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**Foreword**

To enable autonomous operation of the AHNS platform considerable airborne computing power and hardware interfacing is required. This was decided to be achieved with a single-board flight computer. This trade study therefore considered the precise system requirements and high level objects of the system to enable the development of a decision matrix to evaluate a set of single-board computers. The decision matrix reflected the relative importance of the criteria listed; processor type and power, mass, operating system support, memory, hardware interfaces and cost.

The set of four alternative flight computers was sourced from related projects in commercial and research fields. Each alternative was considered and ranked with the developed decision matrix. Using only these rankings it was possible to determine the Gumstix Overo Fire COM as the most suitable flight computer due primarily to its processor’s support for digital signal processing and extensive hardware interfacing options. AHNS therefore recommends the procurement of the Overo Fire COM along with its two expansion boards, the Pinto-TH and the Summit, for maximum hardware support.

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**Definitions**

|  |  |
| --- | --- |
| AHNS | Autonomous Helicopter Navigation System |
| MAV | Micro Unmanned Aerial Vehicle |
| HLO | High Level Objectives |
| SR-B | Baseline System Requirement |
| SR-D | Derived System Requirement |
| SBC | Single-board Computer |
| COTS | Commercial-off-the-shelf |
| RTOS | Real-time Operating System |
| GPIO | General Purpose Input/Output(IO) |
| I2C | Inter-Integrated Circuit |
| SPI | Serial Peripheral Interface |
| OS | Operating System |
| ADC | Analogue to digital converters |
| PWM | Pulse Width Modulation |
|  |  |
|  |  |

# Introduction

The high level objectives of AHNS 2010 focus on achieving autonomous control, state estimation and localisation of the airborne platform. An ability to communicate with the airborne platform is also required. The scope of the computing tasks that need to be undertaken and based on the requirements for an airborne system dictate that a flight computer, capable of airborne operation be investigated.

This document will examine the system HLOs and SRs in sufficient detail to determine suitable selection criteria for flight computer selection. The criteria will then be applied to a set of alternative flight computers sourced from related projects in commercial and research fields. The outcome of this trade study process will be the recommendation of a suitable flight computer.

## Scope

The scope of this trade study is the selection of the flight computer without consideration of the exact state estimation, localisation and control algorithms to be implemented with it. Nevertheless the general computing tasks required, such as image processing, sensor fusion, matrix calculations and considerable floating point arithmetic, can be used to limit the possible alternatives considered. Indeed these tasks suggest that 8- or 16-bit microcontrollers will not be suitable or will present considerable design challenges. Flight computers considered will therefore be limited to single-board computer designs (SBC).

## Background

In 2009 the AHNS project did not have a requirement or a desire to implement an airborne system capable of autonomous control and state estimation. Airborne tasks, which included sensor data collection and communication, could therefore be achieved with an embedded 8-bit ATMega128 microcontroller (part of a COTS Gumstix robostix board) whilst all control and state estimation was run on the ground control station computer. Prior to 2009 AHNS had procured a commercial SBC in the form of a Gumstix Verdex XM-4bt for use as an airborne computer.

# Reference Documents

## QUT Avionics Documents

|  |  |  |
| --- | --- | --- |
| RD/1 | AHNS-2010-SY-HL-001 | AHNS 2010, High Level Objectives of |
| RD/2 | AHNS-2010-SY-SR-001 | AHNS 2010, System Requirements of |

