Title: Android Underwater Vehicle - A COTS Development Platform

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Abstract:
This paper will describe a vehicle design centered on Commercial Off The Shelf (COTS) components and field expedient manufacturing for integration. Development was centered around an Android based mobile device making use of the Google's Accessory Development Kit(ADK) standard for communication with the vehicle propulsion system.

Introduction

For the duration of project development, many goals were pursued to enhance vehicle performance in the competition. These goals included developing an alternative to accelerometer data for velocity or position reference, maximizing thruster output relative to vehicle weight/drag, and developing an improved heading reference over magnetometer sensor data. A theme consistent to all of these goals was to accomplish them in a cost-effective manner.

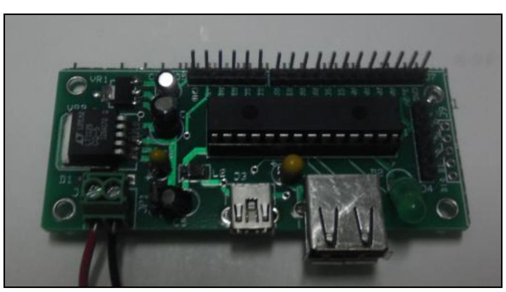
Essentially, could solutions be found that would eliminate the need for inertial dead reckoning, or at least provide sufficiently accurate dead reckoning to meet the requirements of this competition? Best effort specifications allowed for the flexibility to minimize costs, and improvement on the previous year's Mesa College vehicle was used as a yardstick to measure success.

This paper will detail the component selections made to facilitate the accomplishment of these objectives, outline the reasoning behind these decisions, and provide data where possible on their performance.

Processing

Previous attempts by Mesa College to use Android based cellular phones in autonomous vehicles were frustrated by component selection. The difficulties encountered could be best summarized as sensor & processor limitations with entry level pre-paid phones, and power supply issues on the previous year's USB Communication board.

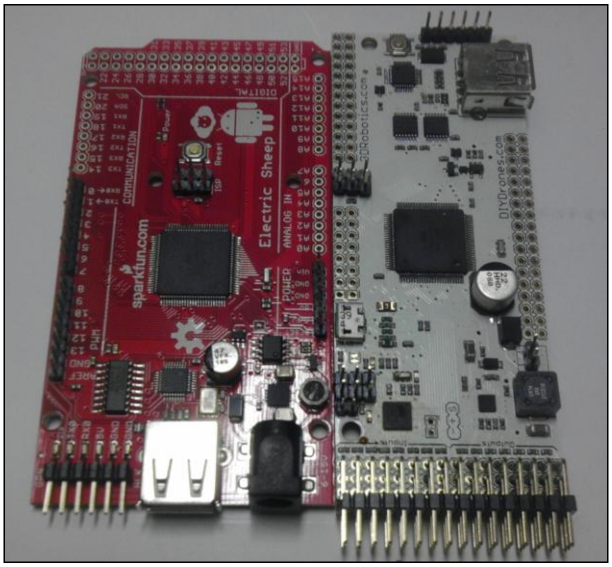
To overcome these difficulties, resources were invested in identifying an ideal phone and microcontroller combination.



Improved IOIO Board Design by a student at Mesa College

Microcontroller:

Driven by a desire to minimize the programming learning curve, and to expand the talent pool capable of developing for the platform, an Atmel based product compatible with the Arduino project was the primary selection criterion.



Sparkfun "Electric Sheep"(Left) beside 3D Robotics LLC "PhoneDrone"(Right)

The Sparkfun “Electric Sheep”, and DIYDrones/3D Robotics “PhoneDrone” were two suitable boards, which were designed to be compatible with Google’s Accessory Development Kit(ADK) USB communication standard. Going with either of these “ADK” options married the project to Android 2.3.4 or later, however this seemed to be a reasonable compromise because of a fast moving mobile market, and the EVO 3D’s compatibility with the ADK standard.

