HALO the Winning Entry to the DARPA UAVForge Challenge 2012

Stephen D. Prior[1], Siu-Tsen Shen[2], Mehmet Ali Erbil[1], Mantas Brazinskas[1], and Witold Mielniczek[1]

[1] Faculty of Engineering and the Environment, University of Southampton, Highfield Campus, Southampton SO17 1BJ, United Kingdom
s.d.prior@soton.ac.uk
[2] Department of Multimedia Design, National Formosa University, 64 Wen-Hua Rd, Hu-Wei 63208, Taiwan
stshen@nfu.edu.tw

Abstract. The DARPA UAVForge challenge was designed to bring together a diverse group of UAV enthusiasts to develop the next generation, low cost, small unmanned air system (SUAS) for perch and stare operations in a military context. The challenge combined a web-based collaboration site with a live competitive fly-off event held at Fort Stewart, Georgia, USA in May 2012. UAVForge was a Defense Advanced Research Projects Agency (DARPA) and Space and Naval Warfare Systems Center, Atlantic (SSC Atlantic) initiative to leverage the exchange of ideas among an international community united. More than 140 teams and 3,500 registered citizen scientists from 153 countries participated in this year long event. From several selection rounds, a core of nine teams competed in the fly-off event and in June 2012 Team HALO from the UK was declared the winner scoring 47.7 points out of a maximum possible 60 points, with their co-axial tri-rotor Y6 design.

Keywords: DARPA, UAVForge, SUAS, Crowd Sourcing, NLOS.

1 Introduction

In July 2011, DARPA together with SSC Atlantic jointly announced a crowd sourcing competition to develop the next generation, low cost, Small Unmanned Air System (SUAS) for use in a perch and stare military scenario. The target unit cost per system would ideally be less than US$10k.

The concept was for a man-portable, Vertical Take-Off and Landing (VTOL) SUAS to have the capability to be carried into a forward operating base from where it would be launched by a single operator on a mission to reconnoiter a target some 3.2 km away in a Non Line Of Sight (NLOS) location, which consisted of an urban terrain environment, namely the Colmar UTS at Fort Stewart, Georgia, USA.

The challenge began with Milestone 1, a 1 min 'Concept Video Submission' stage which had the effect of stimulating debate and encouraging team formation.

A. Marcus (Ed.): DUXU/HCII 2013, Part III, LNCS 8014, pp. 179–188, 2013.

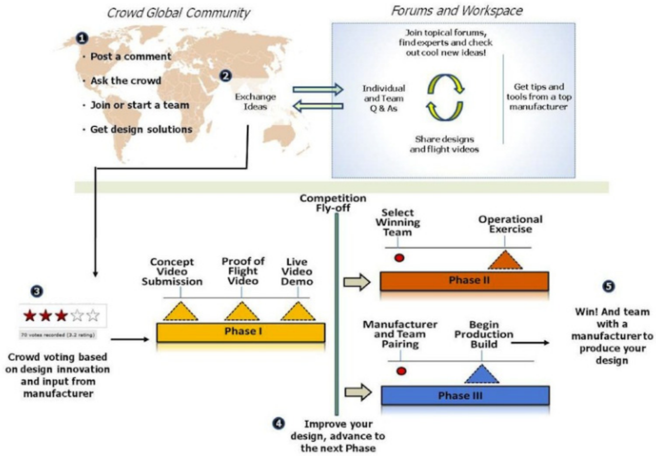

Fig. 1. DARPA's Crowd Sourcing Model [2]

Teams consisted of individuals, companies, universities, as well as groups of enthusiasts brought together either by the challenge or already working on Open Source UAV projects [1].

