Cover Page

NIST - The Unmanned Aerial Systems Flight and Payload Challenge

Title: Sliding Rotor UAV for Higher Endurance and Maneuverability

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Description:

Currently, in the operation of Unmanned Aerial Systems (UAS/UAV) that carries a payload for any application, great care is taken to position the payload such that its center of mass aligns with the center of the vehicle. This is an artificial constraint that we must overcome for using UAVs in future days when the vehicle is expected to carry payloads of any arbitrary form, shape, and weight distribution. In the current design of the UAVs, any payload that is heavier on one side than the other, causes the rotors on the heavier side to work significantly harder than those on the other side. This situation forces uneven distribution of power, and severely affects endurance of the vehicle as well as its maneuverability.

We have an innovative and patent-pending design, that will efficiently correct the situation described above, and increase the flight time of the vehicle. Currently the frame design of standard multirotor UAVs are of fixed geometry and does not allow any change in configuration during the flight. In our innovative design, the rotors of the UAV will not be fixed in place but would have the freedom of sliding along the arms of the vehicle. We plan to create a closed loop system where the load imbalance is sensed in real-time during the flight, and consequently the rotors are moved to appropriate locations on their respective arms in order to balance the load evenly among all the rotors.

This proposed design, besides addressing the endurance issue which is of prime importance, also carries the promise of solving two other issues related to such multirotor UAVs. One of them is agility, which is also of great importance in adverse weather condition as well as for avoiding obstacles. Our design will enhance the agility of the UAV by augmenting the standard maneuver mechanism with continuous repositioning of the thrust generators. The second issue is of dynamic payload that shifts its weight distribution during the flight; for example, a sling load, slushing load, or a robotic arm attached to the UAV which cause the center of mass to move around. Our system would be able to re-adjust the center of thrust continuously and efficiently to adjust for that variation. Overall, we strongly think that this new system would change the way the UAVs are built today, and would solve multiple problems related to carrying an arbitrary payload.

Project Description

Robodub is a Seattle based startup, developing a new generation of drones. This technology, which we call Morphing, allows the vehicle to change its physical configuration in a number of ways in order to achieve higher endurance and superior maneuverability over conventional multirotor UAVs.

In this section we will first briefly describe the standard design and controls of a quadrotor UAV, followed by the description of the proposed mechanism that was outlined in the previous page, i.e. how by changing the location of the rotors on the arms of the UAV can increase the endurance and performance of the vehicle carrying an arbitrary payload.

Figure 1 illustrates how different types of maneuvers are achieved for a standard X-type quadrotor, whose four rotors are marked as 1, 2, 3 and 4. The rotors 1 and 3 spin clockwise, and the rotors 2 and 4 spin counter-clockwise. At a steady hover state, all the four propellers move at equal speed, causing the quadrotor to float steadily without any forward, backward, or sideways motion. Also, the reaction torque from clockwise rotating rotors 1 and 3 perfectly balances the reaction torque from counter-clockwise rotating rotors 2 and 4, causing no net yaw motion.

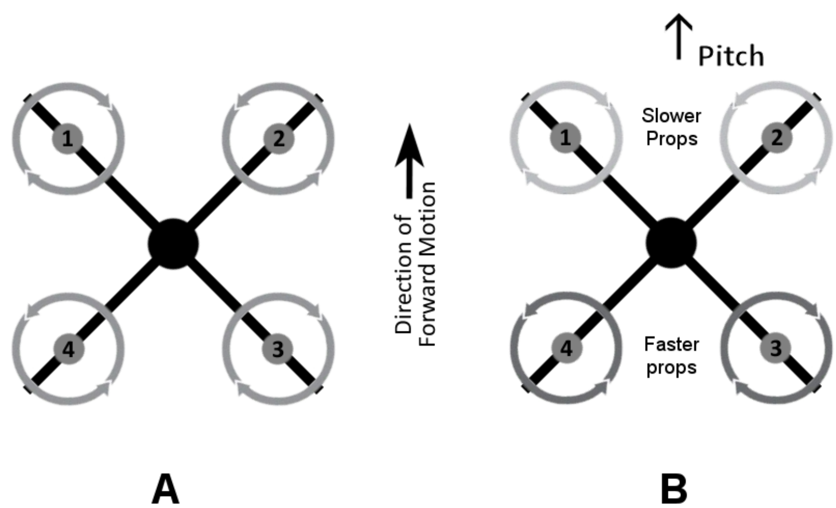

Fig. 1

If rotor 1 and 2 slow down and the opposite rotors 3 and 4 start going faster at the same time, then front side will tip down, and the quadrotor will have a pitch motion and will move forward, as shown in Fig. 1B. Inversely, if rotor 1 and 2 speed up and rotors 3 and 4 slow down, then the craft will move backward.