Ultimately, the PhoneDrone was selected based on its form factor, which is specifically designed to cater to hobby component based autonomous vehicles.[1]

Phone:

A selection criterion was developed which emphasized an unlocked bootloader and a 3 axis gyroscope as key features. The unlocked bootloader allowed for the platform to grow with the Android Operating System (OS) independent of mobile carrier kernel upgrades. The gyroscope allowed for yaw stabilization, heading reference independent of magnetic interference, and compatibility with the open source Inertial Navigation System (INS) “Demo6DoF”[2]

Several phones and tablets were evaluated to arrive at the conclusion of an appropriate platform. The HTC EVO 3D exceeded all requirements, and included other desirable features such as a 2 MP stereoscopic camera, 1.3 MP front facing camera, and dual-core 1.2GHz processor.[3]

HTC EVO 3D

HTC EVO 3D features a stereoscopic camera(Right)

The HTC EVO 3D's list of features presented possibilities that actually exceeded the team's resources to develop for them. HTC has released an SDK allowing for application developers to use both the stereoscopic camera and 3D display.[4] Having multiple cameras allows the capability to focus computer vision in several directions without requiring a pan/tilt mechanism or shift in vehicle attitude to change the direction of focus.

<u>IMU/AHRS/INS:</u>

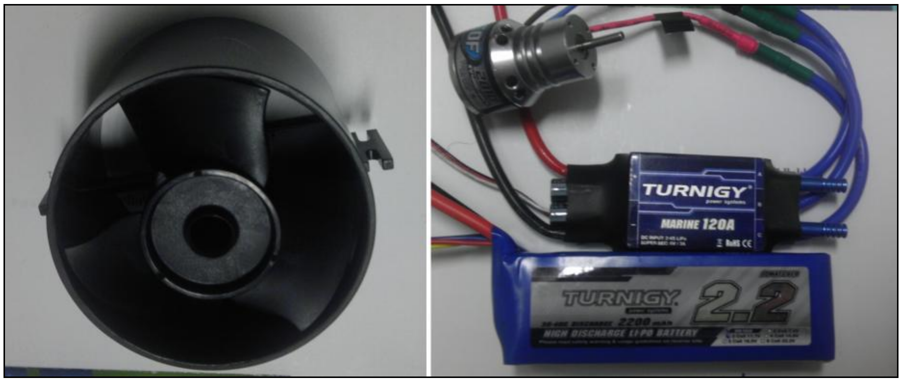
The promise of plug & play "sensor fusion" was a feature which was relentlessly pursued to improve vehicle performance, and code development accessibility. By incorporating components featuring sensor fusion in to the platform, the hope was to reduce barriers to entry for students looking to participate in advanced robotics activities.

Initially, concern about sharing processor resources between computer vision and inertial navigation motivated the decision to pursue a dedicated IMU board. After researching the ST iNemo, InvenSense MPU6000/6050, and the more recent MPU9150, a very basic prototype surface vehicle autopilot was developed using the MPU-6000/Atmega328 based "ArduIMU V3" from DIYDrones/3DRobotics LLC. To accommodate the ArduIMU V3's limited number of PWM outputs, some progress was made reflashing COTs Turnigy Plush 18A ESCs to include reverse throttle and I2C control^ [https://github.com/sim-/tgy]

This effort was yielding results; however because of the team's limited progress with computer vision, continuing on this path was making the Android phone and PhoneDrone redundant. Facing the prospect of entering a minimalist torpedo for a vehicle, returning to the original idea of using the HTC EVO 3D's included IMU seemed more consistent with the original project vision. If successful, this direction also offered more potential for growth.

Android has included "Sensor Fusion" libraries in its API since kernel version 2.3.1,[5] An open source application called "Demo6DoF"[2] was discovered by the team earlier in the year. This application not only used a DCM algorithm to process sensor data, but integrated a Kalman filter. The code was well-commented and this allowed for a simplified version of Google's ADK API developed by DIYDrones community member and github user Falko Richter,[6] to be incorporated in the code.

Propulsion



Low-cost propulsion system using COTS components

As mentioned in the introduction, "maximizing thruster output relative to vehicle weight/drag" was one of the goals of development during this project. This design goal departed from the others in its focus moving away from navigation and localization, towards other aspects of vehicle performance. Primarily, by vehicle weight, but also by improving total thruster output. Toward this end, EDF Kits, compatible BLDC outrunner motors, and 120A ESCs were combined to make a thruster system capable of both powering an RC plane, as well as submerged operation.

