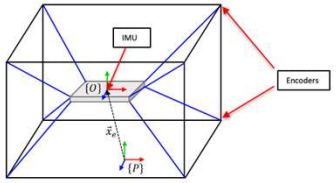
NRI:FND: 3D Concrete Printing with Macro-Micro Cable-Driven Robots

Ian D. Walker, Venkat N. Krovi, Prasad Rangaraju, and Matthias J. Schmid, Clemson University

Project URL: https://cecas.clemson.edu/armlab-cuicar/research/manufacturing-autonomy

Macro-robot unit to provide 3-DOF (x-y-z) positioning over the controllable workspace



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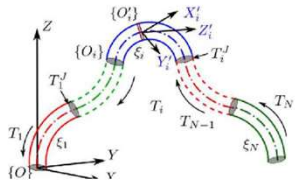

Micro-robot unit to provide 6-DOF (x-y-z-ϕ-θ-ψ) positioning over the local workspace

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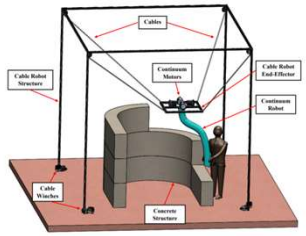


Challenge

Dexterous "active hoses" to interactively assist construction workers for 3D printing of concrete

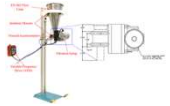
Background

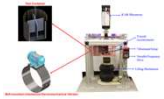
Construction industry vital for national economy:

- ~ 5% of US Gross Domestic Product (GDP)
- 1.463 trillion, 6.7 M workforce (in 2017)
- Construction one of least automated industries in the world
- Productivity hindered by lack of automation tools
- Concrete operations a foundational element in construction

Materials Research Results

- Designed/manufactured active-rheology control test setup
- Material trials in rheometer and flow rate measurement completed.





- Active-stiffening test setup designed and fabricated.
- Three refereed journal papers in submission on (a) impact of chemical accelerators on properties of printable mixtures (b) effect of vibration on active-rheology of cementitious materials and (c) inter-test correlation of physical and chemical properties of 3D printable cementitious mixtures.
- Technical Presentation to be given at the ACerS 13th Advances in Cement Based Materials, June 14-16, 2023.

Proposed Solution

Intelligent novel cable-driven macro/micro co-robot:

- Cable-robot acts as the macro-base
- Cable-driven continuum robot (integrated with concrete delivery hose) serves as micro-unit
- Field Intelligence: Situational awareness and physical-assist

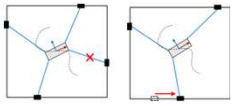
Impact of Solution

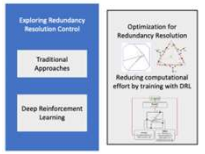
- Fundamental research in rheology of 3D-printable concrete
- New generalizable modeling of coupled cable-driven macro-micro robot systems
- Intelligent assist for concrete delivery in construction industry

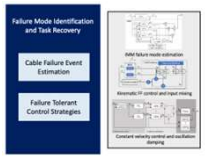
Macro Cable Robot Results

- Modeling, Control & Estimation of Reconfigurable Cable Driven Parallel Robots (rCDPRs)

- Raman Thothathri, Adhiti, (2023), "Modeling, Control and Estimation of Reconfigurable Cable Driven Parallel Robots," *Ph.D. Dissertation, Clemson Univ.*, https://tigerprints.clemson.edu/all_dissertations/3172
- Walker, I.D. et al. (2023). 3D Concrete Printing with Macro-micro Robots. In: *Proc. of the Future Technologies Conference (FTC) 2022*, https://doi.org/10.1007/978-3-031-18344-7_34
- Raman, A., Walker, J., Krovi, V., & Schmid, M. (2022), "A Failure Identification and Recovery Framework for a Planar Reconfigurable Cable Driven Parallel Robot," *IFAC-PapersOnLine*, *55*(37), 369-375. https://doi.org/10.1016/j.ifacol.2022.11.211
- Raman, A., Schmid, M., & Krovi, V. (2021), "Wrench Analysis of Kinematically Redundant Planar CDPRs," In *Cable-Driven Parallel Robots*, pp. 90-104, June 2021 DOI: https://doi.org/10.1007/978-3-030-75789-2_8







Broader Impacts

- 4 Ph.D. Students (2 female) and 2 REU students hired
- 2 NSF INTERN Supplements
- Paper in Journal of TRR: Transportation Research Record
- Industry and conference (IEEE ICRA/IROS, CableCon, ACI, TRB, ACerS) presentations
- Plenary and Workshop talks (IEEE RoboSoft, IEEE ICMRE, TRB Meeting on Active Rheology Control for 3D Printing)
- Summer outreach seminars to K-12 schools and industry
- Public Outreach on 3D Printing through ArTispHerE
- External Advisory Board (EAB) to Phinnize J Fisher Middle School (STEAM school)
- Developing a University-Industry Collaboration for Design and Construction of Scaled-3D Printed Models for Concept Validation

Continuum Hose Robot Results

- Euler curve variable curvature (VC) kinematic model for multiple continuum robot sections significantly improved end effector (EE) pitch control compared to constant curvature (CC) model
- Statics-based model to compensate for axial compression in TDCRs ensuring uniform EE velocity and curvature at all bending planes developed for single section
- Closed loop control of single section using IMU feedback with statics model feedforward dramatically improves EE accuracy
- Model for elasticity compensation due to tendon extension under development

2023 NRI & FRR Principal Investigators' Meeting
May 2-3, 2023

Award ID#: 1924721