledge the event.

2) *Workload Measurement*: This study focuses on the operators' (participants') workload is also used as an indication of their performance. To assess the workload experienced by the participants, NASA-TLX [35] is employed.

The participants' workload score is evaluated from a form which asks the participant to rate the different attributes of workload, and the significance of each of those attributes. These scores are then tallied and summarised to produce a workload index (in a form of a percentage).

The NASA-TLX evaluation form is administered to the participants along with the SAGAT queries. It is expected that there will be a change of participant workload, in the different segments of the experiment, due to the information that the participant is required to process.

3) *SA Measurement*: The operators' (participants') *perception* and their *comprehension* of both their mission environment and UAV capabilities are the metric of SA measurement. To assess the participants' SA, SAGAT [37].

The SAGAT queries used in this experiment are designed based on levels one (perception) and two (comprehension) SA. However, it is modified where level one SA was the participant's environmental perception (environmental data, such as the UAV flight path and hazard zones etc.), and level two is the asset comprehension (UAV subsystem information, such as fuel quantity, navigation autonomy etc.).

During the experiment, there are ten SAGAT queries to each segment, which consisted a mixture of environmental perception and asset comprehension queries. These queries are answered by the participants to the best that they can recognise and recall. This reflects their SA of the segment that they have just completed.

TABLE XII

T-TEST STATISTICS OUTPUT OF MEAN WORKLOAD SCORE WITH 24 SAMPLES

Mean Workload Score	Sample Size
High LOD (minimum info)	58.50
Mixed LOD (mixed info)	59.42
Mixed LOD (mixed info)	59.42
Low LOD (maximum info)	66.63

4) *Hypothesis for Segment 1 and Segment 2*: The hypotheses used to test for significant difference between segment 1 and segment 2 workload are:

$$H_0 : Seg_1 WL = Seg_2 WL \quad (1)$$

$$H_a : Seg_1 WL \neq Seg_2 WL \quad (2)$$

The hypotheses used for SA are:

$$H_0 : Seg_1 SA = Seg_2 SA \quad (3)$$

$$H_a : Seg_1 SA \neq Seg_2 SA \quad (4)$$

5) *Hypothesis of Segment 2 and Segment 3*: The hypotheses used to test for significant difference between segment 2 and segment 3 workload are as follows:

$$H_0 : Seg_2 WL = Seg_3 WL \quad (5)$$

$$H_a : Seg_2 WL \neq Seg_3 WL \quad (6)$$

And for SA are:

$$H_0 : Seg_2 SA = Seg_3 SA \quad (7)$$

$$H_a : Seg_2 SA \neq Seg_3 SA \quad (8)$$

VI. RESULT AND DISCUSSION

Results on workload and SA were obtained via querying/self-rating techniques and analysed using within-subject analysis of variance; T-Test method for both performance measures.

A. Workload

Operators' workload scores are analysed using SPSS, performing both two and one tailed T test.

Table XII shows the mean workload scores of each comparison test based on 23 test samples.

The p -value for the first comparison pair is 0.728, one can establish that between segments 1 and 2, the null hypothesis (H_0) can be accepted, that is; a paired samples T-Test reveals that there is no statistically reliable difference between the mean workload score of the minimum (high LOD) amount of information display configuration ($\bar{x}_1 = 58.5$, $\sigma = 10.245$) and the mixed amount of information display configuration ($\bar{x}_2 = 59.42$, $\sigma = 14.711$), at $CI = 98\%$, $\alpha = 0.02$.

The p -value of the second paired comparison (segment 2 and segment 3) of workload is 0.014, one can establish that between segments 2 and 3, the null hypothesis (H_0) can be rejected at confidence interval of 98%, that is; a paired samples T-Test reveal a statistically reliable difference

TABLE XIII

T-TEST STATISTICS OUTPUT OF MEAN SA RATING SCORE WITH 23 SAMPLES

Mean SA Score	Sample Size
High LOD (minimum info)	0.5799
Mixed LOD (mixed info)	0.5712
Mixed LOD (mixed info)	0.5712
Low LOD (maximum info)	0.5292

between the mean workload score of the mixed amount of information display configuration ($\bar{x}_2 = 59.42$, $\sigma_2 = 14.711$) and the maximum (low LOD) amount of information display configuration ($\bar{x}_3 = 66.63$, $\sigma_3 = 8.459$), at $CI = 98\%$, $\alpha = 0.02$.