<u>Electronic Speed Controllers (ESCs):</u>

Prior experiences with 64mm EDF fans had shown motor current requirements of >50A at 12V in air. All else being equal, basic testing had also demonstrated BLDC motor current requirements to be about twice as high in water as in air. As a result of these experiences, the ESCs were specified based on the operating current of 120A at 3s(11.1V) with the capability of 2-6s(7.4-22.2V). Another consideration being that because of limited PWM outputs, a built in programmable "Reverse" feature was preferred. The "Turnigy Marine 120A" ESC from HobbyKing met all of these requirements.

"Turnigy Marine 120A" ESC from HobbyKing

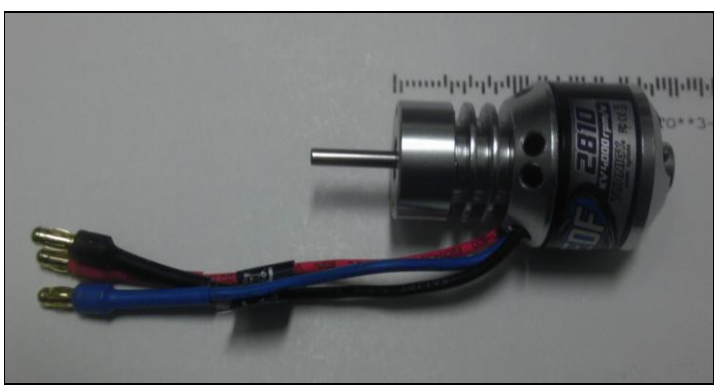
Energy Storage System (ESS):

Pressure tolerant Lithium Polymer chemistry[7]

To reduce the exposure to single point failures, every thruster has an independent Lithium battery. This translates to additional hull penetrations on the battery enclosure, however has "failover" benefits where a single ESC failure does not have a cascading impact on other vehicle systems. “Turnigy” 2.2Ah 12V Lithium Polymer batteries were selected based on the cost/Wh metric, as well as brand recognition for being reliable components. At a 40C discharge rating, they should be capable of discharging up to 88A of current.

BLDC Motors:

Turnigy Outrunner EDF Motors were selected for their low-cost, combined with their compatibility with COTS EDF fan blades designed for a 28mm motor footprint. Matching EDF kits with motors was one of the challenges in developing this vehicle. Finding an appropriate propeller pitch & diameter for a given motor size can be difficult, so the EDF kit was selected first based on user reviews, and motors were chosen which had a reputation for being compatible. A "best-effort" was made and the ESCs were over-spec'ed to accommodate the expected current requirements resulting from inefficiencies.



Turnigy 2810 EDF Outrunner 4000kv for 55/64mm EDF

EDF Kit:

EDF Ducted Fan Unit 3Blade 2.75inch 70mm

This EDF Fan Unit was selected based on positive user reviews, and a basic understanding of propeller requirements developed through reading "The Propeller Handbook" by Dave Gerr.[13] Using the Turnigy 2810 4000KV BLDC motor, initial testing indicates that, in Air, this Fan unit draws approximately 24Amperes at 11.4V-10.7V(No-Load/Load) at full throttle. When run underwater this same Fan unit draws 38Amperes continuous with an initial surge of 42A. These results were well inside design allowances

Software

Program Flow:

The main application is a modified version of the open source “Demo6DoF”[2] INS.
Code development has been set to follow a series of functionality milestones of increasing complexity and difficulty.

The first milestone was achieved with successful communication between the Demo6DoF and the PhoneDrone board. The following milestone is yaw stabilization of the vehicle through transmission (“broadcast”) of IMU data compressed in to a value range of 0-255. The PhoneDrone Atmega2560 operates a basic proportional loop modulating PWM outputs to the ESCs and keeping the vehicle heading towards the qualification gate.

Future code revisions would include an “Intent”[8] call to an second application running in the background. This second application would include OpenCV’s SimpleBlobDetector[9] and use the same 0-255 USB communication with the PhoneDrone to keep the correctly colored buoy centered on screen.

In the future, provided a velocity reference signal at the PhoneDrone, a signal could be “received” by the EVO 3D over USB and used to mitigate drift of the inertial INS code. The eventual goal being to provide the INS with a “Vector Walk” through the user interface in order to allow the vehicle to follow waypoint navigation.

