Unmanned Aircraft in Border Patrol Activities

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Nature of border patrol work.

- Monitor shipping, e.g. ships loading oil at oil rigs
- Monitor fishing activities in exclusive economic zones
- Detect small pirate boats
- Detect Self Propelled Semi-Submergible (SPSS) vessels
- Detect the movement of people on foot and in vehicles
- Detect people, drug and weapon trafficking activities

- Day and night time surveillance
- Real time, high definition, still image and video feed
- Ability to read number plates and names on ships and identify small arms and RPG
- Aircraft range in excess of 300 km; payload from 4 to 10 kg
The digital camera is the most typical sensor used in border patrol work.

Above: side looking photograph using a 100mm MACRO lens and camera travelling at 30 mph.

<table>
<thead>
<tr>
<th>Canon EOS 5D Mk II camera body</th>
<th>Canon EF 70 - 200mm f/2.8L zoom lens</th>
</tr>
</thead>
<tbody>
<tr>
<td>5,616 x 3,744 Pixels = 21 MPixels</td>
<td>viewing angle = 10° x 7° at 200mm</td>
</tr>
<tr>
<td>computer interface and control via USB 2</td>
<td>4 stop image stabilisation</td>
</tr>
<tr>
<td>weight = 810 g</td>
<td>weight = 1,490 g</td>
</tr>
</tbody>
</table>

In the above photographs, using a professional “L” series image stabilised Canon lens:
- ISO setting = 800
- shutter speed = 1/2,000 second
1.6 kg ImSar NanoSAR B using less than 30 Watts of electrical power.

<table>
<thead>
<tr>
<th>Key Specifications</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitted Power</td>
<td>Operating Mode</td>
</tr>
<tr>
<td></td>
<td>Stripmap, Spotlight,</td>
</tr>
<tr>
<td></td>
<td>Circular SAR</td>
</tr>
<tr>
<td>Range Resolution</td>
<td>Command and Control</td>
</tr>
<tr>
<td></td>
<td>Lisa Dashboard™</td>
</tr>
<tr>
<td>Standoff Range</td>
<td>Communication</td>
</tr>
<tr>
<td></td>
<td>RS-232, Ethernet</td>
</tr>
<tr>
<td>Slant Swath</td>
<td>Sensor Cueing</td>
</tr>
<tr>
<td></td>
<td>Cursor On Target</td>
</tr>
<tr>
<td>Frequency</td>
<td>Image Products</td>
</tr>
<tr>
<td></td>
<td>Google Earth</td>
</tr>
<tr>
<td></td>
<td>complex image</td>
</tr>
<tr>
<td></td>
<td>NITFS</td>
</tr>
<tr>
<td></td>
<td>JPEG/PNG/BMP</td>
</tr>
</tbody>
</table>

- 1W
- 0.3, 0.5, 1, 2, 5 m
- 1-4 km
- 4000 Resolution Cells
- X-Band
Detection of ships in all weather conditions using Synthetic Aperture RADAR.
Example of manned aircraft currently used in border patrol work.

Dash 8 Maritime Patrol Aircraft (MPA) for the U.S. Department of Homeland Security - Customs and Border Patrol (CBP).
Could unmanned aircraft be used in border patrol work?
The SINUE Project looked into the use of unmanned aircraft in border patrol work

SINUE was an ESA funded Project, in which Indra considered the case of maritime border patrol off the Canary Islands.

Table 4-14: Typical characteristics of vessels for illegal immigration (and smuggling/trafficking)

<table>
<thead>
<tr>
<th>Type/Denomination</th>
<th>Material</th>
<th>Size</th>
<th>Radar Cross Section (RCS) (m²)</th>
<th>Speed (knot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubber boat</td>
<td>Rubber/fibre</td>
<td>5 – 8, ~ 2, ~ 0.5</td>
<td>1 – 5</td>
<td>1 – 60</td>
</tr>
</tbody>
</table>

Figure 4-10: Typical vessels for illegal immigration (and smuggling/trafficking)
“Thanks to the addition of two more Predator B unmanned aircraft to the existing fleet, the U.S. Customs and Border Patrol is now conducting aerial patrols of virtually the entire U.S. Southwest border from California to the Gulf of Mexico in Texas, according to the Department of Homeland Security (DHS).

