Keshav Anand — RSI Application

1. Why did you choose these research fields?

Prompt: Articulate why the research fields chosen on the previous page are intriguing and exciting to you. For each sub-field, state what you perceive as the one or two most interesting questions or problems in this area. Explain why these sorts of questions interest you. Your responses are shared with mentors. Please respond with clarity and specificity, including what specific prior research/coursework/etc experiences have prepared you to "hit the ground running" in these fields at RSI.

- Field 1: Computer Science — Machine Learning for Signal Processing
- Field 2: Robotics/Mechatronics — Autonomous Motion Planning

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It was during a COVID-19 YouTube binge where I was first introduced to the art of modern computer. After stumbling into a rabbit hole of videos explaining the inner-workings of a machine, I immediately fell in love with Computer Science. Over the years, I have also developed a specialized interest in signal processing and its applications. My curiousity in this topic stems from my first Math Club meeting in 9th grade, where a senior officer had explained the fascinating science of how radio signals are transmitted and received using Fourier transforms. These concepts overlapped with my learning of fascinating Calculus concepts, and I was amazed at how signals can be analyzed and processed. Today, the major question that excites me within the field of Signal Processing is how to effectively adapt digital signal processing and machine learning for real-time resource-constrained embedded systems. As a hardcore robotics enthusiast, I have always been not just interested in the theoretical software, but also the practical hardware embedding of these algorithms. This really sparked my interest in the field of signal processing for embedded systems, prompting me to start a 2 year research project that would become the focus of my life. My ISEF-winning research project from 2024 - 2025, GaitGuardian, was my first major experience with signal processing, as I had worked on a project to predict Freezing of Gait (FoG) episodes in Parkinson's Disease patients using a belt-mounted IMU sensor and machine learning algorithms. My novel pipeline involved using fourier transforms, z-score normalization, and wavelet denoising to filter out noise from the raw IMU data. Unlike existing approachs that used time-domain features, I fed the cleaned time-series data into a 1D CNN, acting as an automatic feature extractor (with no flattening). This was passed into a hybrid biLISTM with temporal and spatial attention mechanisms, allowing for segmented windows to be read both forwards and backwards, and a final dense layer would output the boolean state of whether a FoG episode was occuring in real time. The learning I gained from this research led me to pursue other related signal processing tasks to boost the final product for Parkinson's patients. Researching other Parkinsonian symptoms led me to explore tremor detection (uncontrolled shaking of the hands), and I implemented a real-time tremor detection model that involved a bandpass butterworth filter to isolate tremor frequencies between 4-6 Hz, followed by an FFT to extract frequency-domain features. These features were then fed into a lightweight 1D CNN, resulting in state-of-the-art 99% accuracy while limiting false positives. I also looked into signal processing within my FTC robotics team, realizing that IMU data could be used to improve odometry and localization. I implemented a custom Kalman filter to fuse IMU data with wheel encoder reading, significantly reducing drift during autonomous navigation and reducing error buildup over time. My second major interest has been in the field of Robotics, springing from a lucky acceptance into my Middle School's robotics team in 6th grade. Due to COVID-19, out team had to start from scratch, and as a completely inexperienced 7th grader, it took me 7 months to simply learn to spin a motor. The same fascination I had with computers was now being applied to physical hardware, and I have been a loyal participant in the First Tech Challenge (FTC) robotics competition. As the software lead of my globally ranked team, Technical Turbulence FTC, I have learned a lot about the algorithms that empower robots during the 30-second autonomous period of the competition. Today, I am intrigued by two major research questions within the field of autonomous motion planning. First, I wonder how multiple autonomous agents can effectively coordinate in real-time to achieve a common goal while avoiding collisions. This question fascinates me because it combines elements of path planning, communication protocols, and decision-making under uncertainty. Secondly, I am fascinated by the question of whether autonomous robots and vehicles can learn optimal paths from experience rather than relying on pre-programmed maps. This idea of reinforcement learning for motion planning excites me because it provides a pathway for devices to improve performance over time in dynamic environments. My experience with robotics has provided me with a strong foundation to tackle these questions, as I have designed and implemented a custom pathing algorithm for my FTC robot. The motion profiling algorithm I developed uses cubic and quintic splines to generate smooth trajectories between points, using inverse kinematics

and a PID controller to accurate follow the path. By prioritizing endpoint accuracy over time and path accuracy, our robot's pathing is extermely precise, resulting in a top-30 autonomous ranking globally. Outside FTC, I worked on a passion project to allow for pathing of two vaccuum robots in a shared environment. Using A* for initial pathfinding and a custom potential fields algorithm for real-time obstacle avoidance, I made a software system that allowed for efficient cleaning of a dynamic space. Together, my experience in robotics software, signal processing, and machine learning have prrepared me to hit the ground running at RSI, and I am excited to further explore these research questions with the help of expert mentors and resources.

2. What are your long term goals?

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Every word amazed me. ChatGPT did not feel like yet another website so much as a magical portal to infinite knowledge. I still remember the thrill when my computer science teacher unveiled the mystical tool that could ace our rock-paper-scissors coding exam in under a minute. Little did I realize that in less than three years, AI would touch everything I do — from school projects to software debugging, even revising this very essay. But it was in the Summer of 2023 that my best friend asked me a life-changing question: "How does it work?" I was completely clueless, and I told him that a stenographer was typing at the other end. As months passed and my AI usage expontially increased, this question haunted me. I was determined not to be a mere user, but to understand and develop the magic behind the curtains.