Similarly, if rotors 1 and 4 slow down and rotors 2 and 3 go faster, the left side will tip down causing the craft to roll towards left. If rotors 2 and 3 slows down and rotors 1 and 4 speed up, then the craft will roll towards right.

If the opposite rotors 1 and 3 (both rotating clockwise) slow down simultaneously while 2 and 4 (both rotating counter-clockwise) speed up, then the reaction torque from rotors 1 and 3 will not balance that from rotors 2 and 4. There will be an excess reaction torque in clockwise direction, which will make the craft turn clockwise. This is how a quadrotor goes into yaw motion.

All the above maneuvers occurs through the flight control software installed in the flight control board, which controls the speed of the four individual rotors. The flight controller acts on the operator's inputs received through a transmitter-receiver system and the signals received from the on-board sensors.

How Morphing Would Enhance the Load-balancing Capability of the UAV to Increase Endurance

For a UAV carrying a lopsided load (indicated by L in Fig. 2), it must still maintain its ability to hover by staying level, as well as its ability of to perform pitch and roll maneuvers by tilting in appropriate direction. For a standard quadcopter, this is done by speeding up and slowing down the rotors, as described in the previous section using Fig. 1.

For our morphing quadcopter, this standard procedure can be further enhanced significantly by changing the rotor positions appropriately. This will be illustrated using Fig. 2.

Fig. 2A shows the UAV in its standard X configuration, with a lopsided payload L. To maintain a hover, the rotors 3 and 4 must spin up while rotors 1 and 2 slow down in order to balance the lopsided load. This kind of uneven distribution of power over the four rotors causes serious inefficiency because of the non-linear relation between input power and output thrust. Also, these is a limit of how fast a rotor can go; and when it is forced to operate near its limit because of the lopsided payload, it has no extra power available to speed up further that a required pitch or roll maneuver demands. Thus, both endurance and maneuverability of the vehicle is negatively affected.

At this moment there exists no elegant solution to this issue, except for using stronger motors and speed controllers, which also makes the craft heavier and negatively affects the endurance.

The solution we offer is innovative is elegant, as shown in Fig. 2B. In order to balance the lopsided payload, we would move rotors 1 and 2 inwards, and rotors 3 and 4 outwards along the respective arms as shown in Fig. 2B. This reduces the extra load on rotors 3 and 4. It also reduces wastage of power due to inefficiency, while maintaining the same maneuverability.

This technique can be extended further for dynamically changing payloads as well. Fig. 2C illustrates the situation when the load L is not stationary and moves to a new location in the course of time, we would simultaneously move rotors 2 and 3 inwards, and rotors 1 and 4 outwards along the respective arms as shown in Fig. 2C. This makes the vehicle perfectly balanced again. Essentially, morphing works as a mechanism to balance a lopsided load, which may be either stationary or dynamic in nature.