The expanded Predator B flights, originating from Corpus Christy, Texas, are being flown courtesy of $600 million in new funding included in the recently passed Southwest border security bill.

Advantages of using smaller unmanned aircraft in border patrol work.

Unmanned aircraft with two, or more, engines, a Maximum Take-Off Weight of 35 kg, or less, and a range in excess of 300 km have the following advantages in border patrol work:

- they will cause less damage in the event of a crash
- they are generally less complex to operate and / or maintain (smaller logistical footprint)
- they are less expensive to acquire, or lease, and are less expensive to operate
- they are more reliable (if they can fly on 1 engine) than an aircraft with 1 piston engine
- it is easier to get approval to export the unmanned aircraft for use throughout the world

We are developing the InView unmanned aircraft for use in the following applications:

- **scientific** volcanic ash cloud density monitoring
- **commercial** oil and mineral exploration work and pipeline monitoring
- **state** land and maritime border patrol work
Introduction to the InView unmanned aircraft.

Two engines for safety.
It’s no use having quad redundant flight control systems if the UA has one engine.

Lightweight: 20 kg without fuel and payload
Minimised crash damage and simplified flight regulations.

Modular construction for ease of transportation, maintenance and upgrade

Big wheels for operation from rough terrain
### InView unmanned aircraft features at a glance.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Payload</th>
<th>Endurance</th>
<th>Max speed</th>
<th>Loiter speed</th>
<th>Weight</th>
<th>Wingspan</th>
<th>Fuel</th>
<th>Propulsion</th>
<th>Total Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>for scientific, commercial and state missions</td>
<td>4 kg</td>
<td>7+ hours</td>
<td>112 kph</td>
<td>24 kph</td>
<td>19.5 kg without fuel</td>
<td>4 m</td>
<td>Gasoline + synthetic oil 20:1</td>
<td>2x SAITO FG-30 engines</td>
<td>3.6 kW</td>
</tr>
<tr>
<td>comprehensive safety features</td>
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<tr>
<td>modular and easily transportable</td>
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<tr>
<td>assembled and tested within an hour</td>
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<td>can operate from a grass field</td>
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<tr>
<td>capable of very slow flight</td>
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<tr>
<td>user definable payloads can be carried</td>
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</tr>
<tr>
<td>operates in manual, Microprocessor based autopilot and PC autopilot flight modes: <strong>moving towards more automation to reduce the errors introduced by human involvement.</strong></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

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The instruments carried on the unmanned aircraft can be expensive.

To detect difficult targets in all weather conditions, the unmanned aircraft might carry:

- An ImSAR NanoSAR B unit **costing $ 95,000** (budgetary price)
- two Scintrex CS-3SL Cesium beam magnetometers, **total cost $ 40,400**
- an airborne broadband satellite communications terminal **costing $ 35,000** (budgetary)
Safety and reliability features.

- use of **dual flight control units**:
  - manual flight control for flight training and emergency control
  - microprocessor based flight control for safe, but not very versatile, flight control
  - PC based flight control for flexibility and experimentation, but less safe flight control

- **automatic take-off** using the Sky Circuits SC2 autopilot (shown below) to reduce the consequences of human error and ease the logistical footprint

- **automatic landing** using the Sky Circuits SC2 autopilot to enable emergency landings and reduce the consequences of human error

- **distributed, on-board sensor network** to provide early detection of potential failures, so measures can be taken before a more serious condition develops

- **dual rudder** as part of a dual redundant safety system

- **dual elevator** as part of a dual redundant safety system

- **twin engines**, the aircraft can fly on one engine alone

- **parachute deployment** to reduce the kinetic energy
### Accidents and safety.

<table>
<thead>
<tr>
<th>Event</th>
<th>Comment</th>
<th>Ascribed to</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV-01 sheared off undercarriage</td>
<td>pre-flight check error</td>
<td>human error</td>
</tr>
<tr>
<td>IV-02 crash after failure of one engine</td>
<td>lack of situational awareness, pre-flight check deficiency</td>
<td>design error, human error</td>
</tr>
<tr>
<td>IV-03 crash due to little rudder authority</td>
<td>design deficiency</td>
<td>design error</td>
</tr>
<tr>
<td>IV-05 manually landed on top of tall trees</td>
<td>pilot perception error</td>
<td>human error</td>
</tr>
<tr>
<td>IV-06 sheared off undercarriage</td>
<td>hard manual landing</td>
<td>human error</td>
</tr>
<tr>
<td>IV-07 sheared off undercarriage</td>
<td>hard manual landing, design deficiency</td>
<td>human error, design error</td>
</tr>
</tbody>
</table>

Most accidents occurred during take-off and landing. So, as far as we are concerned, unmanned aircraft testing in the U.K. under CAA CAP 722 regulations is fine.

