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Engaging Undergraduates in Research: A Hands-On, Practical Approach

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Engaging Undergraduates in Research: A Hands-On, Practical Approach

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Abstract:

This Evidence-based Practice Paper provides an overview of Fairfield University's Undergraduate Research Summer Residency (URSR) program, designed to promote undergraduate research. Now in its third year, the 2024 program continues to offer students stipends, paid summer housing, and the opportunity to engage in voluntary research. The eight-week program, from June 1st to July 27th, requires students to dedicate 15 hours per week to their respective research projects and attend weekly seminars on topics such as responsible conduct of research, intellectual property rights, regulatory aspects (IRB and IACUC), and grant writing.

This year's program features 34 undergraduate students (11% of the undergraduate body), 14 high school researchers, and 10 faculty mentors, overseeing 25 diverse research projects. Among these, two key highlights is the development of a programmable, affordable drone designed for autonomous swarm navigation in GPS-free environments and Machine Learning for Brain Activity Analysis. With students collaboratively conducting research into innovative technologies.

The program culminates in poster presentations, where students showcase their research to faculty, peers, and the public. Supported by Fairfield University's School of Engineering and Computing, the URSR continues to grow in scope and impact. This paper details the program's structure, participant diversity, and key research projects, with a focus on the drone navigation project and the brain activity analysis project, concluding with survey results that reflect the program's contribution to student development and interdisciplinary learning.

1. Introduction and Background

Undergraduate research has become an essential component of higher education, offering students opportunities to apply classroom knowledge to real-world problems while developing critical thinking, technical skills, and professional competencies. At Fairfield University, the URSR program exemplifies this approach by providing a structured, immersive research experience. Now in its third year, the program continues to grow in scope and impact, fostering collaboration between students and faculty while tackling a wide array of challenges.

Undergraduate research (UR) has been consistently highlighted in academic literature as a critical component of student learning and professional development. Studies such as those by Craney et al. [2] and Lopatto [3] demonstrate significant benefits in terms of professional skill enhancement, deeper academic engagement, and increased readiness for graduate studies. Craney et al. [2] reported substantial improvements in over 450 surveyed students, while Lopatto [3] found that 85% of students engaged in UR continued on to postgraduate education.

Furthermore, institutions are exploring effective strategies to embed UR within the undergraduate curriculum. Haddad and Kalaani [4] proposed a model incorporating summer workshops and research-focused courses, supported by dedicated Undergraduate Research Offices, to foster a broader culture of inquiry and increase research accessibility. Programs like the URSR at Fairfield University exemplify these best practices, integrating accessibility with mentorship.

The impact of UR extends beyond individual achievements, as highlighted by Mabrouk and Peters [6], who found that 98% of participants valued independent research opportunities for their societal

contributions. Hoke and Gentile [7] underscored the necessity of sustained funding and close faculty mentorship, particularly vital in STEM fields, to maintain student engagement. These findings suggest that UR is instrumental in preparing undergraduates for academic and professional success, advocating for broader institutional support and integration of research activities into the educational framework.

Fairfield's URSR program supports student participation through stipends, paid summer housing, and direct faculty mentorship [8]. As a residential, in-person initiative, undergraduate students commit 15 hours per week to research and attend structured activities such as seminars, workshops, plant tours, and poster presentations. The program lowers barriers to research engagement by welcoming students as early as their first year and promoting interdisciplinary collaboration.

Alongside their research work, students participate in a one-hour weekly seminar or workshop. Designed as a part-time summer opportunity, the program's stipends and housing are intended to support full participation without the need for outside employment. Undergraduate students live on campus during the program, while most high school participants commute.

Faculty mentors volunteer their time to oversee one or two projects and provide research guidance, contributing to both student development and the success of the program. Previous versions of this program have resulted in peer-reviewed publications [9], showing the effectiveness of this program.