OpenCV:

At the time of writing, the OpenCV project is now officially supporting the Android OS.[10] This includes both native C++ development via the Android NDK,[11] in addition to a Java API.[10] In support of developers, NVIDIA has released the "Tegra Android Development Pack"[12] which streamlines development environment setup in to a single windows executable. The HTC EVO 3D was chosen, in part, with the potential for future computer vision development in mind. The EVO 3D’s impressive selection of camera sensors, and its processing speed, both make it an ideal choice for Autonomous Vehicle development.

For further reading on OpenCV on Android, the following website is highly recommended: http://opencv.itseez.com/doc/tutorials/introduction/android_binary_package/android_binary_package.html

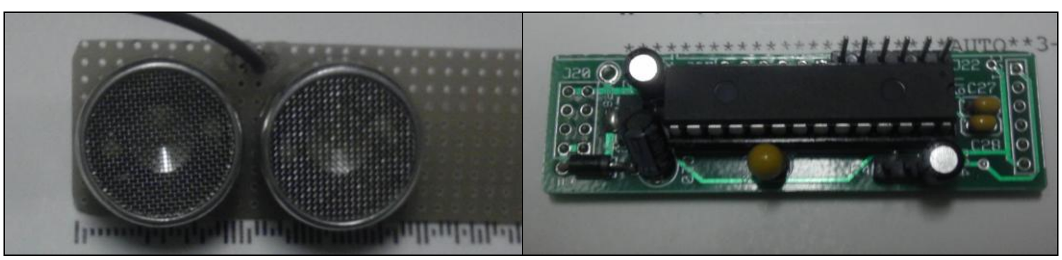
Sonar

"These goals included developing an alternative to accelerometer data for velocity or position reference."

-Introduction

The structure of the Robosub competition provides significant incentives to development of both computer vision and acoustic sonar capabilities.[14] Having to choose between the two to focus development on, sonar's Digital Signal Processing requirements were selected as having a higher probability of success based on team skill-sets. Two sonar projects were pursued, both passive and active.

Passive:



Point of use dsPIC33FJ board to minimize analog noise and hydrophone board developed by student

The dsPIC33FJ has 6x10-bit ADCs @ 1100ksps. It is a 40 MIPS Processor with 12KB of program memory and 1024 bytes of RAM.[15] Code examples for this chip exist that can run a Fast Fourier Transform (FFT) on data collected from an analog input.[16] Three of the above pictured board were fabricated offering the potential in the future to attempt trilateration of the pinger based on time of arrival, or the generation of a velocity reference based on doppler shift of the pinger's beacon. The question we hope to answer in the future: Is a 10 bit ADC capable of measuring doppler shift of a 20khz signal in a useful way at any reasonable speed our vehicle would be traveling?

Active:

PIEZO CERAMIC TRANSDUCER 45KHz 50x3mm

It was recognized that a pulsed reference signal would result in partial loss of velocity data. In order to improve the quality of doppler shift measurements, an effort was made to develop active piezo elements for use as hydrophones. Originally this included scavenging hydrophones from a 350khz COTS Fish Finder[17] but eventually a supplier of small quantity ceramic piezo transducers was identified.[18] For processing, the 2.4MSPS STM32F4 Cortex M4[19], and an NE612 Double Balanced Mixer[20] were both considered. A prototype of the bat detector was made, and the STM32F4 had an ADC read but we ran out of time for development this year and will have to continue development in the future.

Conclusion

In this paper, a low-cost development platform based on an Android mobile device was described. Some details on the rationale behind component selection were discussed. The future goals that this foundation was laid for explained. It is my hope that the topics discussed inspire others to explore Android as a platform for development of Autonomous Vehicles.

