

Resilience and Risk Management in Social Robot Systems: An Industrial Engineering Perspective

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Abstract

The increasing integration of social robots in critical environments such as healthcare, disaster response, and public safety has heightened the need for robust resilience and risk management strategies. This paper explores resilience-building methodologies and risk analysis tools from an industrial engineering perspective to ensure the reliability and safety of social robot systems. Key aspects of resilience, including adaptability, fault tolerance, and recovery, are examined alongside challenges arising from dynamic and unpredictable environments. The paper delves into industrial engineering tools like Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA) to address potential system failures and mitigate risks. FMEA is discussed as a proactive approach to identifying failure modes, analysing causes, and prioritizing risks, with case applications in healthcare robotics. FTA is presented as a deductive methodology for tracing system failures to their root causes, with examples in disaster response. The role of social robots in critical environments is also highlighted, emphasizing their application in search and rescue missions, eldercare, and public safety operations. The research identifies gaps in current frameworks for assessing resilience in social robots, particularly in dynamic environments, and emphasizes the need for adaptive and hybrid risk management frameworks. Future opportunities, such as integrating advanced technologies like AI and IoT, are proposed to enhance system resilience and reliability. This paper underscores the importance of industrial engineering principles in advancing the safe and effective deployment of social robots, contributing to improved outcomes in critical and high-stakes scenarios.

Keywords: Social Robots, Resilience Engineering, Risk Management, Disaster Response, System Reliability

BACKGROUND

The growing integration of social robots into critical environments such as healthcare, disaster response, and public safety presents both remarkable opportunities and significant challenges. These systems are no longer experimental; they are actively deployed in situations where failure is not an option. Social robots are being tasked with vital responsibilities like patient monitoring, eldercare, crowd control, and search-and-rescue missions. In each of these contexts, their ability to interact safely and effectively with humans is paramount. Given their increasingly important roles, it is necessary to examine how these robots can be designed and managed to ensure maximum resilience, particularly when exposed to unpredictable, dynamic environments.

Social robots, unlike traditional industrial robots, must operate in less structured settings where the variables they encounter—human behavior, emotional responses, environmental shifts—are difficult to fully anticipate. This makes them particularly vulnerable to operational disruptions, ranging from software glitches and mechanical failures to miscommunication with human users. Without appropriate planning, these vulnerabilities can lead to service interruption, loss of trust, or even physical harm. As robots transition into frontline roles, society must address how to ensure their reliability and responsiveness in critical, high-pressure scenarios.

The concept of resilience in this context refers to the robot's ability to continue functioning despite faults, recover quickly after disruptions, and adapt its behavior to changing circumstances. These characteristics are crucial when robots operate in environments like hospitals or disaster zones, where a delayed or failed response could be catastrophic. Therefore, engineering resilience into robotic systems is not merely a technical advantage; it is an ethical imperative. Designing for resilience requires deep interdisciplinary collaboration across robotics, software engineering, industrial engineering, human factors, and systems thinking.

Equally critical is the role of risk management. With the increasing complexity of robot systems and their integration with advanced technologies like AI and IoT, the probability of unforeseen failures grows. Effective risk management provides a structured way to identify potential issues, assess their impact, and plan mitigation strategies before problems occur. Risk management ensures that robot behavior remains predictable and that failure modes are understood and addressed in advance. Especially in mission-critical applications, a lack of systematic risk analysis can turn minor faults into major incidents.

Taken together, resilience and risk management form the cornerstone of responsible robotics deployment in critical sectors. Without them, the promise of social robots may remain unfulfilled or, worse, result in unintended harm. Industrial engineering, with its focus on optimization, reliability, and systems integration, provides powerful tools and methodologies to address these needs. By viewing social robot systems through this lens, we can create a roadmap toward safer, more resilient, and more trustworthy robotics capable of meeting the challenges of the real world.

METHOD

To address the challenges of resilience and reliability in social robot systems, this paper applies established industrial engineering tools—Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA). These methodologies are selected for their structured, systematic approaches to analyzing and mitigating risks in complex systems. FMEA focuses on proactively identifying potential failure modes within a system, examining their root causes and possible effects, and ranking their severity using quantitative metrics. In contrast, FTA adopts a deductive reasoning process, beginning with a known system failure and mapping out all possible contributing events through logical diagrams. Together, these tools offer complementary perspectives on risk management.