One featured project in the 2024 program, *"The Future of Drone Navigation: Autonomous Swarms Using IMU and Optical Flow in GPS-Denied Areas,"* engaged students in assembling, programming, and testing programmable hexacopters. While the broader faculty research explores advanced navigation strategies for GPS-denied environments, the student team focused on building the hardware platform, integrating sensors, and conducting initial flight tests. This project offered students valuable hands-on experience in UAV systems and sensor technologies, aligning with the URSR program's mission to connect academic learning with practical research skills. Another project on "*Machine Learning for Brain Activity Analysis*," exposed students to cutting edge brain activity sensors and data analysis techniques.

This paper provides an overview of the 2024 URSR program, detailing its structure, expectations, participant demographics, and seminar series. It also highlights the program's contributions to fostering critical thinking, interdisciplinary collaboration, and research excellence, positioning it as a model for undergraduate research initiatives in higher education.

2. Program Structure

The URSR program offers an intensive eight-week, in-person research experience designed to provide students with hands-on, practical learning opportunities while accommodating summer schedules. With a 15-hour weekly commitment, students engage with their projects under the direct supervision of faculty mentors. The program's structure ensures a balance between meaningful research engagement and personal time, fostering both academic growth and work-life balance.

Faculty mentors play a pivotal role, volunteering to oversee one or two projects and providing detailed summaries of their research initiatives. These summaries are shared with students, highlighting the program's diverse range of topics. In 2024, students explored 25 different projects spanning engineering, technology, and interdisciplinary fields, reflecting the program's expanding scope. Recruitment for the residency involves outreach through email lists and faculty presentations, with clear communication about expectations, stipends, and application procedures. Applicants submit their academic background, a statement of interest, and their preferred faculty mentor choices to ensure an optimal match based on research interests.

The coordination team's success in student placement is evidenced by the program's continued growth. This year, 100% of applicants were matched with suitable mentors and projects, further reinforcing the alignment between student aspirations and faculty research goals.

The URSR program is funded by Fairfield University's School of Engineering and Computing, which provides student stipends and summer housing for undergraduates. Most high school students commute. Faculty mentors volunteer their time, motivated by student engagement, mentoring opportunities, and alignment with their own research interests.

A defining feature of the URSR is its dual focus on hands-on research and educational enrichment. Students apply academic theories to real-world scenarios while participating in seven weekly seminars and workshops that cover essential topics such as:

- Responsible Conduct of Research (RCR), including research integrity and ethical practices.
- Intellectual property rights, patents, and licensing.
- Regulatory protocols like IRB, IACUC, and FCOI compliance.
- Grant writing and proposal preparation.
- Technology transfer and the commercialization of research.
- Emerging topics in precision medicine and clinical inspiration for device design.

The program's holistic structure supports not only technical research skills but also the development of soft skills such as communication, teamwork, and time management. Events like plant tours and collaborative workshops expose students to professional environments, broadening their understanding of career applications.

At the culmination of the residency, students prepare and present research posters at a formal symposium attended by faculty, peers, and members of the public. With over 150 attendees at the 2024 event, the program's visibility and impact have grown significantly. By integrating practical research with theoretical learning and professional development, the URSR equips students with the tools they need for future academic success and career readiness.

3. **Educational Seminars**

The educational seminars in the 2024 URSR program are meticulously designed to address critical aspects of research, equipping students with the foundational knowledge and skills required for success in academia and beyond. Each session delves into a specific topic relevant to aspiring researchers, emphasizing the ethical, technical, and professional dimensions of conducting impactful research.

The seminar series begins with Responsible Conduct of Research (RCR) Training, a cornerstone of ethical research practices. This session covers essential topics such as data management, conflict of interest, collaborative research, and the ethical treatment of human and animal subjects. RCR ensures students develop a strong foundation in research integrity, preparing them to navigate the complexities of modern research environments.

Following the RCR session, students participate in a seminar on Intellectual Property Rights (IPR), which provides critical insights into protecting their research ideas and outputs. This session empowers students by explaining how patents, copyrights, and trademarks function in the research and development ecosystem. In an era where intellectual property plays a pivotal role in innovation, understanding these

principles not only safeguards students' work but also fosters respect for the intellectual contributions of others.

Regulatory compliance is another central focus of the seminar series. Sessions on IRB (Institutional Review Board) and IACUC (Institutional Animal Care and Use Committee) protocols provide students with the knowledge required to obtain necessary approvals for research involving human or animal subjects. Additionally, topics like FCOI (Financial Conflict of Interest) are covered, emphasizing adherence to legal and ethical standards in all research activities.