Our test flight experience has convinced us that **the human is the weak link**, and that more pre-flight test automation and flight control machine intelligence will lead to increased safety.
The key barriers to the use of unmanned aircraft in civil and state applications.

The frequently mentioned barriers are suggested to be:

- Regulations
- Sense and avoid system
- Safety
- Air worthiness
- Type certification
- ATM Integration
- Availability of radio spectrum
- Air crew training
- Human factors and autonomy
- Public perception

An important barrier that is rarely mentioned is:

- **Long term reliability of small engines**

Small engines have a really tough time:
- increased wear due to higher RPM operation
- particulates in the fuel clog small fuel tubes
- Carbon build-up due to the fuel : oil mixture

The twin cylinder SAITO FG-57T four stroke engine is an example of an engine used on long range unmanned aircraft.
Currawong Engineering, located in Australia, have developed an Electronic Fuel Injection unit for use on small gasoline and heavy fuel engines, operating up to 20,000 feet to give them:

- increased power output
- increased torque output
- increased fuel efficiency
- ease of starting in cold weather

Ray Cooper, Monash University's UA pilot, gets a briefing from Gavin Brett, Lead Development Engineer for Aerosonde Ltd. The stunning long range capability of the Aerosonde, the first Unmanned Aircraft to cross the Atlantic, is very much a tribute to the skills of Gavin Brett. Gavin is now the CEO and Director of Currawong Engineering in Tasmania.
<table>
<thead>
<tr>
<th>Category 9</th>
<th>Aerospace and Propulsion</th>
</tr>
</thead>
<tbody>
<tr>
<td>9A</td>
<td>Systems, Equipment and Components</td>
</tr>
<tr>
<td>9A012</td>
<td>&quot;Unmanned Aerial Vehicles&quot;, associated systems, equipment and components, as follows:</td>
</tr>
<tr>
<td>9A012.a.</td>
<td>UAVs having any of the following:</td>
</tr>
<tr>
<td>9A012.a1.</td>
<td>An autonomous flight control and navigation capability (e.g. an autopilot with an Inertial Navigation System); or</td>
</tr>
<tr>
<td>9A012.a2.</td>
<td>Capability of controlled flight out of the direct vision range involving a human operator (e.g. televisual remote control);</td>
</tr>
<tr>
<td>9A012.b.</td>
<td>Associated systems, equipment and components, as follows:</td>
</tr>
<tr>
<td>9A012.b1.</td>
<td>Equipment specially designed for remotely controlling the &quot;UAVs&quot; specified in 9A012.a</td>
</tr>
<tr>
<td>9A012.b2.</td>
<td>Systems for navigation, attitude, guidance or control other than those specified in 7A and specially designed to provide autonomous flight control or navigation capability to &quot;UAVs&quot; specified in 9A012.a;</td>
</tr>
<tr>
<td>9A012.b4.</td>
<td>Air breathing reciprocating or rotary internal combustion type engines, specially designed to propel &quot;UAVs&quot; at altitudes above 50,000 feet (15,240 metres).</td>
</tr>
</tbody>
</table>
Missile Technology Control Regime ("MTCR") export controls.

- If the UAV has a range in excess of 300 km, and a payload in excess of 500 kg, then the UAV falls in Category I "Complete Delivery Systems" Item 1 Part 1.A.2 and getting export approval is that much more difficult.

- If the UAV has a range in excess of 300 km, and a payload of less than 500 kg, as many unmanned aircraft do, then the UAV falls in Category II "Other Complete Delivery Systems" Item 19 Part 19.A.2, and getting a Standard Individual Export License is easier.
Phase 1: Line Of Sight ("LOS") operation during take-off and landing.