## Non-QUT Documents

|  |  |  |
| --- | --- | --- |
| RD/3 | Gumstix Verdex (not Pro) - Feature Overview | Gumstix 2010. Verdex (not Pro) - Feature Overview. Available:  <http://www.gumstix.net/Hardware/view/Hardware-Feature-Overview-Sheets/Gumstix-Verdex-not-Pro-Feature-Overview/112.html> (accessed March 6 2010) |
| RD/4 | robostix | Gumstix 2010. Robostix. Available: <http://www.gumstix.com/store/catalog/product_info.php?products_id=139> (accessed March 6 2010) |
| RD/5 | SoftFloat | Hauser, J. 2008. SoftFloat. Available: <http://www.jhauser.us/arithmetic/SoftFloat.html> (accessed March 6 2010) |
| RD/6 | Overo Air COM | Gumstix 2010. Overo Air COM. Available: <http://www.gumstix.com/store/catalog/product_info.php?products_id=226> (accessed March 7 2010) |
| RD/7 | Pinto-TH | Gumstix 2010. Pinto-TH. Available: <http://www.gumstix.com/store/catalog/product_info.php?products_id=239>  (accessed March 7 2010) |
| RD/8 | Summit | Gumstix 2010. Summit. Available: <http://www.gumstix.com/store/catalog/product_info.php?products_id=215>  (accessed March 7 2010) |
| RD/9 | Overo Fire COM | Gumstix 2010. Overo Fire COM. Available: <http://www.gumstix.com/store/catalog/product_info.php?products_id=227>  (accessed March 7 2010) |
| RD/10 | Towards Visual Sensor Networks Related Research on Micro Air Vehicles | Meier, L. 2009. “Towards Visual Sensor Networks Related Research on Micro Air” Available: <http://www.vs.inf.ethz.ch/edu/FS2009/DS/berichte/ds2009_lorenzmeier.pdf> (accessed March 7 2010) |
| RD/11 | BeagleBoard System Reference Manual | BeagleBoard. 2010. BeagleBoard System Reference Manual. Available: <http://beagleboard.org/static/BBSRM_latest.pdf> (accessed 7 March 2010) |
| RD/12 | BeagleBoard | eLinux. 2010. BeagleBoard. Available: <http://elinux.org/BeagleBoard> (accessed 7 March 2010) |

In the event of any conflict between this document and any RD referenced herein, such conflict shall be notified to Luis Mejias.

In the following text, RD/x identifies referenced documents, where "x" denotes the actual document.

# Identification of Constraints and Decision Criteria

The need for a flight computer is intrinsically linked to many of the high level objects and system requirements of AHNS 2010. It is from these therefore that decision criteria need to be developed so as to ensure the selection of a suitable flight computer from the range of alternatives.

## Relevant High Level Objectives

* **HLO-2, HLO-3 and HLO-4**

These high level objectives are the foundation of the requirements to come regarding autopilot development, state estimation and localisation [RD/1]. They place no specific constraints on the selection of a flight computer other than that it should ensure timely code execution to ensure appropriately timed system updates.

* **HLO-6**

The need for a communications link between the airborne and ground systems is morphed to this objective to provide a consumer electronics datalink. The flight computer’s communications interface is therefore flagged as important.

## Relevant System Requirements

* **SR-B-03, SR-B-04, SR-B-05, SR-B-06**

These requirements place a constraint on the update rates required from control and state estimation. During processing operations involving floating point calculations, sensor data collection and hardware output will be required. In terms of the flight computer selection this suggests processing power and operating system task scheduling need to be considered.

* **SR-B-07**

Airborne image processing is not required but in order to achieve timely results a ground based system is not ideal. The flight computer should therefore, if possible, be capable of digital image processing. Considerable processor performance, perhaps even a dedicated processor, along with both system and secondary storage memory will therefore be considered.

* **SR-B-09 and SR-D-05**

Transmission and collection of airborne sensor data is the most basic role of the flight computer so its ability to interface with popular hardware buses, actuator control lines, input-output devices and consumer communication links should be examined.

* **SR-D-01**

With the flying qualities of a helicopter of any sort being heavily reliant on its mass properties ideally the flight computer’s mass should be negligible. By definition it needs to be mounted on the airframe and so only its mass and profile can be considered.