A workshop on Grant Writing and Proposal Preparation helps students develop the skills needed to articulate their research ideas effectively. Through practical exercises, students learn how to structure competitive proposals, communicate their objectives clearly, and secure funding for future projects. These skills are invaluable for advancing research in academic and professional settings, ensuring that students are well-prepared for grant competitions at all levels.

The seminar on Technology Transfer broadens students' understanding of how research can transition from theoretical concepts to practical applications and commercial products. This session highlights the journey from lab to market, exploring innovation, entrepreneurship, and the commercialization of research outputs.

New to the 2024 program are seminars focused on emerging fields and professional inspiration, such as Precision Medicine and Clinical Device Design. These sessions, led by industry experts and academic leaders, expose students to cutting-edge developments in medical technology and offer practical insights into designing devices with real-world clinical applications.

By incorporating such a wide range of topics, the seminar series equips students with both the technical and professional skills necessary for success. These sessions not only complement the hands-on research experience but also broaden students' perspectives on the broader societal impact of their work.

4. Participation and Diversity:

The URSR program continues to emphasize inclusivity and accessibility, drawing a diverse range of participants from various academic years and disciplines. By lowering barriers through paid housing and stipends, the program ensures that students from all backgrounds can engage in meaningful research. This inclusive approach fosters an environment where participants with different levels of experience collaborate, learn, and contribute to innovative projects.

As shown in Figure 1, in 2024, the program welcomed 48 participants, including 34 undergraduate researchers—representing 11% of the undergraduate population—and 14 high school students. The undergraduate cohort spanned all academic years, with students ranging from first-years to rising seniors. This year's breakdown reflects the program's broad appeal and commitment to engaging researchers at every stage of their academic journey.

The diversity of participants brings a variety of perspectives and skill sets to the program. Novice researchers benefit from exposure to experienced peers, while advanced students hone their leadership and mentorship abilities. Faculty mentors also play a critical role in fostering a collaborative and dynamic community, guiding students as they explore new research areas and refine their skills.

This year's program featured a wide range of projects, including "The Future of Drone Navigation" and "Machine Learning for Brain Activity Analysis". The presence of high school researchers alongside

undergraduates further enriches the research environment, preparing all participants for the demands of multidisciplinary teamwork in professional and academic settings.

The program's ability to attract such a wide demographic underscore its success in cultivating research interest across all levels of education. By emphasizing diversity in participation, the URSR prepares students to collaborate effectively in multidisciplinary environments, equipping them with the skills and experiences necessary for future challenges in professional and academic contexts.

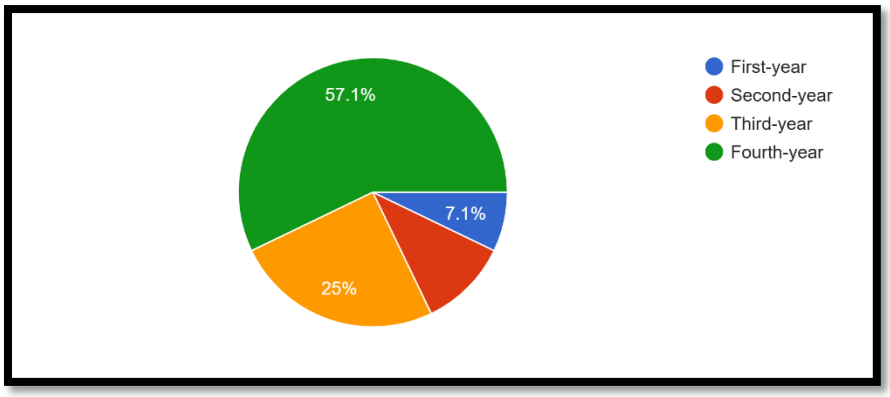

Figure 1: Participant distribution in the 2024 URSR program.