<table>
<thead>
<tr>
<th>Rx / Tx</th>
<th>Frequency GHz</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rx</td>
<td>1.22760</td>
<td>precision GPS PRBS L2 signal, upper and lower 10 MHz side bands</td>
</tr>
<tr>
<td>Rx</td>
<td>1.57542</td>
<td>precision GPS PRBS L1 signal, upper and lower 10 MHz side bands</td>
</tr>
<tr>
<td>Rx</td>
<td>2.400 to 2.483</td>
<td>spread spectrum uplink for manual flight control at 819.2 kbit/sec</td>
</tr>
</tbody>
</table>

Unmanned Aircraft in Border Patrol Activities
Phase 2: Radio Line Of Sight ("RLOS") operation during border patrol mission.

<table>
<thead>
<tr>
<th>Rx / Tx</th>
<th>Frequency GHz</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rx</td>
<td>1.5250 to 1.6605</td>
<td>Inmarsat satellite broadband downlink at 64 kbps</td>
</tr>
<tr>
<td>Tx</td>
<td>1.6252 to 1.6605</td>
<td>Inmarsat satellite broadband uplink at 64 kbps</td>
</tr>
<tr>
<td>Rx &amp; Tx</td>
<td>5.725 to 5.850</td>
<td>Wireless Ethernet bridge IEEE 802.11a OFDM link at 6 Mbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rx sensitivity is -74 dBm at 54 Mbps and -94 dBm at 6 Mbps</td>
</tr>
</tbody>
</table>

RLOS volume

RLOS range 60 km

PI 3.141592654
Circum Earth (Polar) 40008 km
Radius Earth 6367.470963 km
Height tree 10 m
Distance to tree 300 m
Angle to horizontal 1.909152433 degrees
Angle total 91.90915243 degrees
RLOS range 60 km

RHS 40573742.21 km^2

H minimum

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>km</td>
<td>2.281</td>
</tr>
<tr>
<td>feet</td>
<td>7484</td>
</tr>
</tbody>
</table>
The InView avionics architecture uses an Ethernet based connectivity.

On the UA:
- Fast Solid State Hard Drive
- Interface to Flight Control Unit
- IMU + GPS unit

On the UA (real-time sensor data processing):
- Intel Single Board Computer
- Intel Single Board Computer
- USB

Other components:
- Ethernet HUB
- Ethernet bridge
- Ethernet HUB
- Ethernet bridge
- PTZ IP camera CAM 1
- Digital Camera Canon EOS 5D Mk II

Ground Control Station:
- 60 km range

Unmanned Aircraft in Border Patrol Activities
The InView Ground Control Station and Data Processing Centre.

HPC Cluster
Automated Data Processing

Internet

60 km range

unmanned aircraft

Ethernet bridge

Ethernet HUB

PC #1
Flight CTRL

PC #2
Comms + HM

PC #3
Payload

Ground Control Station

Unmanned Aircraft in Border Patrol Activities
Two unmanned aircraft on patrol can provide improved identification capability.

UA at 8,000 feet AGL provides wide area coverage

5.8 GHz IEEE 802.11a Ethernet link
RLOS between UA and the GCS

2.4 GHz IEEE 802.11N WLAN link

UA flying at 400 feet AGL provides high resolution side looking image for ID
Ground Control Station handover is advantageous in the patrol of long borders.
Conclusions

Border Patrol using unmanned aircraft has already started with Predator B unmanned aircraft being used to monitor the US Southwest border with Mexico.

Smaller unmanned aircraft with a Maximum Take-Off Weight of less than 35 kg have advantages over the use of heavier, and usually larger, unmanned aircraft, especially in lower leasing and operational costs and reduced impact of a crash.

In order to relay the high bandwidth video stream from the unmanned aircraft to the Ground Control Station, the UA needs to remain within Radio Line Of Sight (60 to 250 km) of the GCS.

GCS handover capability is useful in the patrolling of a border outside of the RLOS range.

Acknowledgements

1. The Technology Strategy Board ("TSB") in the STUAC Project to incorporate sensors to monitor the health of an Unmanned Aircraft.
2. The TSB in the INMARA Intelligent Machine Reasoning and Action Feasibility Study
3. The European Space Agency in the form of the UASatCom IAP Feasibility Study

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Thank you.

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