As stated on the UAVForge website:

"This challenge is guided by crowd sourcing. UAVForge provides you with the virtual environment and tools necessary to collaborate independent of geographic location, education, profession, or experience. Individuals, ad hoc teams or any other formative organizations are encouraged to submit innovative ideas, designs, algorithms, materials, etc. where other members of the crowd can respond, vote, comment and contribute." [2]

By the deadline of November 2011, forty-eight submissions had been received. These consisted of rotary-winged as well as fixed-winged hybrids, tail sitters, ducted-fans, etc. There was even a suggestion to attach a camera to an eagle and train it to fly the mission. By far the most prevalent solution was a conventional quadrotor design in an 'X' or '+' configuration. Registered users had the opportunity to post comments, ask questions and ultimately score each design out of five stars. The top scoring team (4.128) at this point was MAAV - A team from the University of Michigan with sponsorship from Northrop Grumman. The HALO team's submission was ranked 24th with a score of 2.4.

The next phase, Milestone 2, was a 1 min 'Proof of Flight' video. By the submission date in January 2012, twenty-two teams had entered. The necessity to actually prove that something could be built and could fly whittled down the entries by over 50%. The clear favorite at this point was the GremLion team (3.148) from the National University of Singapore with their co-axial rotorcraft, moving up from second place in the previous round. At this juncture, the HALO team was also on the move, ranked 8th with a score of 2.611 with our detachable arm Y6 design.

The final phase (Milestone 3) before the fly-off, was a 'Live Fly Demo' whereby each team had to operate their UAVs to perform a series of set tasks whilst connected via Skype to the organizers in the US. Twenty teams entered this phase by the March 2012 deadline and the leader at this point was the Dhaksha team (4.487) from MIT India with their range of quadrotors and hexrotors. Interestingly, after using a filtered crowd rating system, the icarusLabs team from MIT in the USA came out top with a score of 3.59. Team HALO was in fifth place with a score of 3.02.

Analysis of these systems shows that there were: 10% Single Rotor, 10% Tandem Rotor/Co-Axial, 35% Quadrotor, 10% Quadrotor (Tail sitter), 10% Hybrid Rotor/Fixed Wing, 20% Hexrotor/Y6, 5% Octorotor.

After further deliberation by an independent governmental judging panel based in the US, the top twelve teams going to the fly-off were announced:

Table 1. Final Fly-off Selection

Team Name	Country	UAV Type
AeroQuad	Intl.†	Y6
ATMOS	The Netherlands	Tail sitter 4Rotors
DHAKSHA	India	Octorotor
Extractor X	Singapore	Tail sitter 4Rotors
GremLion	Singapore	Co-axial
HALO	UK	Y6
icarusLabs	USA	Hybrid Ducted-Fan
Navy EOD	USA	Quadrotor
Phase Analytic	USA	Quadrotor
SQ-4 Recon	UK	Quadrotor
SwiftSight	USA	Quadrotor
WIDrone	Italy	Quadrotor

†The AeroQuad team was based in the US, but had an international mix of team members based around their online community of UAV enthusiasts.

As can be seen in Table 1 above, Quadrotors still dominated the field in the final fly-off selection. The members of the HALO team also participated in the SQ-4 Recon team and were therefore the only representatives from the UK and the only team to have two teams in the final selection. However, before the fly-off took place, three teams pulled out, citing commercial interests (WIDrone, SQ-4 Recon) or system failure (icarusLabs).

2 Milestone 4 - The Fly-Off Event

2.1 Target Location

The venue chosen for the fly-off event was the Colmar Urban warfare Training Site (UTS) at Fort Stewart, Georgia, USA. This was an old U.S. Army base constructed