5. Sample Projects

1) The Future of Drone Navigation

The 2024 Summer Research Program in Drone Navigation offered undergraduate students hands-on experience in drone technology as part of a faculty-led project on autonomous navigation in GPS-denied environments. While the broader research focuses on developing advanced navigation algorithms, the student work centered on building, assembling, and testing programmable hexacopters and learning key principles of UAV systems and sensor integration. This project reflects the URSR program's goal of connecting theoretical learning with practical research experience.

Goals

1. Acquiring Knowledge about Drone Technology
    - Develop an understanding of drone components, flight dynamics, sensors (e.g., IMUs and optical flow), and communication systems.
    - Stay informed about emerging trends and innovations in UAV technology.
2. Develop Practical Skills in Drone Assembly
    - Gain hands-on experience in building and programming drones from scratch.
    - Explore various types of drones, materials, and assembly techniques while focusing on quality control.
    - Prioritize safety and regulatory compliance during the design and assembly process.
3. Understand Drone Navigation and Control

- Learn principles of drone navigation, including flight modes, stability, and maneuverability.
- Implement autonomous control systems to enable drones to complete specific tasks and missions in GPS-denied environments.
- Explore innovative navigation algorithms integrating IMU sensors and optical flow for real-time path optimization.

4. Enhance Critical Thinking and Problem-Solving Abilities
    - Analyze and address challenges in drone navigation and swarm coordination.
    - Optimize flight paths, overcome obstacles, and refine algorithms for improved performance.
    - Foster a creative, solutions-oriented mindset for tackling navigation challenges in complex environments.
5. Foster Collaboration and Teamwork
    - Promote effective teamwork through structured collaboration among participants, divided into two teams of three students each.
    - Encourage communication, idea-sharing, and cooperation to achieve project milestones.
6. Promote Ethical and Responsible Use of Drone Technology
    - Discuss the societal and environmental implications of UAV systems, including privacy concerns and regulatory considerations.
    - Emphasize the importance of ethical decision-making in drone development and use.
7. Develop Research and Presentation Skills
    - Conduct research focused on UAV navigation and data collection in field tests.
    - Analyze flight data, validate algorithms, and draw meaningful conclusions.
    - Present findings through formal presentations and poster sessions, culminating in the program's closing symposium.

Structure

- Duration: June 1 to July 27, 2024
- Weekly Schedule:
    - Group meetings every Thursday for project updates, short presentations, and reports.
    - Hands-on activities focused on drone assembly, programming, and testing.
    - Outdoor flight tests to validate navigation algorithms and collect data.

Highlights

Under the guidance of faculty mentors, participants accomplished significant milestones throughout the program. These included:

- Designing and assembling programmable hexacopters with IMU and optical flow integration.
- Conducting outdoor maneuverability tests to validate the drones' performance in GPS-free environments.
- Applying real-time navigation algorithms and analyzing flight data to optimize performance.
- Manufacturing drone components using Fairfield University's 3D printing facilities, emphasizing cost efficiency and customization.

Figure 2 illustrates key stages of the drone navigation project, including drone assembly, sensor integration with IMU and optical flow sensors, and outdoor flight testing. These images highlight the hands-on nature of the project and the students' active involvement throughout the process.

Figure 2: (a) Drone assembly process. (b) Sensor integration setup. (c) Outdoor flight testing.

This project not only demonstrated the students' ability to translate theoretical concepts into practical solutions but also highlighted the importance of collaboration, problem-solving, and innovation in modern UAV research. The work culminated in a poster presentation at the 2024 closing symposium, attended by over 150 faculty members, students, and public stakeholders. An example of the final student poster presentation is included in Appendix 1.

2) **Sample Project:** ***Machine Learning for Brain Activity Analysis***

The 2024 URSR program also featured a computer science project titled "Machine Learning for Brain Activity Analysis," which explored the classification of human trust in AI responses using brain activity data collected via functional Near-Infrared Spectroscopy (fNIRS) device. This interdisciplinary project bridged computer science, Psychology, and Neuroscience, providing students with hands-on experience in statistics and machine learning (ML), data analysis, and ethical considerations in AI and human-subject research. By analyzing neural activation patterns, the project aimed to develop a practical method to classify trust, contributing to advancements in human-AI interaction, as shown in Figure 3.