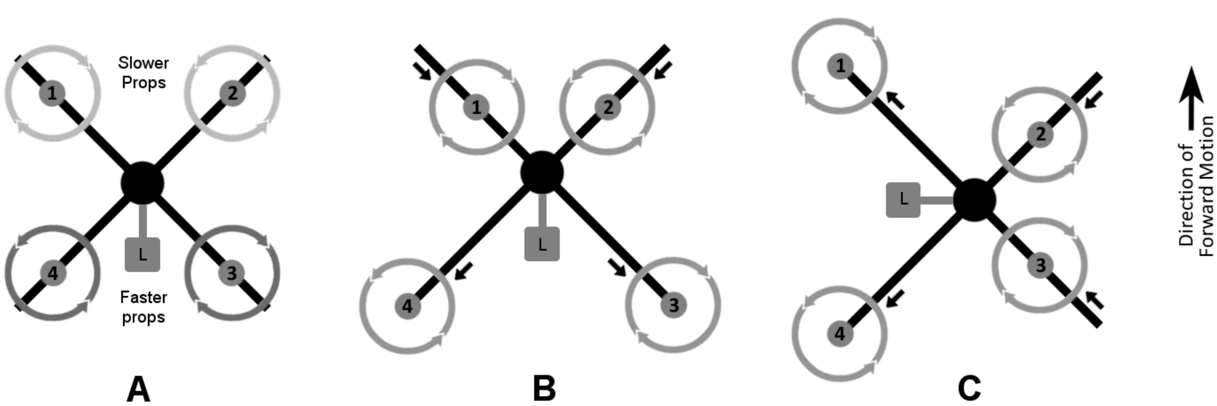

Fig. 2

Hardware: The Sliding Rotor Vehicle

The vehicle we are proposing to build will have four arms in a symmetric X configuration, with one rotor fitted to each arm, like a standard quadcopter. But in our design the rotors will be movable along the length of the respective arms, as illustrated in Fig. 3. Each rotor will be mounted on a carriage that can slide along the arm it is on. In this figure, the carriage is shown to move from one position (A) to another (B) along the arm.

The linear sliding motion of the carriages on the four arms can be achieved by a number of mechanical arrangements. We are planning to use either a rack-and-pinion gear arrangement or a belt-and-pulley arrangement, along with an encoder that can sense the location of the carriage on the arm. The net result will be the same on the dynamics of the vehicle.

For the mechanical design mentioned above, the actuation can also be done in a number of ways using various electro-mechanical devices, including continuous servo motors, stepper motors, or standard DC motors. We are planning to use high grade smart servo motors with built-in optical encoder for the actuation.

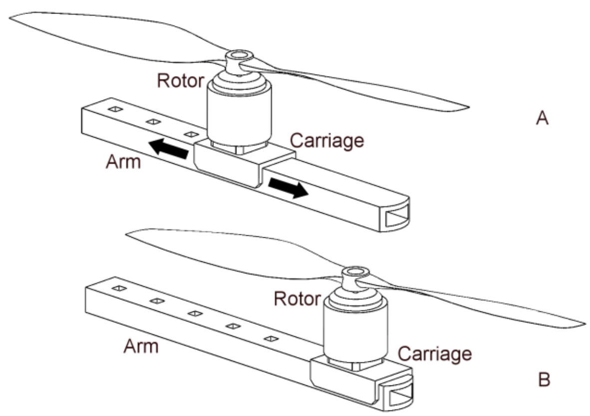

Fig. 3

Software: Control System and Actuation

The control software, which is a major part of the innovation, would control both the flight of the vehicle as well as the change of rotor position of the arms. The software sits in the controller board and its companion computer on-board of the vehicle.

We will briefly describe the control system, using Fig. 4. For a standard quadrotor (Fig. 4A) the flight controller receives input from the user through the radio receiver, and receives data from the on-board sensors like gyro and accelerometer. Using those two things, the controller sends signals to the ESC (electronic speed controller) of the four motors in order to perform various maneuvers like pitch, roll, yaw, upward and downward movement.

The control system of our UAV (Fig. 4B), in addition to the system described above, will have an onboard companion computer controlling a set of four servo actuators. The computer will determine the optimal position of the four rotors in real time from the data of the on-board sensors, and will drive the actuators to move the rotors to their desired positions. The whole operation will be on a closed-loop feedback system to maintain the best stability of the vehicle. Robodub will develop the necessary algorithms for the system operation.

In future work, we also plan to include artificial intelligence (AI) and implement advanced algorithms such as deep neural net to determine the drone actuations based on its dynamic environments.