## Decision Matrix and Rationale

The decision matrix shown in Table 3.1 has been constructed by considering the recurring importance of the considerations outlined in the requirements and high level objectives. Processor speed and architecture is weighted at 30% due to its impact on all control, state estimation and localisation activates that can be performed. Mass is also of importance so as to avoid hindering the airborne system. The operating system support for task scheduling and build environment set up is also equally weighted with memory and hardware interfacing. Finally cost is not greatly considered since few SBCs are beyond the project’s budget.

.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Weighting** | **Score (/5)**  Table . - Decision Matrix | | | | |
|  | **5** | **4** | **3** | **2** | **1** |
| **Processor** | 30% | 32-bit Clock Speed of 1000-600MHz Hardware Floating Point Support Digital Signal Processing Support | 32-bit Clock Speed of 1000-400MHz Hardware Floating Point Support | 32-bit Clock Speed of 1000-400MHz Lack of Hardware Floating Point | 32-bit Clock Speed of 399-200MHz | 32-bit  Clock Speed of <200MHz |
| **Mass** | 20% | <5g | 5g-9g | 10-19g | 20-29g | >30g |
| **OS Support** | 15% | Embedded UNIX based RTOS support with precompiled images and drivers available. | Embedded UNIX based and support with precompiled images and drivers available. | Embedded UNIX based and support with documentation. | Embedded operating system other than a UNIX based one. | No operating system. |
| **Memory** | 15% | Digital Expansion Card >128MB of Flash  >128MB of RAM |  | 128-64MB of Flash 128-64MB of RAM |  | <64MB of Flash  <64MB of RAM |
| **Hardware Interface** | 15% | Without need for non-commercial extension boards or modifications:  802.11 Wifi Bluetooth > 4 x PWM Lines >4 x ADC Ports I2C Bus USARTs SPI Bus GPIOs | Without need for non-commercial extension boards or modifications:  802.11Wifi 4 x PWM Lines 4 x ADC Ports I2C Bus USARTs SPI Bus GPIOs | With or without need for extension boards or modifications:  802.11 Wifi 4 x PWM Lines 4 x ADC Ports I2C Bus USARTs GPIOs | With or without need for extension boards or modifications:  802.11 Wifi PWM Lines ADC Ports I2C Bus USARTs GPIOs | With or without need for extension boards or modifications lacks one of 802.11 Wifi PWM Lines I2C Bus USARTs GPIOs |
| **Cost** | 5% | <$100 | $100-$199 | $200-299 | $300-$399 | >$400 |

# Flight Computer Trade Study

The four alternative flight computers being considered have each been used in robotics or embedded system before. The SBCs considered are the Verdex XM4-bt, the Overo Air COM, the Overo Fire COM and the open-source BeagleBoard.

## Alternative 1 (Verdex XM4-bt)



Figure . - Gumstix Verdex XM4-bt [RD/3]

### Description

The verdex was purchased previously for AHNS use and is summarised in . Noteworthy features include the requirement of the COTS robostix board for hardware interfacing [RD/4] and a lack of hardware floating point arithmetic. As a result non-integer calculations are emulated in software with the SoftFloat [RD/5] software library.

### Features

Table . - Gumstix verdex XM4-bt Summary [RD/3]

|  |  |
| --- | --- |
| **Processor** | 400MHz Marvell® PXA270 with XScale  No hardware floating point support |
| **Mass** | 8g |
| **OS Support** | Linux 2.6.27+ |
| **Memory** | RAM 64MB, Flash 16MB |
| **Hardware Interface** | *With aid of robostix expansion board:*  Bluetooth UARTs I2C Bus SPI Bus *(if robostix board modified)* GPIO > 4 x ADCs > 4x PWM Lines |
| **Cost** | *AHNS Inherited Asset* |

## Alternative 2 (Overo Air COM)



Figure . – Gumstix Overo Air COM [RD/6]

### Description

The Gumstix Overo Air COM is based on the Texas Instruments OMAP3503 processor which supports hardware floating point arithmetic [RD/6]. It is the least expensive Overo to come with a Wifi communication link and like most SBCs it relies on external expansion boards for access to its the full of hardware interfaces. At a minimum the expansion board required for hardware access is the Pinto-TH [RD/7] however this board does not provide a console port for on board software debugging and update, thus an additional Summit expansion board [RD/8] is required for full operation of the Air. The build environment and software image provided based on a non real-time Linux OpenEmbedded Environment [RD/6].