Goals

1. Acquire Knowledge in Machine Learning, Psychology and Neuroscience: Develop expertise in ML algorithms (e.g., classification models) and fNIRS-based brain activity measurement, focusing on oxygenated and deoxygenated hemoglobin levels in the frontal cortex.
2. Develop Practical Skills in Data Analysis: Gain proficiency in Python programming for data preprocessing, statistical analysis, and automation of repeated tasks.
3. Understand Trust in AI: Investigate neural activation patterns associated with trust in computer-generated responses, exploring real-world implications for human-AI collaboration.
4. Enhance Problem-Solving Skills: Address challenges in analyzing complex brain activity datasets, including handling noise and identifying significant differences between trust and mistrust groups.
5. Foster Interdisciplinary Collaboration: Promote teamwork among students from computer science, Psychology and Neuroscience, integrating technical and domain-specific expertise.
6. Promote Ethical Research Practices: Educate students on the importance of ethics in human subject experiments. Ensure compliance with Institutional Review Board (IRB) protocols and address ethical considerations in AI and human-subject research.
7. Develop Research and Presentation Skills: Conduct experiments, interpret preliminary results, and present findings through a poster session at the URSR symposium.

Structure

- Duration: June 1 to July 27, 2024
- Weekly Schedule:
    - Meetings every Tuesday to review data format, and plan statistical analyses.
    - Hands-on activities focused on fNIRS data preprocessing, Python script development, and statistical testing.

Highlights

- Under the guidance of the faculty mentor, this project achieved significant milestones:
- Developed a Python script to process data, automate statistical testing, and calculate p-values for various fNIRS channels to identify differences between trust and mistrust groups.
- Identified statistical variations in brain activity, with certain channels showing lower activity in the trust group compared to the mistrust group, suggesting potential statistically significant differences.
- Presented a poster at the 2024 URSR symposium, attended by over 150 stakeholders, detailing the statistical tests, preliminary findings, and future research directions.
- The project demonstrated students' ability to integrate machine learning with Psychology and Neuroscience, addressing real-world challenges in human-AI trust. While preliminary results indicate differences in neural activation, further data collection and analysis are needed to

confirm these patterns. This work underscored the URSR's commitment to fostering innovative, interdisciplinary research with societal impact.

