Designing an Efficient Distributed Maximum Power Point Tracking System for the UVA Solar Car Team
(Technical Paper)

Navigating Emotional Bonds with Technology: Ethical and Social Impacts of Autonomous Systems
(STS Paper)

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

How will society look 50 years from now? No one knows the answer to this question, but trends point to electrification and automation. Fossil-fuel-powered technologies are becoming electrified, and we are embedding autonomous systems into various aspects of daily life. For instance, electric cars and automated delivery drones are becoming increasingly common in cities, transforming transportation and logistics (Papandreou, 2024; Heineke et al., 2024).

Given this societal shift, there is a growing need for technologies that efficiently harness and automate the control of electrified systems. My capstone project focuses this aim within the transportation realm, where we are developing a distributed Maximum Power Point Tracking (MPPT) system for the UVA Solar Car team to optimize and autonomously control the power gain of their solar panels.

This automation trend extends beyond transportation, growing roots in areas like healthcare and manufacturing. As technology becomes deeply integrated into society, our reliance on it increases, often manifesting in emotional attachment. This leads to an important question: How might emotional attachment to automated systems lead to ethical issues, especially when we rely on technology to make decisions that impact human well-being?

My preliminary research suggests that emotional bonds with autonomous systems indeed raise significant ethical challenges. AI personal assistants and companion robots are often designed to foster unidirectional emotional bonds with users, encouraging people to depend on autonomous systems for tasks these machines may not be equipped to handle (Sharkey & Sharkey, 2011). Privacy concerns, such as data collection and surveillance, are prevalent among autonomous systems users, with emotional attachment sometimes leading to complacency around sharing sensitive information (Müller, 2023). This is particularly worrisome in sensitive areas like healthcare, where privacy is not the only concern. A deeper philosophical question emerges: should machines be entrusted with moral authority? If people begin to view AI counselors or caregiving robots as reliable moral agents, it could reshape society's relationship with technology in profound ways, potentially diminishing human agency and judgment (Chatila & Havens, 2019).

In both the technical and ethical dimensions, my work aims to explore how we can advance autonomous, electrified systems responsibly—balancing the benefits of innovation with safeguards to maintain human autonomy and ethical integrity.

Technical Project

My capstone team is building a Distributed Smart Solar Charge Controller (D.S.S.C.C.) for the UVA Solar Car Team to optimize the car's solar panel power output during a race under variable light conditions. It will do so by adjusting the voltage and current outputs depending on those variable conditions. Our project will be a scaled down version of what the Solar Car team needs, as we will use three solar panels and a smaller battery due to budget and time constraints. Despite this, the project will be easy to replicate and scale up for the Solar Car Team's needs due to extensive documentation. The overall goal of our project is to prove that our smart distributed Maximum Power Point Tracking (MPPT) system is more efficient than Solar Car's current model.

According to the U.S. Energy Information Administration (Hess & Tsai, 2024), solar power is expected to make up the majority of new energy production in 2025. However, solar power generation and transmission is nowhere near perfect, and using these solar panels effectively is a challenge. A main issue that we identified is mismatch losses, where an array of solar panels is prevented from operating at its maximum power due to differences in shading of individual solar panels (Xu et al., 2010). This can cause major efficiency losses in the system as well as solar panel damage due to hot spot generation (Solórzano & Egido, 2014).

The Solar Car Team's current MPPT design uses a bypass diode solution, where bypass diodes are placed in line with each solar panel. When a panel is producing less current than the surrounding panels, the corresponding bypass diode will conduct current, "bypassing" the affected panel. This solution is not perfect, as the bypass diode completely cuts off power from the shaded panel rather than providing the power that is still generated.

Our solution to make their MPPT more efficient is to use a Distributed MPPT, where a buck/boost converter is placed on each panel. The converters on each panel match the output current, allowing all panels to provide usable power to the system. This design was inspired by an efficiency analysis report that praises Distributed MPPTs for their ability to mitigate mismatching losses and optimize the output power of photovoltaic systems under varying conditions (Alonso et al., 2010), ensuring that even shaded panels are providing power.

Not only will our design provide more power gain for the system during a race, it is easily repairable and customizable, more so than their current design. Our design is more cost effective, as our project budget is $500, and the Solar Car's current MPPTs were purchased for $3000 total.

To ensure the design meets the UVA Solar Car Team's requirements, our methods focus on iterative testing and refinement. We will develop the Distributed MPPT in stages, beginning with simulations and progressing to physical testing. Throughout the development process, we will closely coordinate with the Solar Car Team to confirm compatibility and performance expectations.

1. **Simulation and Prototyping**: We will begin by simulating each subsystem, particularly the buck/boost converter and the Distributed Maximum Power Point Tracking (MPPT) algorithm. This will help us verify that each component can meet the anticipated power requirements under variable lighting conditions.
2. **Component Testing**: Each hardware component, including the STM32 microcontroller, current and voltage sensors, and MOSFETs, will be tested on a breadboard before PCB integration. Using multimeters and oscilloscopes, we will validate that each component performs to specification.
3. **Algorithm Validation**: The Distributed MPPT algorithm will be tested independently on the microcontroller to verify its accuracy in tracking maximum power under varying conditions. We will implement a DC Sweep mode to chart the power curve, which will confirm the algorithm's ability to achieve the global maximum power point.
4. **PCB Integration and Heat Testing**: Once individual components are tested, we will integrate them onto a PCB and monitor thermal performance. This step includes a manual thermal inspection to ensure no hotspots form under full load conditions, safeguarding against overheating.