### Features

Table . - Gumstix Overo Air COM Summary [RD/6]

|  |  |
| --- | --- |
| **Processor** | 600MHz OMAP 3503 with ARM Cortex-A8 CPU |
| **Mass** | 6g |
| **OS Support** | Linux 2.6.31+ |
| **Memory** | RAM 256MB, Flash 256MB, MicroSD Card |
| **Hardware Interface** | *With aid of expansion board (purchased or made):*  802.11g Wifi Bluetooth UARTs I2C Bus SPI Bus GPIO 6 x PWM 6 x ADC |
| **Cost** | $199 USD –ex. Postage |

## Alternative 3 (Overo Fire COM)



Figure . – Gumstix Overo Fire COM [RD/9]

### Description

The Overo Fire COM provides the same connectivity as the Overo Air but with an improved processor and additional support for digital image processing. The support for image processing has been documented and used in other undergraduate MAV helicopter and quadrotor projects [RD/10]. Again this does not diminish the requirement for the purchase of two expansion boards, the Summit and the Pinto-TM to enable interfacing with the full range of supported hardware.

### Features

Table . – Gumstix Overo Fire COM Summary [RD/9]

|  |  |
| --- | --- |
| **Processor** | 600MHz OMAP 3530 with ARM Cortex-A8 CPU plus a C64x+ digital signal processor (DSP) and 2D/3D accelerator. |
| **Mass** | 6g |
| **OS Support** | Linux 2.6.31+ |
| **Memory** | RAM 256MB, Flash 256MB, MicroSD Card |
| **Hardware Interface** | *With aid of expansion board (purchased or made):*  802.11g Wifi Bluetooth UARTs I2C Bus SPI Bus GPIO 6 x PWM 6 x ADC |
| **Cost** | $219 USD –ex. Postage |

## Alternative 4 (BeagleBoard)

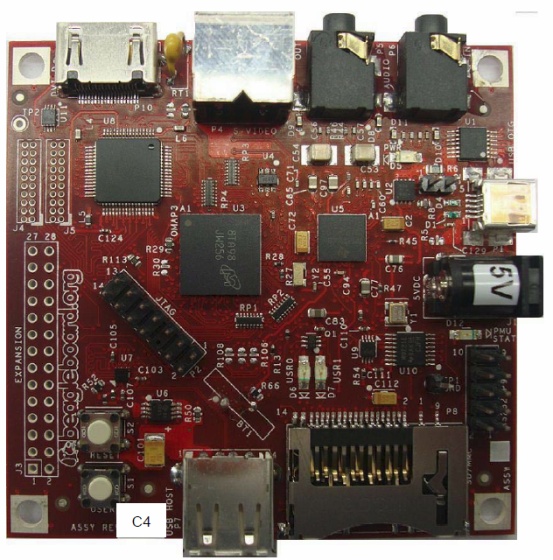


Figure . – Texas Instruments BeagleBoard COM [RD/11]

### Description

The BeagleBoard is a SBC aimed to deliver “laptop-like” performance in an embedded package [RD/11]. Although it boasts audio and visual hardware interfaces, it is not oriented towards lower-level tasks such as analogue to digital conversions or SPI/I2C device management and so to facilitate these tasks custom made expansion boards are required. Owing to its open-architecture it supports and has been used with many operating systems including the real-time QNX OS [RD/12].