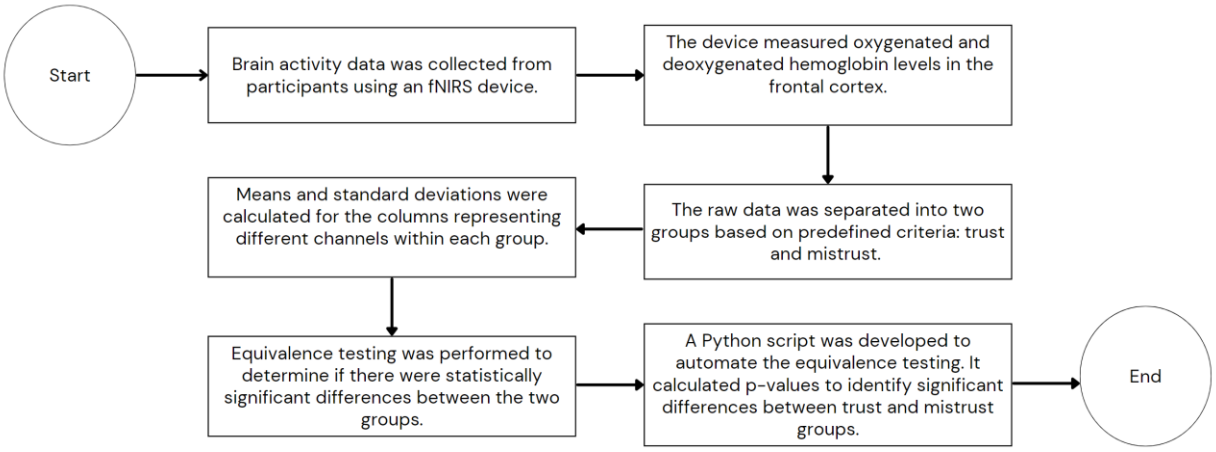

Figure 3: Workflow for fNIRS data processing and analysis

5.2 Challenges and Lessons Learned

While the drone navigation project successfully engaged students in hands-on research and technical skill-building, the project faced several challenges that contributed to valuable learning experiences. One difficulty was the time required for students to become familiar with drone assembly, sensor calibration, and programming tools, particularly for those without prior experience. The limited duration of the eight-week program also posed constraints on the depth of algorithm development and testing. To address these challenges, faculty mentors provided additional workshops and troubleshooting sessions, and the teams prioritized achievable milestones such as stable flight control and sensor integration before attempting more advanced navigation features.

6. Survey Methodology and Data Analysis

To assess participant experiences and gather feedback on the Undergraduate Research Summer Residency (URSR) program, an anonymous online survey was administered to students at the conclusion of the 2024 summer session. The survey was designed for internal program assessment purposes and not intended as formal research. The questions focused on students' self-reported perceptions regarding skill development, confidence in conducting research, teamwork, and communication.

The survey included a series of Likert-scale questions with response options ranging from "Strongly Agree" to "Strongly Disagree," alongside several open-ended prompts inviting students to share comments about their experience. Survey content was informed by commonly used evaluation approaches in undergraduate research programs but did not include original or experimental instruments.

Participation in the survey was voluntary, and responses were collected anonymously using the Qualtrics platform. No identifying information was linked to survey responses. Out of 34 undergraduate participants, 30 completed the survey, resulting in an 88% response rate.

The analysis focused on descriptive statistics, reporting the percentage of respondents selecting each response option. To simplify presentation, results are grouped into combined categories of "Strongly Agree" and "Agree." Open-ended responses were reviewed qualitatively to identify recurring themes and participant feedback.

6.1. Survey Results and Research Highlights

This study aimed to evaluate the impact of the 2024 URSR program. Feedback collected from participants highlights a high level of satisfaction and significant learning outcomes, underscoring the program's continued success. The program's achievements are further illustrated through flagship projects, such as *"The Future of Drone Navigation" and "*Machine *Learning for Brain Activity Analysis*" which showcased students' ability to apply theoretical knowledge to practical challenges in innovative ways.

Survey results from participants in the engineering program indicate overwhelmingly positive responses across a variety of aspects:

- Increased Interest in Engineering: 94% of respondents strongly agreed or agreed that the program increased their interest in engineering.
- Impact on Confidence to Succeed in Engineering: 89% of participants reported a significant increase in confidence to succeed in engineering.
- Understanding of Engineering Design: 83% noted an increase, while 17% reported a substantial increase in their understanding of engineering design.
- Development of Critical Thinking Skills: 83% strongly agreed that their critical thinking skills improved, while 17% agreed.
- Development of Communication Skills: 85% strongly agreed or agreed that they developed stronger communication skills.
- Ability to Work Independently: 88% strongly agreed that they learned to work independently.
- Ability to Work as Part of a Team: 88% strongly agreed or agreed that their teamwork skills improved.
- Ability to Conduct a Research Project: 90% agreed or strongly agreed that the program enhanced their ability to conduct research.
- Increased Confidence in Research Skills: 88% strongly agreed or agreed that their research skills improved significantly.
- Increased Confidence in Becoming a Successful Engineer/Professional: 88% strongly agreed or agreed with this statement.
- Relevance of Academic Coursework: 87% strongly agreed or agreed that the program made their coursework feel more relevant.
- Interest in Pursuing Graduate Studies: 82% of participants reported an increased interest in pursuing graduate studies.

The positive responses reflect the program's success in combining hands-on research with professional development. Students consistently praised the opportunity to apply classroom knowledge to real-world projects, work collaboratively with peers, and build strong mentoring relationships with faculty. Limitations of this assessment include reliance on self-reported survey data and the short duration of the summer program, which may limit long-term skill development. Future efforts could include longitudinal tracking of participant outcomes and expanded project timelines to support deeper engagement with complex research tasks.