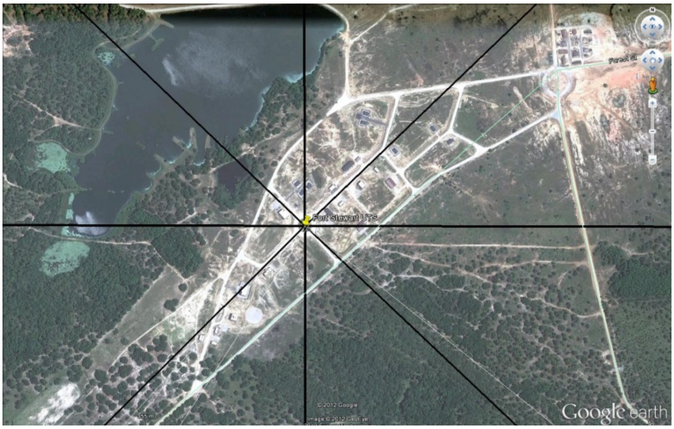

Fig. 2. Google Earth Map of the Colmar Urban Warfare Training Site

during WWII and home to the 3rd Infantry Division. The base covers an area of 1,100 km^2 and contains the recently built Colmar (UTS). Colmar consists of a number of buildings arranged in a typical town complex arrangement as shown in Figure 2.

2.2 Mission Scenario

The mission scenario was to outfit a fictional Task Force with an unmanned remotely operated micro air vehicle system. The entire air vehicle system must fit within a rucksack and a single person travelling by foot must be able to carry and operate the vehicle without assistance. The job of the Task Force is to conduct observations of suspicious activities occurring within the vicinity of two nondescript buildings in an urban area. Due to security in the region, all operations must be conducted beyond line of sight so as not to compromise your presence. If the UAV system is detected the mission will be jeopardized. The total observation time may require up to three hours of pictures and/or video to document the facts. Once key observations have been made, the team must quickly retreat to their designated rendezvous location. It is possible the vehicle will be handed off to another member of the Task Force to ensure mission success.

Due to the nature of the task and the variety of the proposed solutions put forward, it was clear from the start that the perch and stare task could be achieved in a number of different ways. The UAVForge website stated that:

"Once the vehicle has flown to the predefined search area, the vehicle needs to identify a vantage point from which to conduct observations. This task can be accomplished by any means which includes landing, adhering, hanging, and/or hovering above or under a physical structure." [2]

Clearly there was a degree of ambiguity in the rules, which was designed to cater for an unknown type of UAV which could have been deployed, i.e. a blimp or a balloon.

2.3 Technical Performance Requirements

- The complete air vehicle system must fit in a rucksack carried by a single person.
- The air vehicle must take off vertically from a starting location, fly out to an observation location, perform observations, return to an ending location that is different from the starting position, and land vertically.
- The air vehicle must be able to operate successfully in winds up to 6.7 m/s.
- At the observations area, the air vehicle system must be able to identify persons or activities of interest up to 30 m away.
- The air vehicle system must send real time video or pictures from its observation area back to the operator (a distance up to 3.2 km).
- The vehicle design must consider noise reduction features to make it as quiet as possible so as not to attract undue attention.
- The air vehicle user interface and vehicle controls should be simple and intuitive.

2.4 Scoring

The scoring for the fly-off event was sub-divided into three elements:

- Baseline Objectives (30 points)
- Advanced Behaviors (140 points)
- Manufacturability (30 points)

Therefore the maximum possible score was 200 points. Each of the Baseline Objectives was pass-fail, and all of the baseline objectives must have been completed in order to be eligible to earn points for advanced behaviors. Teams were given the opportunity to conduct the Advanced Behaviors assessment before or after attempting the Baseline Objectives.

The manufacturability assessment was conducted by Northwest UAV (experienced UAV manufacturers) contracted in by DARPA. The teams had to submit a detailed Bill of Materials (BOM) which included pricing information, as well as upload CAD files for all manufactured components.

3 The Halo Small UAS

Our entry to the competition took the form of a Y6, co-axial tri-rotor design. The concept for this was originally developed for the MoD Grand Challenge Event in 2008 [3]. The Y6 configuration has six rotors: two co-axial rotors, situated at three locations, as can be seen below.