Acknowledgements

A sincere thank you to my Robotics advisor Dr. Colin Bradbury, the entire SDCC team for their assistance, and the founders of the El Cajon hackerspace "Neucleon"for generously hosting this team for the past two years.
http://neucleon.org/

References

(1) http://store.diydrones.com/PhoneDrone_Board_p/br-phonedrone.htm
(2)https://github.com/yigiter/Demo6DoF
(3)http://www.gsmarena.com/htc_evo_3d-3901.php
(4)http://htcdev.com/devcenter/opensense-sdk/stereoscopic-3d
(5)http://androidheadlines.com/2010/11/gingerbread-to-bring-sensor-fusion-support-just-like-the-wii.html
(6)https://github.com/deadfalkon/HelloADK
(7)http://www.batterypoweronline.com/images/PDFs_articles_whitepaper_appros/Bluefin%20Robotics.pdf
(8)http://developer.android.com/reference/android/content/Intent.html
(9)http://opencv.itseez.com/modules/features2d/doc/common_interfaces_of_feature_detectors.html
(10)http://opencv.org/platforms/android.html
(11)http://docs.opencv.org/doc/tutorials/introduction/android_binary_package/android_binary_package_using_with_NDK.html
(12)http://developer.nvidia.com/tegra-android-development-pack
(13)http://www.amazon.com/Propeller-Handbook-Installing-Understanding-Propellers/dp/0071573232
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(15)http://www.microchip.com/wwwproducts/Devices.aspx?dDocName=en520467
(16)http://www-ssrl.slac.stanford.edu/esg/index_files/page399.htm
(17)http://www.harborfreight.com/portable-fish-finder-94511.html
(18)http://www.steminc.com/
(19)http://www.mouser.com/stm32F4/
(20)bertrik.sikken.nl/bat/ne612het.htm

Bill of Materials

Component	Price	Quantity	Supplier	Model Number	Link/Datasheet
Cellular Phone	$200.00	1	Craigslist	HTC EVO 3D	http://www.gsmarena.com/htc_evo_3d-3901.php
Waterproof Bag Case	$7.40	1	DealExtreme	67328	http://www.dealextreme.com/p/waterproof-bag-case-with-strap-for-cell-phone-mp3-mp4-white-67328
USB Communication Board	$99.99	1	DIYDrones	br-phonedrone	https://store.diydrones.com/PhoneDrone_Board_p/br-phonedrone.htm
Electronic Speed Controller	$49.99	4	Hobby King	TR-M-120A	http://www.hobbyking.com/hobbyking/store/uh_viewItem.asp?idProduct=8946
EDF Fan Kit	$12.79	4	Hobby King	701F	http://www.hobbyking.com/hobbyking/store/uh_viewItem.asp?idProduct=11260
80A Bullet Connectors(3.5mm)	$1.50	2	Hobby King	AM1001A	http://www.hobbyking.com/hobbyking/store/__68__PolyMax_3_5mm_Gold_Connectors_10_PAIRS_20PC.html
4000KV 28mm BLDC Motor	$10.44	4	Hobby King	T28102B4000	http://www.hobbyking.com/hobbyking/store/uh_viewItem.asp?idProduct=10932
200A Battery Isolator Switch	$7.55	1	American Battery	309101-001	http://www.quickcable.com/products.php?pageId=596
MAXI inline fuse holder, 60 amp	$2.95	4	Sherco-Auto	IHMX8	http://www.sherco-auto.com/electacc.htm
Liquid Electrical Tape BLK	$5.99	1	Home Depot	32076064037	http://www.homedepot.com/h_d1/N-5yc1v/R-100119178/h_d2/ProductDisplay?catalogId=10053&langId=-1
Liquid Electrical Tape RED	$5.99	1	Home Depot	32076064020	http://www.homedepot.com/h_d1/N-5yc1v/R-100179027/h_d2/ProductDisplay?catalogId=10053&langId=-1
6 circuit Terminal Block	$5.99	1	Home Depot	32076069896	http://www.homedepot.com/h_d1/N-5yc1v/R-202522482/h_d2/ProductDisplay?catalogId=10053&langId=-1
12-10AWG 3/8" Ring Terminal 15PK	$2.39	2	Home Depot	32076075002	http://www.homedepot.com/h_d1/N-5yc1v/R-202522881/h_d2/ProductDisplay?catalogId=10053&langId=-1
80A Fuse	$3.29	4	Autozone	BP-MAX-60-RP	http://www.autozone.com/autozone/parts/Bussmann-Fuse/_/N-8gd05?itemIdentifier=32434
60A Fuse	$3.29	4	Autozone	BP-MAX-80-RP	http://www.autozone.com/autozone/parts/Bussmann-Fuse/_/N-8gd05?itemIdentifier=32435

Total
$661.95