RAINSTORM: Rooftop Assembly Inchworm Network and Swarm Tiling Optimization for Rooftop Maintenance

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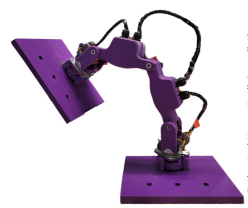
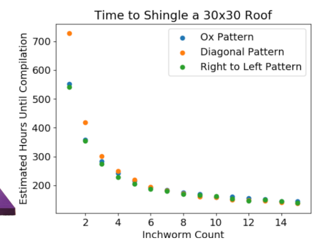
Context. Retrofitting existing structures is a major part of the construction industry. As of 2011, over 40% of residential buildings within the U.S. had been built before 1970. Since building codes and energy regulations have changed over time, many of these buildings are not compliant with modern standards. Retrofitting buildings can increase disaster resistance, structural integrity, energy efficiency, and overall safety. However, construction jobs are dangerous, with the construction industry accounting for one in five workplace deaths in 2019. Equipping this workforce with automated systems will reduce the number of people on roofs, and will increase workplace safety in the roofing industry.

Problem statement. We aim to design a novel robotic concept for roofing applications. We focus on applying shingles to a roof in an autonomous manner. To make operations faster and more reliable, we study how to take advantage of the parallelism and redundancy afforded by coordinated multi-robot systems.

Related work. Robotics for construction is a blooming field. In particular, several multi-robot solutions have been proposed, which generally focus on the problem of creating structures *ex novo*. Examples include TERMES, BILL-E, SRoCS, and SMAC. Retrofitting, however, has received little attention in the field, with the sole example of RoboRoofer, a robot designed to take shingles *off* roofs rather than installing them.

Hardware. We adapted the original SMAC hardware [1] to shingle roofs. SMAC is a "symbiotic" system in which smart blocks reason on the structure to build as they are being assembled, and inchworm-shaped robots act as dumb builders. The inchworm, in particular, offers versatile navigation and block manipulation. We replaced the smart blocks with shingles that contain metal pieces, and replaced the end effectors of the inchworms with permanent electromagnet that can be enabled and disabled. An NFC tag allows the robot to store data on the shingles for coordination and localization.





Simulation. We modeled the physics of inchworms, shingles, and a roof in Gazebo using an open-source magnet plugin. Our system can simulate any roof and swarm configuration. To quickly test and evaluate different swarm behaviors, we also developed a lightweight simulator to model a swarm of robots shingling a roof. This simulator allowed us to rapidly test novel decentralized shingling algorithms, and evaluate the performance of differently sized swarms.

Control. The robots communicate through writing and reading data from the shingles, similar to how insects leave chemical trails in the environment to communicate. Shingling proceeds through motion and coverage patterns aimed to maximize parallelism and efficiency.

Testing. We tested and compared three motion patterns: boustrophedon, diagonal, and left-to-right, showing improved performance with increasing number of inchworms involved.

References

[1] C. Wagner, N. Dhanaraj, T. Rizzo, J. Contreras, H. Liang, G. Lewin, and C. Pinciroli, "SMAC: Symbiotic multi-agent construction," *IEEE Robotics and Automation Letters*, vol. 6, no. 2, pp. 3200–3207, 2021.