A one-tailed T-Test was conducted to further investigate the effect on operator workload hypothesis between segment 2 and 3 with CI of 98%:

$$H_0 : Seg_2 WL = Seg_3 WL \quad (9)$$

$$H_a : Seg_2 WL < Seg_3 WL \quad (10)$$

H_0 is rejected if the t -value of one-tailed is less than that of the observed, and $\bar{x}_2 < \bar{x}_3$ must also comply.

$$(t_{1-tailed} \approx 2.492) < (t_{obs} = ||2.666||) \quad (11)$$

$$(\bar{x}_2 = 59.42) < (\bar{x}_3 = 66.63) \quad (12)$$

As seen above, both equations' conditions are satisfied. Therefore one can conclude that a T-Test reveal a statistically reliable evidence to suggests that the mean workload score of experiment segment 2 ($\bar{x}_2 = 59.42$, $\sigma_2 = 14.711$) is higher than segment 3 ($\bar{x}_3 = 66.63$, $\sigma_3 = 8.459$) at $\alpha_{1-tailed} = 0.01$.

B. Situation Awareness

This section presents the results for SA.

Table XIII shows the mean SA scores of each comparison test based on 23 test samples.

The p -value for the first pair of SA comparison is 0.899. A Confidence Interval (CI) α value of 0.02 is used. The null hypothesis (H_0) can be accepted between segments 1 and 2 at CI of 98%. This means that the paired samples T-Test reveals that there is no statistically reliable difference between the mean SAGAT score of experiment the minimum (high LOD) amount of information display configuration ($\bar{x} = 0.5799$, $\sigma = 0.20776$) and the mixed amount of information display configuration ($\bar{x} = 0.5712$, $\sigma = 0.24373$), at $p = 0.899$, $\alpha = 0.02$.

The p -value of the second pair of comparison to be 0.417, one can establish that between segments 2 and 3, the null hypothesis (H_0) is accepted at a confidence interval of 98%, which suggests that this paired samples T-Test reveals a lack of statistically reliable difference between the mean SAGAT score of the mixed amount of information display configuration ($\bar{x} = 0.5712$, $\sigma = 0.24373$) and the maximum (high LOD) amount of information display configuration ($\bar{x} = 0.5292$, $\sigma = 0.18292$), at $p = 0.417$, $\alpha = 0.02$.

TABLE XIV

T-TEST RESULTS OF WORKLOAD AND SA MEASUREMENT AT CI = 98%.

Comparison Pair	Metric	p - value	Outcome
High & Mixed LOD	Workload	0.728	No Sig. Diff.
Low & Mixed LOD	Workload	0.014	Significant Diff.
High & Mixed LOD	SA	0.899	No Sig. Diff.
Low & Mixed LOD	SA	0.417	No Sig. Diff.

C. Experiment Set-Up

The mixed display of the UAVs' LOD information through the application of the proposed functional capability framework has shown significant statistical evidence that there is a reduction in operator workload when compared to the maximum display of UAVs' LOD information (low LOD). Also, with this decrease in workload, there is no significant statistical difference in the operator SA.

Table XIV summarises the statistical comparison between the three segments/scenario configuration.

Further observations on operator workload indicate that the experiment participants suggest that segment 1 has too little information to give the confidence on UAVs' functionality, as the participants were continuously trying to access more information even after they were explicitly instructed not to do so. There are also indicators that suggest the participants felt segment 3 has too much information which is not needed, as exhibit a certain level of surprise when the segment became active.

The participants were able to demonstrate some awareness of specific aspects of the experiment, but can not produce accurate recounts of the event details.

VII. CONCLUSION

This paper has revisited the functional capability framework first introduced by Chen *et al.* [10] and briefly described the IA methodology to produce the framework.

Furthermore, experiments involving 25 participants were conducted on a touch interactive table to validate the effects of applying mixed LODs to multiple autonomously heterogeneous UAVs on operator workload and SA, when comparing with high and low LOD configurations.

Results were collected and tested with comparing the means statistical T-Test. At 98% confidence interval, there is no significant statistical difference in operator workload between a high LOD (least information/abstracted form) and a mixed LOD configuration. However, there is sufficient statistical evidence to show that there is a significant difference in operator workload between a mixed LOD and a low LOD (most information/physical form). Further analysis using a one-tailed T-Test shows that in a mixed LOD configuration, there is significant decrease in operator workload when comparing to a low LOD (most information) configuration.

SA results were also collected and testing using the same statistical T-Test. At 98% confidence interval, there is no significant statistical difference between a high LOD (least information) and a mixed LOD configuration, as well as

between a mixed LOD and a low LOD (most information) configuration.

Therefore, by applying the functional capability framework in a mixed LOD configuration to manage multiple autonomously heterogeneous UAVs; a significant decrease in operator workload is evident when comparing to the framework in a low LOD (most information) configuration, while operator SA is maintained in any configurations.

Ongoing work will focus on assessing the effects of autonomy visualisation for flight path displays on operator workload and SA.

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