Fig. 3. HALO UAV Landed on the Target Location at the Colmar UTS

3.1 HALO UAS Specification

- Mass: 2.5 kg
- Endurance: 32 min+ (hover)
- Range: 6 km (max)
- Props: 16 inch Carbon Fibre
- GPS Waypoint Control via Tablet Computer
- 50 Waypoints/Point of Interest
- Flight Controller : WK-M (900 MHz or 2.4 GHz)
- Autonomous Take-off and Landing
- GPS Hold, Altitude Hold and Return to Home
- Fail safes – Low Battery, Loss of Communications, etc
- 11,000 mAh Li-Po (4S) Battery
- 1280 MHz, 2.5 W Video TX
- Detachable Arms
- Detachable Legs
- Two Switchable Micro Cameras (one gimbaled)
- Ability to Land on Flat Ground or on a Roof Apex

The complete HALO UAS is self-contained within a single back packable flight case which contains the UAV, two LiPo batteries, tablet computer, tripod, aerials, video RX, 7 inch preview screen, FPV goggles and operators seat. The total system mass is approximately 15 kg. The system set-up takes less than five minutes and with an optimum flight velocity of 10 m/s the UAV has an operational range of approximately 6 km (max), the limiting factor being the capacity of the current generation of LiPo batteries (Specific Energy = 197.3 Wh/kg).

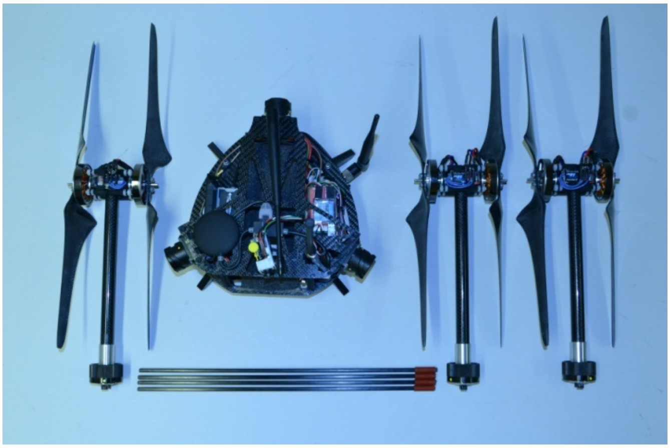

Fig. 4. HALO UAV Showing Detachable Elements

HALO was designed to have two micro cameras, one forward facing on a gimbal and one fixed at the center pointing directly downwards. The operator can switch between the two views at any time during the mission. The downwards facing camera is particularly useful for landing.

For the UAVForge mission scenario the concept was to attempt a perch landing on the church which would provide an excellent viewpoint over the target area.

4 Problem Areas

All of the teams that attempted the Baseline Objective over the 10 day fly-off period at Fort Stewart encountered problems with data communications. The NLOS environment was not conducive to good RF communications. Even though this was anticipated, it still represented a considerable problem. When combined with possible interference (whether intentional or unintentional from other military users) this made the challenge that much more demanding.

Analysis of the terrain elevation profile using Google Earth (Figure 6) provides some answers as to why this was such a difficult task (the launch site is on the LHS and the target, at the center of the Colmar UTS, is on the RHS at 3.2 km).

Fig. 5. Google Earth Elevation Profile at the Colmar UTS

Fig. 6. Viewpoint of the launch site at about 23 m AGL

When combined with the dense, 30 m high woodland which surrounded the Colmar UTS and the launch site, it was incredibly difficult to approach any landing location with good communications (data and/or video).

Each team tried to overcome this situation in different ways, some increased the output power (up to 7 Watts) without much luck and some teams decided to increase the height of their antennae using tripods or helium balloons, sometimes combined with directional Yagi antennae.

The HALO team, like all the others, experienced this issue during its first two flights. Whereas we could reach the target using GPS waypoints, every time that we reduced the altitude we lost the video downlink. This would occur at around 50 m AGL. Our initial response to this was to increase the height of our Yagi antenna (13 dBi) by placing it together with the receiver in a tree about 23 m AGL. This definitely helped with the range; however, communications over the target were still not reliable enough to attempt a landing. On the last but one day, we tested a higher power 1280 MHz video transmitter moving from 1.5 to 2.5 Watts. This setup gave us good video link all the way down to roof top height during a range test with HALO flying over Colmar under manual control and the GCS situated at the launch site.

