Development of an Unmanned Aircraft Mounted Software Defined Ground Penetrating Radar

J. F. Fitter, A. B. McCallum & J. P. Leon
University of the Sunshine Coast, Sippy Downs, Australia
Objective 1

- Evaluate sensor platforms suitable for mounting of GPR (Ground Penetrating Radar) and operation in alpine and arctic environments while meeting specific technical specifications;

Objective 2

- Evaluate the viability of using a SDR (Software Defined Radio) to implement a GPR suitable for use on a small, lightweight RPA (Remotely Piloted Aircraft). The design specifications for the GPR are defined explicitly;
Project Justification

- Alpine snow field inspection
- Masonry chimney inspection
- Glaciology
- Geological survey
- Sea ice survey
- Land mine detection

8-Sep-16
Objective #1

Evaluate sensor platforms suitable for mounting of GPR (Ground Penetrating Radar) and operating in alpine and arctic environments while meeting the following specifications:

- Small and Low cost.
- Portable.
- Lightweight (WH&S limits < 14 Kg/person).
- Easily deployed.
- Medium payload capability (~ 5 Kg).
- Medium endurance (> 1 hour).
- Exceptionally stable.
- Can operate in harsh or cold environment.
- Easily transportable by air or land vehicle.
- Low operator skills required.
Objective #2

Evaluate the viability of using a SDR (*Software Defined Radio*) to implement a GPR suitable for use on a small, lightweight RPA (*Remotely Piloted Aircraft*). The design specifications for the GPR are as follows:

- Small and Lightweight (< 5 Kg).
- Low cost.
- Low power consumption (< 20W).
- Resolution < 1m to a depth of 10m.
- Local data storage (~ 1TB).
- Capable of rapid re-configuration.
- Precise GPS positioning and tracking.
- Accurate position data without GPS.
- Telemetry downlink for low resolution data.
- Low operator skills required.

8-Sep-16
Survey of Sensor Platforms
Sensor Platform Types

- Quadcopter
- Multicopter
- Helicopter
- Coanda Effect VTOL
- Coanda Multicopter
- Aeroplane
Quadcopter - 4 motors, 4 arms, consumer grade.

Small, simple & Reliable
Easy to Transport & Deploy
Exceptionally Stable & Good for Image Capture
Poor endurance & Payload
Octacopter - 8 motors.

8 arms.

Large
Stable
Efficient

Compact
Less stable
Less efficient

8-Sep-16
Multicopter Endurance Modelling

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor Coefficient</td>
<td>1000 rpm/V</td>
</tr>
<tr>
<td>Propulsion</td>
<td>8.13</td>
</tr>
<tr>
<td>Propeller</td>
<td>3 kg</td>
</tr>
<tr>
<td>Core weight</td>
<td>2.25 kg</td>
</tr>
</tbody>
</table>

Multicopter Endurance Simulation

Motor Specific Power

Energy Source Specific Energy (Wh/kg)
Multicopter Endurance Modelling

Maximum endurance vs Total vehicle weight

- Endurance increases rapidly with battery weight increase.
- Endurance gains decrease and become negative at high total weight.
- Endurance is moderately effected by motor power density.
Multicopter Endurance Modelling

Maximum endurance vs battery/frame weight ratio.

- Endurance increases rapidly with increasing battery/frame weight ratio.
- Endurance gains plateau at a battery/frame weight ratio of approximately 2.
- Higher motor specific power enables a higher battery/frame weight ratio.
**Multicopter Endurance Modelling**

Maximum endurance vs Battery specific energy

- Endurance is a linear function of battery specific energy.
- Motor specific power has little effect on endurance.
- Endurance is strongly effected by battery technology.
Multicopter Endurance Modelling

Extended plot of maximum endurance vs Battery specific energy

- Internal combustion engines using liquid fuel currently outperform electric power solutions even at efficiencies of below 40%.
- Hydrogen fuel cells offer great promise as a replacement for Lithium batteries.
- Endurance is strongly effected by battery technology.
Review of Energy Sources

Stored Electrical Energy
- Lithium Ion Polymer Pouch Cells
- Lithium Ion Cylindrical Cells

Direct Conversion Electrical Energy
- Hydrogen PEM (Proton Exchange Membrane) Fuel Cell
Lithium Ion Polymer Prismatic Pouch Cells

- Lightweight & efficient
- Moderate specific energy
- Exceptionally low cost
- High energy density due to exceptionally tight packing
- Extremely low source impedance
- Requires special handling above 60C and below 5C
- Exceptionally hazardous if mishandled or overcharged
- Severe public transport limitations
Lithium Ion Cylindrical Cells

- Lightweight & efficient
- High specific energy
- Exceptionally low cost
- Low energy density due to HCP packing limitations
- Moderate source impedance
- Safer than LiPo pouch cells
- Requires special handling above 60C and below 5C
- Severe public transport limitations
Hydrogen PEM$^1$
Fuel Cell Stack

- Lightweight & efficient
- Very high specific energy
- Exceptionally low energy density
- High endurance limited only by available fuel supply
- High source impedance (cf. Lilon)
- Requires high purity hydrogen
- Gaseous fuel management risky
- Solid fuel is expensive

$^1$ Proton Exchange Membrane
Software Defined Radio GPR
**Radio Architecture**

- **Classic radio**
  - All components physically and logically combined

- **Software defined radio**
  - Physically independent components
  - Logically independent components

---

ISC’5
SDR Physical Implementation

Airborne system

Ettus B200-Mini

UDOO-X86
Pulse Radar Basics

GPR Operating Principle

A-Scan

B-Scan
SFMCW Radar Basics

Figure 1. Ranging with an FM-CW system

Actual HIL Simulation
Radar Resolution Enhancement

The problem – Range resolution, $R_R = c/2B$

The solution: A sequence of chirps, each with a different centre frequency

$R_R = c/2NB$
End of Presentation

Thankyou for your attention.
Fig. 10. ARDrone2.0 Endurance: Model accounting for battery variability together with Experimental Results for Stable Operation. Flights at an AUW exceeding 550g exhibited unstable behaviour which frequently necessitated manual landing prior to vehicle autolanding.
Fig. 3. Hovering time as a function of the battery ratio.

Figure 1.2.2 Mass and efficiency comparison of propulsion systems providing a shaft power of 50kW for 2 hours (hepperle, 2012).
Low KV direct drive Out-runner. Optimised for Multicopter use.
Motor specific power 3W/g
Motor constant 100 KV

High KV in-runner with 6.7:1 planetary reduction drive. Optimised for high performance aeroplane use.
Motor specific power 6W/g
Motor constant xxx KV
Li-Ion Cell Welding

DIY welding of Cylindrical Li-Ion cells using low cost commercial electric spot welder.

Connecting strips are Nickel. Cell casing is steel.
Survey Mission Profile

3,000m (12min)

Hover

Transit to survey

Climb

Return from survey

Descent

Takeoff

Landing

500m (3min)

30min Survey

Dangerous Area
Noisy GPS Data Simulation
Visual SLAM Simulation