FMEA provides an effective framework for evaluating the reliability of a robot by cataloging all known and potential ways in which a system component might fail. In healthcare robots, for example, failure modes could include sensor malfunctions, data processing errors, or actuator delays. Each of these is evaluated using three key dimensions: severity, occurrence, and detectability. These scores are multiplied to generate a Risk Priority Number (RPN), which helps prioritize the most critical risks for immediate action. This prioritization enables engineers to allocate resources effectively and implement design improvements before failures happen.

FTA, on the other hand, is most valuable when a failure has already been observed and its underlying cause needs to be identified. This method uses logic gates—AND and OR—to trace how various faults interact and cascade to produce a top-level failure. In disaster response robots, an FTA might reveal how environmental noise, software bugs, and hardware fatigue together contribute to communication breakdowns. By visualizing these relationships, FTA allows designers to implement targeted interventions such as redundant components, noise filtering, or predictive maintenance protocols.

Both tools can also support iterative development by informing continuous testing and validation processes. As robots evolve through multiple design cycles, FMEA and FTA help ensure that new features do not introduce new vulnerabilities. Moreover, these methods can be adapted for use in both hardware and software components, making them applicable across the full stack of robot development. They are especially useful when integrated into agile or lean development frameworks where rapid iteration must be balanced with risk oversight.

In this study, these tools are applied in conceptual case studies focused on healthcare and disaster response—two fields where robotic failures pose high risks to human life. By using FMEA and FTA to model risks in these scenarios, the study demonstrates how industrial engineering principles can directly support the safe deployment of social robots. This methodological approach also lays the groundwork for future work aimed at creating more adaptive and standardized frameworks for resilience assessment in robotic systems.

RESULT AND DISCUSSION

The application of FMEA and FTA in social robot systems reveals three central pillars of resilience: adaptability, fault tolerance, and recovery. These features are not independent; rather, they function synergistically to ensure the robot's performance in adverse conditions. Adaptability refers to a robot's ability to adjust its operations based on environmental stimuli or user behavior. For instance, a healthcare robot might detect patient discomfort and change its routine accordingly. Fault tolerance ensures that a robot continues operating even if one or more components fail. This could involve using redundant sensors or backup power systems. Recovery, meanwhile, is the robot's capacity to restore normal function after a disruption, such as a software crash or mechanical jam.

FMEA helps to evaluate these dimensions by breaking down the robot system into components and examining how each one might fail. In doing so, it allows engineers to understand how a fault in one part—such as a temperature sensor—might affect the system as a whole. If a failure could result in patient harm or system shutdown, it is flagged as high priority. These insights support the implementation of mitigation strategies such as component redesign, improved calibration, or enhanced error detection routines. In real-world settings like hospitals, where robots must operate continuously and accurately, such preemptive planning is crucial.

FTA complements this analysis by offering a macroscopic view of failure interdependencies. For example, communication failure in a disaster-response robot might be traced to a combination of software errors, inadequate shielding from electromagnetic interference, and battery degradation. By mapping these out, engineers can see not only where failures occur but how they interact. This systems-level thinking is vital in environments

where robots must coordinate with human teams or other machines, and where single points of failure can have cascading effects.

Another key finding is that resilience must be engineered into both hardware and software components. While hardware failures are more visible and often easier to diagnose, software bugs—such as incorrect data parsing or poor user interface design—can be equally damaging. These issues can erode user trust, lead to wrong decisions, or trigger unexpected robot behaviors. Using FMEA and FTA to identify and address such risks ensures that social robots are robust not only in form but also in function.

Ultimately, these tools help convert abstract notions of safety and resilience into measurable engineering objectives. They make it possible to test assumptions, quantify vulnerabilities, and verify improvements over time. In doing so, they provide a vital foundation for designing next-generation robots that can be trusted in roles where human safety and public confidence are on the line.

CONCLUSION

This study demonstrates that applying industrial engineering methodologies like FMEA and FTA to social robot systems can significantly enhance their resilience, safety, and overall performance. These tools allow for systematic identification, evaluation, and mitigation of risks, enabling robots to function reliably even in high-pressure, unpredictable environments. As social robots continue to expand their roles in critical sectors, ensuring their dependable operation becomes not just a technical goal but a societal requirement.

One of the most important takeaways is the need for proactive design thinking. Rather than reacting to failures after they occur, developers must anticipate possible issues and engineer solutions in advance. FMEA and FTA offer structured ways to do this, supporting not only better design but also more effective training, maintenance, and deployment strategies. By integrating these tools into early development cycles, teams can build systems that are more durable, responsive, and user-friendly from the outset.