7. Conclusion

Now in its third year, the URSR program has continued to evolve based on participant feedback and faculty experience. Early iterations focused on research skill-building, while recent years have expanded seminar offerings and interdisciplinary project opportunities. Lessons learned emphasize the importance of clear project milestones, consistent mentor-student communication, and additional support for students with limited prior research experience.

The program demonstrates how smaller academic institutions can successfully offer meaningful undergraduate research experiences through structured mentorship, financial support, and intentional program design. Looking ahead, Fairfield University plans to strengthen the URSR by developing alumni follow-up surveys to better understand long-term outcomes and exploring new project areas, including potential industry collaborations to broaden research opportunities.

This assessment is based on self-reported survey data collected at the conclusion of the summer program, which provides valuable insights into student perceptions but may not fully capture long-term impact. Future efforts may include longitudinal tracking of participants to assess career paths, graduate study enrollment, and continued engagement in research activities.

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Appendix 1: Sample poster at the end of the program (without header and footer to hide university information)

BACKGROUND

- Develop technology for drones to operate in areas without GPS signals.
- Applications: Search & Rescue, Military Operations.
- Develop affordable drone swarm on open source firmware

Key System Components:

- Flight controller with inertial measurement to handle attitude control
- Video Transmitter for live video feed from the aircraft
- Speed controllers to control motor speed from Flight controller signal
- GPS for global satellite positioning
- R/C receiver long range low latency control link for stable control

- Integration of multiple sensors to enable precise drone navigation.
- Ensuring reliable drone operation in challenging environments.

HARDWARE/SENSORS

- Flight Controller (StM32F722)
- IMU (BMI270)
- Barometer (BMP280)
- OSD chip (AT7456E)
- GPS (BN-880)
- 500MB Flight Recorder
- Optical Flow
- Magnetometer

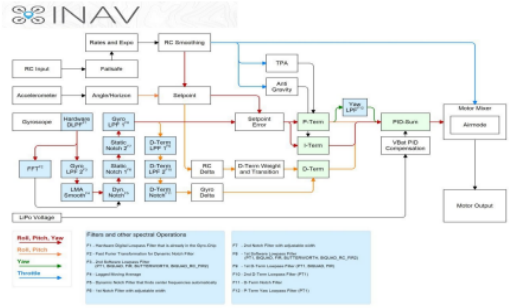
OBJECTIVE

Our goal in this project is to combine various sensors and sensor data via fusion to navigate drone swarms in GPS denied environments. This can allow drones to fly safely in places that would normally lose signal and get lost.

METHODOLOGY

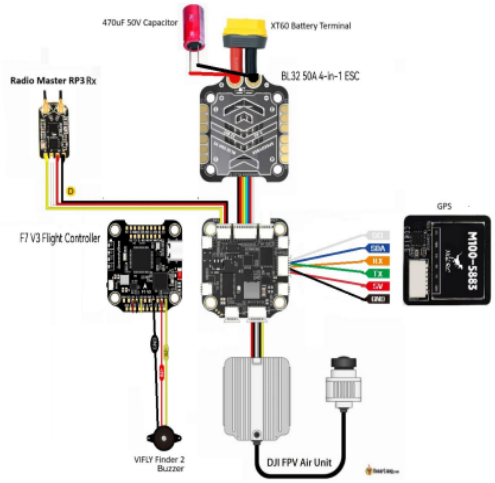
- We start by building the frame of the drone and attach the motors. Once the skeleton of the drone was built, we solder the motors onto the motor controller. The next step is to solder the rest of the sensors to the board.
- We then connect the drone to INAV to run tests to make sure that the motors and other sensors are working properly. Then conduct a hover test to make sure that everything is working correctly.
- The tuned drones will be a platform for mounting additional sensors for data collection.

SYSTEM PROCESS



Logical diagram of PID flight controller commonly know by pilots as "fly by wire" flight controls

RESULTS



This shows the wiring diagram that was used to build the drone, it shows the different sensors and how they are wired onto the board

CONCLUSIONS

- Better knowledge of how to build a drone was gained
- The ability to solder and a better understanding of wires was gained
- The ability to produce an electrical diagram was gained

AKNOWLEDGEMENT

- Open source Developers of INAV, ELRS, EdgeTX, and many more