5. **System Testing with Solar Panels**: The full Distributed MPPT system will undergo testing with three solar panels under different lighting conditions. Data will be recorded and transmitted via UART communication to display real-time metrics on a laptop. We will evaluate the system's efficiency against baseline values from the Solar Car Team's current MPPT model.
6. **Field Testing and Adjustments**: Finally, we plan to conduct field tests simulating racing conditions, assessing system response to dynamic lighting and load changes. Adjustments will be made as necessary, particularly to the Distributed MPPT algorithm, to ensure optimal performance and power efficiency.

STS Project

In a world increasingly integrated with autonomous systems, the emotional bonds that humans form with these technologies present new ethical and social challenges. My research question—*How can emotional attachment to automated systems lead to ethical issues, especially when we rely on technology to make decisions that impact human well-being?*—aims to explore the nuances of this attachment and its societal implications. Using the Politics of Knowledge, the Social Construction of Technology (SCOT), and Bridge Analysis frameworks, I will analyze how this emotional attachment arises, the risks associated with it, and potential solutions for ethical AI design.

The Politics of Knowledge framework helps analyze the power dynamics in the development and deployment of automated systems. Automated technologies, such as companion robots and virtual assistants, are often designed to foster trust and emotional bonds (Boine, 2023). This design choice is not neutral; it is influenced by tech companies who prioritize user engagement and data acquisition over transparency. As automated systems grow in influence, the knowledge they provide and the emotional connections they foster shape how people perceive them. As Kate Crawford discusses in The Atlas of AI, these systems embed societal power dynamics, often prioritizing corporate interests at the expense of user autonomy and privacy (Crawford, 2021). Emotional attachment may cause users to rely on AI for personal or mental health decisions (Saeidnia et al., 2024) in ways that compromise their autonomy and privacy (Müller, 2023). This highlights the need for transparent AI design that acknowledges these power dynamics and respects users' well-being and autonomy.

Through the SCOT framework, this research will examine how different social groups influence AI's purpose and meaning. In the case of companion robots, certain user groups, such as the elderly or children, may form emotional attachments that heighten dependence on these technologies (Sharkey & Sharkey, 2011). Josef Barla's analysis of how the spirometer was shaped by societal biases reveals how societal expectations influence technological designs (Barla, 2023). Similarly, companion robots may reflect societal values about caregiving, creating unidirectional emotional relationships where users perceive the technology as genuinely caring, despite it being an algorithmic system incapable of reciprocity (Law et al., 2022). By understanding how these emotional needs shape AI, SCOT reveals the social factors that both enable and constrain how these technologies are designed and utilized.

Bridge Analysis helps address the ethical implications of emotional attachment by linking the perspectives of designers, users, and regulators. Ethical AI guidelines, such as those proposed by the IEEE Global Initiative (Chatila & Havens, 2019), emphasize the need for transparency, accountability, and privacy. Bridge Analysis facilitates conversations between technologists and ethicists to ensure that ethical standards align with user needs (Hagerty & Rubinov, 2019). These interdisciplinary efforts can foster AI designs that act as “mediators” rather than emotional companions, encouraging genuine human-to-human connections instead of substituting them (Law et al., 2022). Additionally, I will use bridge analysis to link the perspectives of various sources, coming to a common consensus of how emotional attachment is harmful in many different aspects.

By integrating Politics of Knowledge, SCOT, and Bridge Analysis, this research seeks to understand how autonomous systems, while technologically beneficial, may unintentionally compromise human autonomy. Addressing these social factors provides insight into designing responsible AI systems that respect user privacy, reduce dependency, and promote ethical usage. Through this framework, we can work towards a future where autonomous systems support human well-being without diminishing the importance of human relationships or ethical integrity.

Conclusion

In summary, my technical project will deliver a Distributed Smart Solar Charge Controller for the UVA Solar Car Team, demonstrating a scalable, efficient solution to optimize power gain from solar panels under varying light conditions. This device aims to maximize power output, reduce costs, and increase reliability, ultimately leading to an electrified autonomous system. Meanwhile, my STS research offers a critical understanding of the ethical and social factors that arise from emotional attachment to autonomous systems. By using the Politics of Knowledge, SCOT, and Bridge Analysis frameworks, I will explore the unintended consequences of reliance on autonomous technology and identify ethical design approaches to mitigate risks related to user autonomy and privacy.

Together, these projects address the sociotechnical challenge of responsibly integrating autonomous, electrified systems into society. By grounding my technical design in insights from the STS research, I aim to promote a balanced approach where technological innovation aligns with ethical integrity, ensuring these systems support human well-being while preserving autonomy and privacy.

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