At the same time, this paper highlights key limitations in current risk assessment practices. There is a lack of standardized frameworks tailored to the unique conditions in which social robots operate. Most engineering tools assume controlled, predictable environments, which do not reflect the real-world complexities of healthcare wards, disaster zones, or public spaces. Future research must focus on adapting and extending these tools to capture the nuanced interplay between technical and social systems in which robots function.

Furthermore, emerging technologies such as artificial intelligence and IoT offer opportunities to enhance resilience through real-time data analysis, predictive modeling, and autonomous decision-making. These innovations must be incorporated into updated risk frameworks that reflect the cyber-physical nature of modern robots. Integrating AI with FMEA and FTA could enable dynamic, self-updating risk assessments that evolve as robots learn and adapt in the field.

In conclusion, resilience and risk management are not peripheral concerns but central design challenges in social robotics. Addressing them requires a rigorous, multidisciplinary approach that spans engineering, psychology, ethics, and policy. By adopting industrial engineering principles and continuously evolving our methodologies, we can create social robots that not only meet performance standards but also earn the trust of the people they are meant to serve.

DAFTAR PUSTAKA

- Avram, O., Baraldo, S., and Valente, A. (2022). Generalized behaviour framework for mobile robots teaming with humans in harsh environments. *Frontiers in Robotics and Ai*, 9. <https://doi.org/10.3389/frobt.2022.898366>
- Ballesteros, E. and Ramos-Ballesteros, P. (2019). Social-ecological resilience as practice: a household perspective from Agua Blanca (Ecuador). *Sustainability*, 11(20), 5697. <https://doi.org/10.3390/su11205697>
- Belpaeme, T., Kennedy, J., Ramachandran, A., Scassellati, B., and Tanaka, F. (2018). Social robots for education: a review. *Science Robotics*, 3(21). <https://doi.org/10.1126/scirobotics.aat5954>
- Berlet, M. (2024). Toward telemedical diagnostics—clinical evaluation of a robotic examination system for emergency patients. *Digital Health*, 10. <https://doi.org/10.1177/20552076231225084>
- Botta, A., Cacace, J., Vivo, R., Siciliano, B., and Ventre, G. (2021). Networking for cloud robotics: the dewros platform and its application. *Journal of Sensor and Actuator Networks*, 10(2), 34. <https://doi.org/10.3390/jsan10020034>
- Bouchard, K. (2023). Cardiology professionals' views of social robots in augmenting heart failure patient care. *European Heart Journal - Digital Health*, 5(1), 69-76. <https://doi.org/10.1093/ehjdh/ztad067>

- Campbell, A. (2024). Developing a conceptual framework for characterizing and measuring social resilience in blue-green infrastructure (bgi). <https://doi.org/10.20944/preprints202403.0715.v1>
- Cao, J. and Chen, N. (2022). The influence of robots' fairness on humans' reward-punishment behaviours and trust in human-robot cooperative teams. *Human Factors the Journal of the Human Factors and Ergonomics Society*, 66(4), 1103-1117. <https://doi.org/10.1177/0018720822113327>
- Delgado, J., Ajayi, A., Akanbi, L., Akinadé, O., and Bilal, M. (2019). Robotics and automated systems in construction: understanding industry-specific challenges for adoption. *Journal of Building Engineering*, 26, 100868. <https://doi.org/10.1016/j.jobbe.2019.100868>
- Delmerico, J., Mintchev, S., Giusti, A., Gromov, B., Melo, K., Horvat, T., ... and Scaramuzza, D. (2019). The current state and future outlook of rescue robotics. *Journal of Field Robotics*, 36(7), 1171-1191. <https://doi.org/10.1002/rob.21887>
- Ezeanyim, O. C., Ewuzie, N. V., Aguh, P. S., Nwabueze, C. V., and Nwamekwe, C. O. (2025). Effective Maintenance of Industrial 5-Stage Compressor: A Machine Learning Approach. *Gazi University Journal of Science Part A: Engineering and Innovation*, 12(1), 96-118. <https://dergipark.org.tr/en/pub/gujsa/issue/90827/1646993>
- Filho, W. (2024). An assessment of priorities in handling climate change impacts on infrastructures. *Scientific Reports*, 14(1). <https://doi.org/10.1038/s41598-024-64606-3>
- García-Córdova, F. (2024). Bioinspired control architecture for adaptive and resilient navigation of unmanned underwater vehicle in monitoring missions of submerged aquatic vegetation meadows. *Biomimetics*, 9(6), 329. <https://doi.org/10.3390/biomimetics906032>
- Garofalo, E., Bevione, M., Cecchini, L., and Chiolerio, A. (2022). On the pyroelectric and triboelectric phenomena in ferrofluids. *Advanced Materials Technologies*, 7(10). <https://doi.org/10.1002/admt.202200127>
- Guertler, M. (2024). A matrix-based approach to step-wise assess the safety of collaborative robots in manufacturing. *Proceedings of the Design Society*, 4, 2555-2564. <https://doi.org/10.1017/pds.2024.258>
- Guo, D., Shan, M., and Owusu, E. (2021). Resilience assessment frameworks of critical infrastructures: state-of-the-art review. *Buildings*, 11(10), 464. <https://doi.org/10.3390/buildings11100464>
- Hartmann, F., Baumgartner, M., and Kaltenbrunner, M. (2020). Becoming sustainable, the new frontier in soft robotics. *Advanced Materials*, 33(19). <https://doi.org/10.1002/adma.202004413>

