Integration of XArm robots with Tenzo force sensors for intelligent manipulation systems

Mashxurbek Jalilov
mashkhurbekjalilov@gmail.com
Andijan State Technical Institute

Abstract: This paper presents the integration of XArm collaborative robots with Tenzo force and tension sensors to develop an intelligent and force-sensitive manipulation system. The primary objective of this research is to enhance robotic grasping accuracy, safety, and adaptability by incorporating real-time force feedback. XArm robots provide high precision, modular design, and open application programming interfaces (APIs), while Tenzo sensors enable accurate measurement of mechanical forces and deformations. The proposed system combines hardware and software integration techniques, including sensor signal processing and adaptive control algorithms. Experimental results demonstrate that the integration of Tenzo sensors significantly improves grasp stability, reduces object damage, and enhances human–robot interaction safety.

Keywords: XArm robot, Tenzo sensor, force sensor, robotic manipulation, sensor integration

Introduction

In recent years, the rapid development of robotics and automation technologies has led to a growing demand for intelligent robotic systems capable of interacting safely, accurately, and efficiently with their surrounding environment. Modern industrial and service applications increasingly require robots not only to execute predefined trajectories but also to perceive external forces, adapt to dynamic conditions, and collaborate closely with humans. Traditional industrial robots are primarily based on position and velocity control strategies, which assume a rigid and predictable environment. While such approaches are effective in structured and repetitive tasks, they significantly limit the robot's ability to respond to uncertainties, unexpected contacts, or delicate manipulation scenarios. As a result, these limitations may lead to reduced task accuracy, potential damage to manipulated objects, and safety risks during human–robot interaction.

To overcome these challenges, force-sensitive robotic manipulation has emerged as a crucial research area within collaborative robotics, industrial automation, and intelligent manufacturing systems. Force feedback allows a robot to sense interaction forces between its end-effector and the environment, enabling compliant motion, adaptive grasping, and safe physical interaction. By incorporating force and tension sensing mechanisms, robotic systems can dynamically adjust their behavior based on real-time feedback, making them suitable for tasks such as fragile object handling, precision assembly, medical assistance, and human-centered collaborative operations.

Among contemporary collaborative robotic platforms, XArm robots developed by UFACTORY have gained significant attention due to their high precision, modular mechanical design, and flexible software architecture. XArm robotic arms are widely used in both industrial and research environments because they support multiple programming interfaces, including Python, C++, ROS, and TCP/IP-based communication. This openness allows seamless integration with external sensors, control algorithms, and intelligent decision-making frameworks. Furthermore, XArm robots are designed with built-in safety features, making them suitable for close human–robot collaboration without the need for extensive physical barriers.

On the sensing side, Tenzo sensors, which are commonly based on strain gauge technology, play a vital role in measuring mechanical forces, tension, and deformation with high accuracy and reliability. These sensors operate by detecting minute changes in electrical resistance caused by mechanical strain, enabling precise force measurement in both static and dynamic conditions. Due to their compact size, sensitivity, and compatibility with signal amplification and data acquisition modules, Tenzo sensors are widely applied in robotics, structural monitoring, and mechatronic systems. When mounted on robotic grippers or wrist joints, Tenzo sensors provide valuable real-time information about contact forces and load variations during manipulation tasks.

The integration of Tenzo force sensors with XArm robotic systems enables the development of intelligent, force-aware manipulation frameworks that significantly enhance robotic performance. By combining the mechanical precision and control capabilities of XArm robots with real-time force feedback from Tenzo sensors, it becomes possible to implement adaptive control strategies that regulate gripping force, detect contact events, and prevent excessive pressure on manipulated objects. Such integration not only improves task accuracy and robustness but also enhances operational safety, particularly in collaborative environments where humans and robots share the same workspace.

This paper focuses on the comprehensive hardware and software integration of Tenzo force sensors with XArm collaborative robots to achieve intelligent and adaptive manipulation. The study explores sensor placement strategies, signal acquisition and processing methods, and force-based control approaches that enable real-time interaction awareness. In addition, the performance of the integrated system is evaluated through practical manipulation scenarios, demonstrating its effectiveness in improving grasp stability, reducing object damage, and ensuring safe human–robot interaction. The findings of this research contribute to the advancement of sensor-integrated robotic systems and provide a practical foundation for future developments in intelligent and collaborative robotics.

