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DEPARTMENT: EMERGING ROCKSTAR

Jingxian Wang: "Pushing the Limits of Battery-Free Internet-of-Things"

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FROM THE EDITOR

The "Emerging Rockstar" segment in *IEEE Pervasive Computing* highlights rising stars in the field of pervasive computing through captivating interviews. In the series' inaugural article, Dr. Lakmal Meegahapola, a member of *IEEE Pervasive Computing's* editorial board, conducts an interview with Dr. Jingxian Wang, an Assistant Professor at the National University of Singapore.

Jingxian Wang is an Assistant Professor with the National University of Singapore's Computer Science Department. Previously, he was a Researcher with Microsoft Research, Redmond, WA and has a Ph.D. from Carnegie Mellon University. His research is in the area of wireless systems. In 2023, he was honored with the ACM SIGMOBILE Dissertation Award. His contributions to wireless systems and ubiquitous computing have earned best paper awards at top-tier venues, including ACM UbiComp/ISWC 2020 and ACM/IEEE IPSN 2021. Furthermore, his innovations have twice been featured as Research Highlights in *Communications of the ACM*. He is also the recipient of the Microsoft Research Ph.D. Fellowship.

IEEE Pervasive: Could you provide an overview of your research in battery-free Internet-of-Things, some of the key challenges in the area, and how you have addressed these challenges in your work?

Jingxian Wang: The dream of the Internet of Things (IoTs), or pervasive computing, is to have everyday objects such as clothing and keys smartly connected to the Internet. However, there is a challenge: reliance on batteries is a major drawback. Batteries require frequent replacements, add weight, and increase costs. My research is focused on creating a battery-free Internet of Things. We have observed how tiny and cost-effective RFID tags can be, setting a precedent for future IoT platforms. However, these technologies currently face limitations in communication range and sensing capabilities. Overcoming these limitations is exactly what my work aims to achieve.[1,2,3,4,5,6,7]

In battery-free IoT systems, the main issue is their short communication range. This is because their energy sources blindly disperse wireless power in all directions. What we need is a more focused energy transfer, like beamforming in wireless communication. However, the challenge with battery-free devices is that they do not provide feedback before receiving power, unlike battery-powered devices such as mobile phones. That is where our innovation comes in—"blind wireless beamforming." By precisely delivering the wireless energy without prior feedback from the device, we have significantly extended the communication range of these systems.[8] Interestingly, this concept has inspired our team to apply wireless beaming

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in a microwave oven, such as for evenly heating a pizza slice.[9]

Pervasive: Regarding your work with electronics-free soft robots, could you detail the specific aspects you focus on? In addition, what are the ultimate objectives or aspirations you have for this area of your research?

Wang: Electronics-free soft robots, composed entirely of stretchable, shape-memory polymers, represent a fascinating area of research.[10] These robots are also battery-free and are actuated by heat. Traditionally, tethered connections to a dc power supply provide the necessary heat, but our aim is to use beamforming techniques to wirelessly heat and move the robot. This involves two primary challenges: precisely directing wireless energy to the robot as it moves and developing a new material architecture for the robot to efficiently absorb and utilize the wireless energy. Our experiments with a 2-watt WiFi system have been promising,[11,12] demonstrating the robot's movement through wireless actuation. The long-term goal is to develop these robots as autonomous, battery-free sensors or wireless computing platforms that can navigate complex environments.

IT IS ACTUALLY OUR NETWORKS FOR WIRELESS COMMUNICATION THAT CONSUME THE MOST ENERGY.

Pervasive: Considering the nature of your work, which spans fields such as artificial intelligence, robotics, and materials science, what challenges do you encounter in conducting such interdisciplinary research?

Wang: Jumping into fields such as robotics, materials science, and AI from wireless systems is like moving to a new country—exciting, but also a bit intimidating. At first, it is tough to step out of your comfort zone. But once you do, you start seeing how your own expertise, such as understanding signal propagation, communication, and wireless networks, can actually shake things up in these other areas. It is all about connecting the dots between different fields to create something totally new and groundbreaking.

Pervasive: What advice would you offer to upcoming researchers interested in pursuing a career in a similar research field as you, based on your experiences and insights?

Wang: I encourage researchers to broaden their horizons beyond their specific areas of study. Reading papers and engaging in activities outside your primary field can be incredibly enlightening. This approach has been instrumental in helping me generate unique ideas and solve complex problems by integrating perspectives from various disciplines. It not only enriches your research, but also brings in unexpected yet valuable insights. In addition, my research is highly problem driven. I focus on the practical challenges and everyday problems, which has been a key driver in developing solutions that are both theoretically sound and practically impactful. This problem-driven approach, combined with a broad, interdisciplinary perspective, is truly essential.

Pervasive: Finally, what are your future goals?

Wang: Looking forward, my focus is on developing wireless systems that are both sustainable and efficient. At first glance, one might assume that the most energy-consuming sector of the digital world is the "Cloud"—data centers storing vast amounts of data and running computationally intense AI algorithms. Surprisingly, that is not the case. It is actually our networks for wireless communication that consume the most energy. This is especially true with the rise of emerging technologies like 5G, IoT, and Industry 4.0, which have been overlooked in this regard. In fact, they account for over 55% of worldwide energy consumption in computing systems. The critical question then becomes: How can we build wireless connectivity that is both energy-efficient and sustainable? This is likely to be the next big challenge in achieving next-generation wireless ubiquity. By enhancing the scalability, longevity, and energy efficiency of wireless systems, my research stands to make a significant contribution toward a more connected and sustainable future.

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