- Hoorn, J. (2018). From lonely to resilient through humanoid robots: building a new framework of resilience. *Journal of Robotics*, 2018, 1-17. <https://doi.org/10.1155/2018/8232487>
- Igbokwe, N. C., Nwamekwe, C. O., Godwin, H. C., & Mba W. (2025). Optimization of Overall Equipment Effectiveness Factors in A Food Manufacturing Small and Medium Enterprise. *Journal of Research in Engineering and Applied Sciences (JREAS)*, 10(1), 836-845. <https://qtanalytics.in/journals/index.php/JREAS/article/view/4660>
- Igbokwe, N. C., Okpala, C. C., & Nwamekwe, C. O. (2024). The Implementation of Internet of Things in the Manufacturing Industry: An Appraisal. *International Journal of Engineering Research and Development*, 20(7), 510-516. <https://www.ijerd.com/paper/vol20-issue7/2007510516.pdf>
- Jamil, A. (2024). Resilience and sustainability in tourism-forestry systems through risk management framework: review and concept. *Journal of Law and Sustainable Development*, 12(1), e1120. <https://doi.org/10.55908/sdgs.v12i1.1120>
- Jin, Y., Wang, G., Yuan, D., Wang, P., Wang, J., Chen, H., ... and Zan, X. (2023). Bio-inspired environmental adaptability of swarm active matter. *Chinese Physics B*, 32(8), 088703. <https://doi.org/10.1088/1674-1056/acd688>
- Khan, Z., Siddique, A., and Lee, C. (2020). Robotics utilization for healthcare digitization in global covid-19 management. *International Journal of Environmental Research and Public Health*, 17(11), 3819. <https://doi.org/10.3390/ijerph17113819>
- Li, Y. (2024). Advances in the application of ai robots in critical care: scoping review. *Journal of Medical Internet Research*, 26, e54095. <https://doi.org/10.2196/54095>
- Licardo, J. (2024). Intelligent robotics—a systematic review of emerging technologies and trends. *Electronics*, 13(3), 542. <https://doi.org/10.3390/electronics1303054>
- Liu, Z. (2023). Linking supply chain collaboration, collaborative advantage, and firm performance in china: the moderating role of government subsidies. *Sustainability*, 15(21), 15329. <https://doi.org/10.3390/su152115329>
- Mitsuhashi, T. (2024). Heterogeneity of the effect of the covid-19 pandemic on the incidence of metabolic syndrome onset at a japanese campus. *Peerj*, 12, e17013. <https://doi.org/10.7717/peerj.17013>
- Monteleone, S., Negrello, F., Grioli, G., Catalano, M., Bicchi, A., and Garabini, M. (2023). A method to benchmark the balance resilience of robots. *Frontiers in Robotics and Ai*, 9. <https://doi.org/10.3389/frobt.2022.817870>
- Mudholkar, D. (2024). Impact of artificial intelligence and internet of things on performance management: a systematic review. *ijer*, 4(1). <https://doi.org/10.52783/ijer.v4i1.606>