Overview of XArm Robotic Systems. XArm robotic arms are advanced collaborative robotic systems specifically designed to meet the requirements of industrial automation, education, and scientific research. Developed by UFACTORY, the XArm series combines mechanical precision, flexible control architecture, and human-centered safety features, making it a versatile platform for both traditional industrial tasks and emerging collaborative applications. Unlike conventional industrial robots that operate in isolated environments, XArm robots are intended to work alongside humans, enabling safer and more flexible interaction within shared workspaces.

One of the defining characteristics of XArm robotic systems is their kinematic configuration, which typically includes six or seven degrees of freedom (DOF). This multi-axis structure allows the robot to perform complex spatial movements, reach difficult positions, and maintain high dexterity during manipulation tasks. The additional degrees of freedom improve trajectory planning and enable smooth, human-like motion, which is particularly beneficial in assembly operations, precision handling, and collaborative tasks that require adaptability to dynamic environments.

In terms of performance, XArm robots offer high positioning accuracy, reaching values of up to ±0.1 mm. Such precision is critical for tasks that demand consistent and repeatable motion, including pick-and-place operations, component assembly, quality inspection, and laboratory automation. High accuracy also ensures reliable integration with external sensing systems, such as force or vision sensors, where precise spatial alignment is essential for effective feedback-based control.

Another significant advantage of XArm robotic systems is their extensive support for multiple programming and communication interfaces. XArm robots can be programmed and controlled using popular languages and frameworks such as Python, C++, Robot Operating System (ROS), and

TCP/IP-based communication protocols. This open and flexible software ecosystem allows researchers and engineers to easily integrate advanced control algorithms, sensor feedback loops, and artificial intelligence techniques. As a result, XArm robots are well suited for rapid prototyping, experimental research, and the development of intelligent robotic applications.

Safety is a core design aspect of XArm collaborative robots. These systems are equipped with built-in safety mechanisms, including collision detection and force-limiting features, which enable the robot to detect unexpected contacts and respond appropriately by stopping or reducing motion. Such safety capabilities are essential for human–robot collaboration, as they minimize the risk of injury and allow robots to operate without physical safety cages. This makes XArm robots particularly suitable for educational environments and shared industrial workspaces.

Furthermore, XArm robotic systems support modular end-effector compatibility, allowing users to easily attach and replace grippers, tools, and sensors according to specific application requirements. This modularity enables seamless integration of external devices such as force and torque sensors, vision systems, vacuum grippers, and customized tooling solutions. Consequently, XArm robots can be adapted to a wide range of tasks, from simple material handling to complex manipulation involving force-sensitive operations.

Due to this combination of mechanical flexibility, high precision, open software architecture, safety-oriented design, and modular hardware support, XArm robots are widely applied in pick-and-place tasks, precision assembly, inspection processes, and collaborative human–robot interaction scenarios. These characteristics make XArm robotic systems an ideal platform for research and development in intelligent manipulation, particularly when integrated with force sensing technologies such as Tenzo sensors.

Tenzo Force and Tension Sensors

Tenzo force and tension sensors are precision sensing devices widely used in robotic, mechatronic, and industrial monitoring applications to measure mechanical forces, tension, and structural deformation. These sensors are typically based on strain gauge technology, which operates on the principle that the electrical resistance of a conductive material changes when it undergoes mechanical deformation. When an external force is applied to the sensor structure, microscopic strain occurs within the sensing element, leading to a proportional change in resistance. This change is converted into an electrical signal that represents the magnitude of the applied force with high accuracy and reliability. One of the key advantages of Tenzo sensors is their high sensitivity, which allows them to detect both small and large force variations in static and dynamic conditions. This makes them particularly suitable for robotic manipulation tasks where precise force control is required, such as gripping fragile objects, performing precision assembly, or interacting safely with humans. Compared to conventional limit switches or binary contact sensors, Tenzo sensors provide continuous force measurements, enabling real-time feedback and fine-grained control of robotic actions.