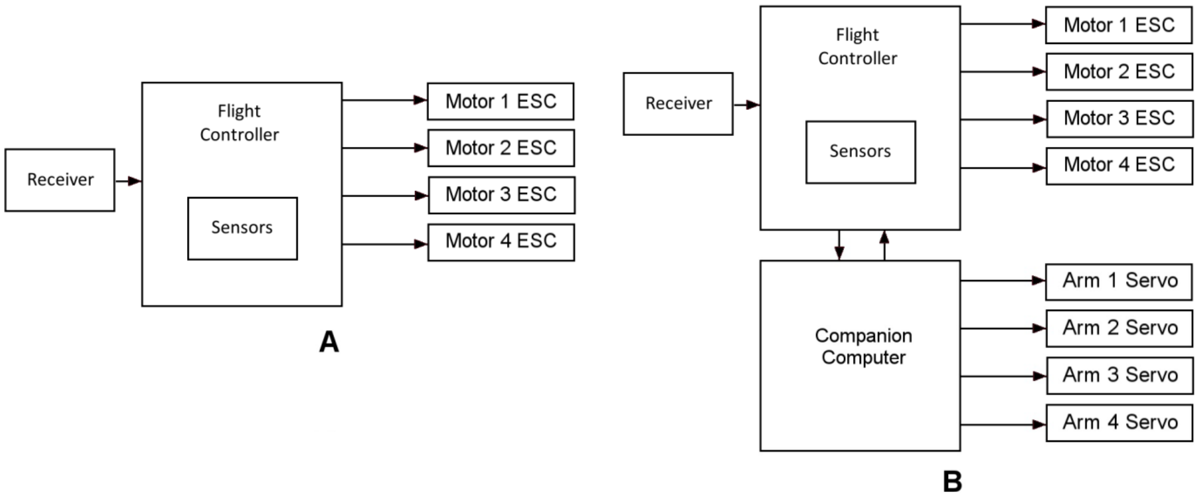

Fig. 4

Evaluation: The effectiveness of the system will be tested by attaching various payloads and monitoring the power consumption in hover position at different lopsided configurations of the payload. We will create a matrix including the asymmetry of the payload with respect to the UAV frame, and the power needed to keep the vehicle in hover position with and without our morphing mechanism activated. We expect as much as 50% increase of flight time using our technology.

Team: Our core team comprises of skilled and experienced engineers who are able to solve challenging technical problems with their expertise. The roles and responsibilities of the members of the team are given below, followed by the resume of individual members.

Table 1 below outlines the role and responsibilities of our core team for this project:

Name	Role	Activity
Suvro Datta, Ph.D.	Robodub CTO, Mechanical Engineer	Principal Investigator Mechanical Design System Integration
Parminder Devsi	Robodub CEO Electrical Engineer	Project Manager Electro-mechanical and electronics design
Natat Pico Premvuti	Robotics Engineer	Firmware, Electronics and system integration

Table 1

Suvro Datta

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Seattle, Washington 98115.
Phone: 206-729-6538 / 206-934-0043
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Education :

M.S. (Physics). Carnegie-Mellon University, Pittsburgh, PA. [1987].
Ph.D. (Physics). University of Washington, Seattle, WA.[December 1995].

Experiences :

(Nov. 2014 – Current) Co-founder and Chief Technical Officer, Robodub Inc. A robotics company with focus on both land and aerial robotics. Special interest in innovative design of drones.

(Feb. 2005 – Dec. 2015) Worked at the Engineering Department of Allen Institute for Brain Science as a Sr. Designer Engineer. Duties include - development and testing of custom-built equipment, designing mechanical parts and assemblies, and building prototypes.

(Feb. 2001 – Feb. 2005) Entreprenurial. Founder and owner of Tiasha Enterprises, an online business focused on high end photography and optical equipments.

(Jan. 1996 – Feb. 2001) Research Faculty: Space Sciences Division, University of Washington. Worked on a number of rocket and satellite projects supported by NASA grants. Designed and built rocket-borne hardwares. Acted as the team manager for the data analysis group for the same rocket experiment. Worked on the analysis of the scientific data from WIND satellite.

(1991 – 1995) Doctoral research : Designed, built, and calibrated two magnetic spectrometers (electron detector instruments) for a sounding rocket experiment, as a part of my Ph.D. thesis project. The rocket was launched in May 1993 and the instruments worked successfully.

Research assistant : Took part in a stratospheric ballooning experiment (a multi-university collaboration project to study the X-rays from the aurora) at McMurdo Station, Antarctica, in December 1990-January 1991.

Patents :

Multicopters with Variable Flight Characteristics (S. Datta) (PCT/US15/12075)
Interactive Robotic Game (P. Devsi & S. Datta) (U.S. Patent Appl. No. 62/148,675)

Qualifications :

Experienced in robotics, including liquid handling robots, robotic arm, computer controlled positioning stage.