- Nemitz, M. (2024). A framework for soft mechanism driven robots. <https://doi.org/10.21203/rs.3.rs-4109720/v1>
- Nwamekwe C. O., and Nwabunwanne E. C. (2025). Circular Economy and Zero-Energy Factories: A Synergistic Approach to Sustainable Manufacturing. *Journal of Research in Engineering and Applied Sciences (JREAS)*, 10(1), 829-835. <https://qtanalytics.in/journals/index.php/JREAS/article/view/4567>
- Nwamekwe C. O., Ewuzie Nnamdi Vitalis, Igbokwe Nkemakonam Chidiebube, & Nwabueze Chibuzo Victoria. (2025). Evaluating Advances in Machine Learning Algorithms for Predicting and Preventing Maternal and Foetal Mortality in Nigerian Healthcare: A Systematic Approach. (2025). *International Journal of Industrial and Production Engineering*, 3(1), 1-15. <https://journals.unizik.edu.ng/ijipe/article/view/5161>
- Nwamekwe C. O., Ezeanyim O. C., and Igbokwe N. C. (2025). Resilient Supply Chain Engineering in the Era of Disruption: An Appraisal. *International Journal of Innovative Engineering, Technology and Science (IJIETS)*, 9(1), 11-23. <https://hal.science/hal-05061524/>
- Nwamekwe, C. O., and Igbokwe, N. C. (2024). Supply Chain Risk Management: Leveraging AI for Risk Identification, Mitigation, and Resilience Planning. *International Journal of Industrial Engineering, Technology & Operations Management*, 2(2), 41–51. <https://doi.org/10.62157/ijietom.v2i2.38>
- Nwamekwe, C. O., and Okpala, C. C. (2025). Circular economy strategies in industrial engineering: From theory to practice. *International Journal of Multidisciplinary Research and Growth Evaluation*, 6(1): 1773-1782. https://www.allmultidisciplinaryjournal.com/uploads/archives/20250212103754_MGE-2025-1-288.1.pdf
- Nwamekwe, C. O., and Okpala, C. C. (2025). Machine learning-augmented digital twin systems for predictive maintenance in highspeed rail networks. *International Journal of Multidisciplinary Research and Growth Evaluation*, 6(1), 1783-1795. https://www.allmultidisciplinaryjournal.com/uploads/archives/20250212104201_MGE-2025-1-306.1.pdf
- Nwamekwe, C. O., Chinwuko, C. E. & Mgbemena, C. E. (2020). Development and Implementation of a Computerised Production Planning and Control System. *UNIZIK Journal of Engineering and Applied Sciences*, 17(1), 168-187
- Nwamekwe, C. O., Ewuzie, N. V., Igbokwe, N. C., Okpala, C. C., andamp; U-Dominic, C. M. (2024). Sustainable Manufacturing Practices in Nigeria: Optimization and Implementation Appraisal. *Journal of Research in Engineering and Applied Sciences*, 9(3). <https://qtanalytics.in/journals/index.php/JREAS/article/view/3967>

- Nwamekwe, C. O., Ewuzie, N. V., Igbokwe, N. C., U-Dominic, C. M., andamp; Nwabueze, C. V. (2024). Adoption of Smart Factories in Nigeria: Problems, Obstacles, Remedies and Opportunities. *International Journal of Industrial and Production Engineering*, 2(2). Retrieved from <https://journals.unizik.edu.ng/ijipe/article/view/4167>
- Nwamekwe, C. O., Ewuzie, N. V., Okpala, C. C., Ezeanyim, C., Nwabueze, C. V., Nwabunwanne, E. C. (2025). Optimizing Machine Learning Models for Soil Fertility Analysis: Insights from Feature Engineering and Data Localization. *Gazi University Journal of Science Part A: Engineering and Innovation*, 12(1), 36-60. <https://dergipark.org.tr/en/pub/gujisa/issue/90827/1605587>
- Kato, T., Matsuo, Y., Ueda, G., Aoyama, Y., Omi, K., Hayashi, Y., ... & Takiguchi, S. (2020). Epithelial cyst arising in an intrapancreatic accessory spleen: a case report of robotic surgery and review of minimally invasive treatment. *BMC Surgery*, 20(1). <https://doi.org/10.1186/s12893-020-00927-0>
- Nwamekwe, C. O., Ewuzie, N.V., Igbokwe, N. C., Nwabunwanne, E. C., & Ono, C. G. (2025). Digital Twin-Driven Lean Manufacturing: Optimizing Value Stream Flow. *Letters in Information Technology Education (LITE)*, 8 (1), pp.1-13. <https://hal.science/hal-05127340/>
- Nwamekwe, C. O., Okpala, C. C., and Okpala, S. C., (2024). Machine Learning-Based Prediction Algorithms for the Mitigation of Maternal and Fetal Mortality in the Nigerian Tertiary Hospitals. *International Journal of Engineering Inventions*, 13(7), PP: 132-138. <https://www.ijeijournal.com/papers/Vol13-Issue7/1307132138.pdf>
- Okeagu F. N., Charles Onyeka Nwamekwe, Blessing Precy Nnamani. (2024). Challenges and Solutions of Industrial Development in Anambra State, Nigeria. *Iconic Research and Engineering Journals*, 7(11), 467-472. <https://www.irejournals.com/formatedpaper/1705825.pdf>
- Okpala C. C., Chukwudi Emeka Udu, & Charles Onyeka Nwamekwe. (2025). Sustainable HVAC Project Management: Strategies for Green Building Certification. *International Journal of Industrial and Production Engineering*, 3(2), 14-28. <https://journals.unizik.edu.ng/ijipe/article/view/5595>
- Okpala, C. C., Ezeanyim, O. C., & Nwamekwe, C. O. (2024). The Implementation of Kaizen Principles in Manufacturing Processes: A Pathway to Continuous Improvement. *International Journal of Engineering Inventions*, 13(7), 116-124. <https://www.ijeijournal.com/papers/Vol13-Issue7/1307116124.pdf>
- Okpala, C. C., Udu, C. E., & Nwamekwe, C. O. (2025). Artificial Intelligence-Driven Total Productive Maintenance: The Future of Maintenance in Smart Factories. *International Journal of Engineering Research and Development (IJERD)*, (21)1, 68-74. <https://www.ijerd.com/paper/vol21-issue1/21016874.pdf>