### Features

Table . – BeagleBoard Summary [RD/12]

|  |  |
| --- | --- |
| **Processor** | 720MHz OMAP 3530 with ARM Cortex-A8 CPU plus a C64x+ digital signal processor (DSP) and 2D/3D accelerator. |
| **Mass** | 37g |
| **OS Support** | Windows CE, Android, Linux 2.6.31, QNX, Ubuntu etc. |
| **Memory** | RAM 256MB, Flash 256MB, MicroSD Card |
| **Hardware Interface** | *With aid of expansion board (custom made):*  UARTs I2C Bus SPI Bus GPIO PWM ADC |
| **Cost** | $149 USD –ex. Postage |

# Evaluation of Alternatives

The discussion of the four alternatives has highlighted their key features. The decision matrix will now be used to select the most suitable flight computer from these alternatives.

## Solution 1: Verdex XM4-bt

The Verdex’s evaluation suffers from its lack of hardware processing power and 802.11 interface. Selection of the Verdex, with its diminished numerical performance could be suitable depending on the exact nature of the calculations required but its lack of memory almost certainly rules out image processing.

Table . - Alternative 1 Evaluation

|  |  |
| --- | --- |
|  | **Score**  **(/5)** |
| **Processor** | 3.00 |
| **Mass** | 4.00 |
| **OS Support** | 4.00 |
| **Memory** | 1.00 |
| **Hardware Interface** | 1.00 |
| **Cost** | 5.00 |

* Weighted Total: 57.0%

## Solution 2: Overo Air COM

The Overo Air’s processor, memory and operating system support are all suited to the flight computer task. Its reliance on purchased external extension boards for a full range of hardware interfacing is disappointing but given these boards amount to less than an extra US$80 and their performance is assured, it is not a source of risk.

Table . - Alternative 2 Evaluation

|  |  |
| --- | --- |
|  | **Score**  **(/5)** |
| **Processor** | 4.00 |
| **Mass** | 4.00 |
| **OS Support** | 4.00 |
| **Memory** | 5.00 |
| **Hardware Interface** | 5.00 |
| **Cost** | 4.00 |

* Weighted Total: 86.0%

## Solution 3: Overo Fire COM

The Overo Fire’s evaluation reflects that it is suitable for digital image processing and the computations which could be involved in complete on board control, state estimation and localisation. Cost is the only major drawback with its high base price and the need for the Summit and Pinto-TH expansion boards.

Table . - Alternative 3 Evaluation

|  |  |
| --- | --- |
|  | **Score**  **(/5)** |
| **Processor** | 5.00 |
| **Mass** | 4.00 |
| **OS Support** | 4.00 |
| **Memory** | 5.00 |
| **Hardware Interface** | 5.00 |
| **Cost** | 3.00 |

* Weighted Total: 91.0%

## Solution 4: BeagleBoard

The BeagleBoard’s lack of available hardware interfacing means it is a risk prone solution. In theory it is certainly capable and provides the best operating system support, particularly with its ability to run an RTOS. With not inherent 802.11 or hardware interfacing options it is however difficult to recommend.

Table . - Alternative 3 Evaluation

|  |  |
| --- | --- |
|  | **Score**  **(/5)** |
| **Processor** | 5.00 |
| **Mass** | 1.00 |
| **OS Support** | 5.00 |
| **Memory** | 5.00 |
| **Hardware Interface** | 1.00 |
| **Cost** | 4.00 |

* Weighted Total: 71.0%

# Conclusions

The evaluation of the alternative flight computers in the trade study using the decision matrix laid out from the AHNS system requirements has established the Gumstix Overo Fire COM as a suitable flight computer. It has been used in an image processing and control environment by another institution and it offers flexible computing and hardware interfacing.

# Recommendations

It is recommended that the Gumstix Overo Fire COM be procured for use by AHNS as the airborne flight computer. To enable the full suite of hardware options the Pinto-TH and Summit expansion boards should also be purchased.

# Appendices

No Appendices.