On the final day we were ready to attempt a landing on the church when we lost GPS signal on route to the target. This caused us to have an uncontrollable landing in trees which caused major damage which was not repairable in the field. Subsequent analysis using satellite predictor software [4] showed that at the exact time of the accident (08:20-08:30) we were experiencing a very weak GPS signal (only 3 satellites) caused by a constellation dropout. Had we know about this software tool prior to the event, we would have launched at a different time.

5 Results

Several teams attempted the Baseline Objectives on multiple occasions with partial success. However the HALO team was the only team to score some points under every scoring category. The final results of the challenge were announced on the UAVForge website in late June 2012.

Table 2. Final rank and Scoring

Rank	Team	Final Score
1	HALO	47.7
2	AeroQuad	39.1
3	ATMOS	37.3
4	SwiftSight	37.3
5	Navy EOD	36.5
6	Extractor X	32.0
7	DHAKSHA	31.5
8	Phase Analytic	30.5
9	GremLion	19.2

DARPA stated that as no team had successfully completed the Baseline Objective there would be no award of the US$100k prize and no follow on operational exercise or production of up to 15 units for trials with military units.

It is important to note that the above score is out of 60 points and relates only to the first and third scoring elements. If we were to include the Advanced Behaviors scoring elements then our score would be an estimated 150/200 points.

6 Conclusion

When the UAVForge event was first announced, Wired magazine called this challenge "Beyond the Beyond", which is an apt descriptor for this difficult endeavor.

Some have labeled this event a failure, since none of the teams successfully passed the Baseline Objective. However, one has to remember that all of the entries were experimental aircraft, built by enthusiasts, in their own time and largely out of their own money. People have criticized the inability of any of the systems to perch and stare at the target. However, all of these systems cost less than US$10k, many less than $5k.

It is understood that the AeroVironment Shrike quadrotor (estimated cost US$150k each) was tested over the same course prior to the fly-off event and that it too had problems with data communications and could not perch and stare for the required time. The Shrike was developed over four years, funded by DARPA to the tune of US$4.6 million [5], if this system struggled with the course, it was perhaps no surprise that less resourced systems, costing a fraction of this, also struggled.

If success is measured by how many DIY UAV enthusiasts there are out there, and how far such systems have come over the last decade, then UAVForge was a resounding success. The Y6 configuration (ranked 1st and 2nd) has proved itself an ideal platform for such tasks. Further developments will include active directional antennae, digital video links and improved battery technologies.

Acknowledgement. The authors would like to thank DARPA and SSC Atlantic for hosting the challenge, which spurred on innovations in this exciting area of unmanned systems research.

References

1. Carancho, T.: AeroQuad – The Open Source Quadcopter/Multicopter, http://aeroquad.com/forum.php (accessed January 19, 2013)
2. UAVForge – Crowdsourcing for UAV Innovation, http://www.uavforge.net/uavhtml (accessed February 20, 2013)
3. Prior, S.D., Karamanoglu, M., Odedra, S., Foran, T., Erbil, M.A.: Development of a Co-Axial Tri-Rotor UAV. In: 24th Bristol International Unmanned Air Vehicle Systems Conference, University of Bristol, March 30 -April 1, pp. 15.1–15.16 (2009)
4. Navcom Technology, Satellite Predictor Tool, http://www.navcomtech.com/Support/Tools/satellitepredictor/main.cfm (accessed July 15, 2012)
5. AeroVironment Inc., News and Events, AeroVironment Receives $4.6 Million in DARPA Funding to Develop Stealthy, Persistent, Perch and Stare UAS Based on Wasp (August 20, 2008), http://www.avinc.com/resources/press_release/aerovironment_receives_4.6_million_in_darpa_funding (accessed December 20, 2012)