- Papadopoulos, I., Koulouglioti, C., Lazzarino, R., and Ali, S. (2020). Enablers and barriers to the implementation of socially assistive humanoid robots in health and social care: a systematic review. *BMJ Open*, 10(1), e033096. <https://doi.org/10.1136/bmjopen-2019-033096>
- Park, K., Yuk, H., Yang, M., Cho, J., Lee, H., and Kim, J. (2022). A biomimetic elastomeric robot skin using electrical impedance and acoustic tomography for tactile sensing. *Science Robotics*, 7(67). <https://doi.org/10.1126/scirobotics.abm718>
- Pavone, M. (2023). En-block butterfly excision of posterior compartment deep endometriosis: the first experience with the new surgical robot hugo™ ras. *Facts Views and Vision in Obgyn*, 15(4), 359-362. <https://doi.org/10.52054/fvvo.14.5.104>
- Pontin, M. (2024). Multimodal soft valve enables physical responsiveness for preemptive resilience of soft robots. *Science Robotics*, 9(92). <https://doi.org/10.1126/scirobotics.adk9978>
- Romeh, A. (2023). Theoretical framework and practical considerations for achieving superior multi-robot exploration: hybrid cheetah optimization with intelligent initial configurations. *Mathematics*, 11(20), 4239. <https://doi.org/10.3390/math11204239>
- Saja, A., Teo, M., Goonetilleke, A., and Ziyath, A. (2021). A critical review of social resilience properties and pathways in disaster management. *International Journal of Disaster Risk Science*, 12(6), 790-804. <https://doi.org/10.1007/s13753-021-00378-y>
- Singh, K. (2024). Fog cloud computing and iot integration for ai enabled autonomous systems in robotics. *Eai Endorsed Transactions on Ai and Robotics*, 3. <https://doi.org/10.4108/airo.3617>
- Wang, T. (2024). Multimodal sensors enabled autonomous soft robotic system with self-adaptive manipulation. *Acs Nano*, 18(14), 9980-9996. <https://doi.org/10.1021/acsnano.3c11281>
- Whitesides, G. (2018). Soft robotics. *Angewandte Chemie*, 57(16), 4258-4273. <https://doi.org/10.1002/anie.201800907>
- Yamashita, A., Yoshioka, S., and Yajima, Y. (2021). Resilience and related factors as predictors of relapse risk in patients with substance use disorder: a cross-sectional study. *Substance Abuse Treatment Prevention and Policy*, 16(1). <https://doi.org/10.1186/s13011-021-00377-8>
- Zappetti, D., Sun, Y., Gevers, M., Mintchev, S., and Floreano, D. (2022). Dual stiffness tensegrity platform for resilient robotics. *Advanced Intelligent Systems*, 4(7). <https://doi.org/10.1002/aisy.202200025>

Zhang, Q., Zhou, L., and Xia, J. (2020). Impact of covid-19 on emotional resilience and learning management of middle school students. Medical Science Monitor, 26. <https://doi.org/10.12659/msm.924994>