That Summer was when I embarked on my first long-term goal: to fully understand the inner workings of the devices and programs I use. My journey in achieving this started when I joined my robotics team, Technical Turbulence. As the sole software member, I learned everything from scratch. I started by dissecting each wire, realizing that understanding hardware was crucial to mastering software. From PWM control to I2C communication, I slowly worked up the layers of abstraction, eventually coming to the software that I was responsible to write. Today, I continue my pursuit of deep technical knowledge through my independent research projects. In my ninth grade, I decided to grasp the fascinating concept of a thermoelectric generator. The following year, I completely shifted focus, doving into high-level signal processing and machine learning concepts to develop GaitGuardian, my ISEF-winning Parkinson's research project. Through these experiences, I have learned that true mastery comes from understanding the layers beneath the surface, which is why I am committed to this lifelong goal of deep technical knowledge. As I continue to uncover more information, I continue pursuing this goal through passion projects. My latest endeavor of hosting a full server on an old chromebook is pushing me to learn Linux system administration, networking, and cybersecurity. The final result is the same as a Replit fork, but the knowledge I gain from understanding the server-side is invaluable. It is with this goal in mind that I approach RSI, eager to learn from experts and deepen my understanding of computer science.

My Parkinson's research was also started for this very purpose: to learn an understand the complex fields of signal processing and machine learning with a senior friend of mine. However, it quickly evolved into a mission to use my limited knowledge to make a real-world impact. During our presentation at the Dallas Science and Engineering Fair, a judge approached us after our presentation and shared that his father suffered from Parkinson's disease. I didn't think much of it at the time, but when we emailed the Dallas Area Parkinson's Society (DAPS) to share our findings, the overwhelming response from patients and caregivers made me realize the true potential of our work. Two months later, a close family friend was diagnosed with early-onset Parkinson's, and I realized the hope that research brings to people. Therein lies my second long-term goal: use my knowledge to improve the human condition through impactful research.

Although my skillset is still limited, my goal is to continue to push the boundaries of technological applications to eventually benefit humanity. Not only am I interested in healthcare applications like GaitGuardian, but I am also fascinated by the potential of robotics and software to improve everyday life. For example, I was particularly piqued by the recent advancements in autonomous pathing of multiple agents, as I see huge potential for applications in warehouse automation, constricution, and even self-driving cars. Be it through hardware, software, or a combination of both, I am committed to expand my knowledge and use it to make a positive impact on the world. RSI represents a crucial step in this journey, allowing me to work on relevant research that pushes the boundaries of technology. As a devout Hindu, the Vibuthi (cow ash) I apply to my forehead reminds me that all humans will eventually unite with the Earth, and I want to be remembered for leaving a positive mark on humanity before I do.

My final long-term goal is to encourage and inspire the next generation of students to pursue STEM. As someone

who has experienced the transformative power of a good teacher firsthand, I am passionate about helping others discover the joy of learning. After realizing that a teacher can change my perception on a subject itself, I committed myself to tutoring and helping others. Whether it is through robotics outreach or through my school's ACE tutoring club, I have always sought to share my knowledge and enthusiasm for STEM with others. I hope RSI presents me with an opportunity to further this goal by providing me world-class mentorship and resources, which I can then use to benefit others in the same way RSI will benefit me.

3. What activities and/or hobbies demonstrate your leadership, creativity and uniqueness?

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Music was my first language. Even before I could speak, music became the place where I learned to create. Throughout elementary school, I learned Piano and Classical Indian Carnatic vocals, but even after I picked up flute for my middle school band, but I never felt I was truly expressing myself. It was finally in 8th grade, when I decided to drop my perpetual practicing and pursue a form of music that reflected me: Indian film music covers. Unlike Western music, which centers on albums, popular music in the Indian subcontinent is woven into cinema, with most movies featuring five to six full-length songs. I wanted to not just replicate these songs, but to enhance them, leaving my own fingerprint on familiar melodies.

Here, my creativity finally blossomed in the form of tasteful covers that completely reimagined familiar melodies. After learning about the world of Digital Audio Workstations (DAWs), I realized that most musical instruments can be reproduced with a digital keyboard language known as MIDI. This completely changed my life — propelling me into a universe that lies at the intersection of my two greatest passions: music and technology. I spent countless hours tinkering with plugins and virtual soundtracks to digitally capture the subtle beauty of each sound. I even bought a $50 Black Friday bass guitar and began merging analog and digital sounds. My music started to feel like me.

Joining my first band, High Octavez, was transformative. As a group of hobbyist musicians dedicated to faithfully recreating iconic film music, High Octavez taught me what it mean to collaborate a a high level. Together, we recreated iconic film music with precision, and all proceeds went to charity. As the keyboard player, I didn't just perform; I sculpted the sounds, blending technical skill with creative vision. Performing in two concerts, which collectively raised over $300,000 for charity, showed me how creativity can make tangible impact. Not only was I expressing myself, I was helping my community. Now, as I prepare for my third concert, I am continuing to fuse music and technology. I built a real-time music server that optimizes bitrate to rival commercial platforms, combining my passions in a way that transforms both performance and experience.

4. Describe your participation in extracurricular or community outreach activities?