Strong background in particle and radiation detectors, which includes Photomultiplier tubes (PMT), Microchannel plates (MCP) and Solid State detectors. Trained in use of radioactive materials and radiation hazards.

Use of laboratory equipment like oscilloscope, multimeter, multichannel analyzer (MCA), high voltage supply, and function generator.

Design and building basic electronic circuits.
Analog electronics (Operation amplifiers, discriminators, oscillators, filters).
Digital electronics (AND/OR/XOR , buffer, latch, counter, FIFO).

Use of A/D and D/A cards. Use of PC to control stepper motor system.
Designed and built a positioning system with 3 degrees of freedom, using PC, digital I/O card, mechanical and digital relays, and a number of stepper motors.

Read schematic circuit diagrams. Layout of electronic circuits (using PCAD). Fabrication of printed circuit boards (double-sided) using photo-etching.

Use of Tecan liquid handling robots.

Engineering drawing (3D) using SolidWorks and AutoCAD. Mechanical design.
Machining using CNC lathe and milling machines.

Interests : Photography, image editing, website development, microcontrollers (Arduino), robotics.

References : Available upon request.

Parminder S. Devsi

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parminder@robodub.com Redmond, WA 98052
https://www.linkedin.com/in/parminder-devsi-7032582/

SUMMARY:

- Proven leader with track record to bring an idea/concept to market in short time.
- Over 15 years of experience in leadership roles in startups/ hardware and software/EDA companies
- Conceptualized, designed and implemented high value software while managing large teams
- Mentor/investor to startups

EDUCATION:

Bachelor of Technology, Electrical Engineering (EE), 1996
Indian Institute of Technology (**IIT**), Delhi

EXPERIENCE:

Robodub Inc., Redmond, WA Nov 2014 – present
Founder and CEO

- Set the vision for the company to have 20% of drones to deploy our patented Morphing drone tech by 2025.
- Built a solid Engineering team that has created a world class product.
- Head salesman for the company and bagged orders from a government agency.
- Creating key business partnerships with players like Walmart, Moog and Boeing
- Developed software algorithms for actuation of our Morphing drones
- Designed the (electrical) hardware architecture of our drones
- Designed electro-mechanical setup for the drone including actuators
- Aviation enthusiast and keen drone pilot

EXPERIENCE:

Mentor Graphics Inc., Redmond, WA Aug 2009 – Nov 2014
Sr. Software Engineer

- Leading Interface/Translator team with team members working in Europe & Asia
- Designed & written various Translator software in Visual Studio C++/Windows/MFC which transform data from various EDA tools to Mentor’s proprietary design file format called HYP which is fed to simulation engine
- Implemented Extractor components for Mentor’s Board Station, Expedition, Altium Designer, Cadence’s PCB SI, Synopsys’ Encore. These components provide seamless integration of Mentor’s Signal/Power analysis tools to third party EDA tools
- Accelerated Translator software performance/speed over 20 times by innovative methods especially for Allegro designs.
- Worked on “Real time Connection” technology which links two EDA software tools in real time. This is industry’s first such software
- Instrumental in getting a huge orders from Nokia by solving a complex proprietary problem that was critical for the sale

Sigrity Inc., Santa Clara, CA Feb 2001 – Aug 2009
Software Engineer

- Responsible for creating all the Translator/interfaces which would connect Sigrity's simulation tools with all design//Layout tools
- Implemented pad-stack editor component across all Signal & Power GUI tools
- Created Eye diagram feature in SPDSIM & JEDEC wire-bond model viewer in all Sigrity GUI editors
- Knowledge of Boundschecker/Truetime tools to improve quality of code and to reduce processing time
- Responsible for providing swift solutions for pre-sale translation glitches
- Achieved **$1.2 million extra revenue** because of my decision to provide solution for negative layer designs as this opened doors to new set of customers
- Beat Ansoft's Autolinks in handling large designs up to 1GB to become most favored vendors for many customers
- Responsible for debugging translation issues on customer-site & also for maintaining licenses & installation for all third party EDA tools on local server
- Written testing software to automate regression testing

Silicon Valley Systech, San Jose, CA Jan 2000 – Feb 2001
Software Consultant

- Implemented several projects at client sites in C++/Win/MFC environment
- Designed a B2B application called ARC Planwell GUI Console for MirrorPlus technologies which allowed its customers to upload architectural designs.
- Implemented a language engine at Langoo.com which required mapping of phonetics on English key-board to actual characters in the selected language without downloading native fonts.
- Worked on a product called "uWare" which provided its users an application to make internet browsing more efficient by providing touch tiles on the desktop so that favorite sites of the user are one click away.
- Responsible for creating test cases and maintaining QA standards

Parsec Technologies, Gurgaon, India Jul 1996 – Dec 1999
Software Consultant

- Responsible for production of Unified Messaging Solutions
- Developed new algorithms to make the products more efficient
- Studied other products available in the market in order to create specifications for new features of Unified Messaging.
- Part of the team which created in-house software for project reports for finance department.
- Recruited new developers

MANAGEMENT EXPERIENCE:

- First angel investor in a media start-up company, Madhouse Media
- Served on advisory board and played a key role in securing funding for first round

Natat “Pico” Premvuti
Email: natatp@uw.edu | Cell: 360-747-7880

Education

(2012 - 2016) Bachelor of Science in **Electrical Engineering** at **University of Washington**

- Concentration in Embedded Computing Systems

Experience

(2017) **Robotics Engineer** at **Robodub** (Independent Contractor)

- Firmware development of a flight controller for drones based on STM32/ARM
- Wrote embedded applications in C for NuttX RTOS
- Designed system architecture and implemented system for control of onboard mechanical actuators

(2014, 2015) **Summer Intern** at **Sharp Laboratories of America**

- R&D internship focusing in software, electrical, and mechanical engineering
- Used ROS, Pixhawk, C++, Python to develop high-level control algorithms for UAV
- Wrote ROS Package for UAV navigation and state estimation, combining computer vision, IMU, and LIDAR estimates
- Performed field tests of an unmanned ground vehicle, analyzing control and driving dynamics
- Wrote and implemented serial communication protocol specifications
- Implemented PID controllers in C++

(2011) **Research Intern** at **University of Pennsylvania**

- Designed and built a quadrotor UAV, working closely with a faculty researcher
- Created CAD models using SolidWorks

Research / Organizations

(2015 - 2016) **Autonomous Flight Systems Laboratory**, Undergraduate Research Assistant

- Explored the functionality of Pixhawk and ROS applied to autonomous ground and air vehicles
- Performed flight tests of experimental vehicles

(2015 - 2017) **Advanced Robotics UW**, Engineering Lead, Accountant

- Engineering lead of a 40-member student organization participating in a robotics competition hosted by DJI
- Led introductory workshops and lectures for team members on PID control, ROS, and serial communication
- Developed real-time applications for STM32 microcontroller; used device peripherals (USART, CAN, Timers, etc.)
- Performed design reviews to ensure robots meet requirements (physical constraints, manufacturing process, cost)
- Used ROS, Python, C to perform system integration of computer vision, control inputs, and mechanical actuators

(2015 - 2016) **EcoCAR**, Cloud Backend Developer

- Developed backend and database for in-car computer using Flask and PostgreSQL

(2009 - 2012) ***FIRST*** **Robotics Competition**, Electrical and Mechanical Team Member

Projects

(2016) *EEGV*; Brain wave controlled remote vehicle using PIC. Developed for capstone design course.

(2014 - 2015) *PowerNode*; Power monitoring for real-time web-based predictive maintenance of industrial machinery. Developed for Environmental Innovation Challenge and UW Business Plan Competition.

(2011) *Intelligent Home Energy Management System*; A web-based home energy automation system using Arduinos, C, Python, HTML/CSS, and PHP. Developed for WSU Imagine Tomorrow competition.

Skills

Languages: **Java**, **C**, **Python**, **Verilog**, **HTML/CSS**, **LaTeX**, **PHP**, **SQL**, **XML**, **JavaScript**

Tools & Frameworks: **Node.js**, **Flask**, **Git**, **ROS** (Robot OS), **SolidWorks**

Platforms: **Arduino** (Atmel AVR), **STM32/ARM**, **PIC**, **Altera FPGA**, **Windows**, **Linux**

Skills: Computer Networking, Relational Databases, Soldering, Data Structures, Engineering Drawings, Circuit Design