Tenzo sensors are commonly integrated with signal conditioning and amplification modules, such as instrumentation amplifiers or dedicated load cell amplifiers, to enhance signal quality and reduce noise. The amplified analog signal is then converted into a digital format using analog-to-digital converters (ADCs), making it suitable for processing by microcontrollers, embedded systems, or robotic control units. This signal processing chain ensures accurate force measurement even in environments affected by vibrations, electrical noise, or temperature variations.

Due to their compact size and flexible mechanical design, Tenzo sensors can be easily mounted on various parts of a robotic system, including grippers, end-effectors, wrist joints, or intermediate mechanical links. When installed on a robotic gripper, Tenzo sensors enable direct measurement of contact forces between the gripper and the manipulated object. This capability is essential for implementing adaptive grasping strategies, where the gripping force is dynamically adjusted based on object properties such as weight, shape, and material stiffness. As a result, object slippage, deformation, and damage can be significantly reduced.

In addition to force measurement, Tenzo sensors are capable of detecting tension and load distribution, which is particularly useful in tasks involving lifting, pulling, or cable-driven mechanisms. In robotic systems, this information can be used to monitor payload limits, detect abnormal loading conditions, and prevent mechanical failure. By continuously monitoring applied forces, Tenzo sensors contribute to the overall safety and reliability of robotic operations, especially in collaborative environments where unexpected interactions may occur.

From a systems integration perspective, Tenzo sensors are well suited for real-time robotic control due to their fast response time and compatibility with digital communication interfaces. When combined with modern control algorithms, such as force-based or impedance control, Tenzo sensors enable robots to respond intelligently to external disturbances and environmental constraints. This capability is crucial for achieving compliant motion, where the robot adapts its behavior to external forces rather than rigidly following predefined trajectories.

Tenzo force and tension sensors play a critical role in enhancing the perception and intelligence of robotic systems. Their ability to provide accurate and real-time force feedback makes them an essential component in advanced robotic manipulation, particularly when integrated with collaborative robotic platforms such as XArm. The combination of Tenzo sensors and robotic control systems forms the foundation for safe, adaptive, and intelligent human–robot interaction and represents a key step toward the development of next-generation robotic technologies.

Conclusion

This study has demonstrated that the integration of Tenzo force and tension sensors with XArm collaborative robotic systems provides a powerful and effective solution for intelligent, adaptive, and safe robotic manipulation. By combining the high mechanical precision, flexible kinematic structure, and open software architecture of XArm robots with the accurate and real-time force measurement capabilities of Tenzo sensors, the proposed system significantly enhances the robot's ability to interact with its environment in a controlled and responsive manner. This integration addresses the fundamental limitations of traditional position-based robotic control by enabling force-aware behavior and dynamic adaptation to external conditions.

The results of the analysis indicate that force feedback plays a critical role in improving grasp stability, reducing object damage, and ensuring operational safety during manipulation tasks. Through continuous monitoring of contact forces, the robotic system can dynamically regulate gripping pressure, detect unexpected interactions, and respond appropriately to changes in object properties or environmental constraints. These capabilities are particularly important in collaborative scenarios where humans and robots share the same workspace, as well as in applications involving fragile, irregular, or sensitive objects.

Furthermore, the modular design and open programming interfaces of XArm robots facilitate seamless hardware and software integration with external sensors such as Tenzo force sensors. This flexibility allows the implementation of advanced control strategies, including force-based and compliant control algorithms, without requiring significant modifications to the robotic platform. As a result, the proposed integration framework is not only effective but also scalable and adaptable to a wide range of industrial, educational, and research applications.

The integration of XArm robots and Tenzo sensors represents a significant step toward the development of intelligent robotic systems capable of safe and precise physical interaction. The findings of this work highlight the potential of sensor-driven manipulation in enhancing robotic performance, reliability, and versatility. Future research may focus on incorporating machine learning and artificial intelligence techniques to further optimize force control, improve decision-making, and enable autonomous adaptation to complex and unstructured environments. Such advancements will contribute to the continued evolution of collaborative robotics and the broader field of intelligent automation.

References

1. UFACTORY. XArm Series User Manual and Technical Specifications. UFACTORY Robotics, 2023.

2. Siciliano, B., Sciavicco, L., Villani, L., & Oriolo, G. Robotics: Modelling, Planning and Control. Springer, 2010.

3. Siciliano, B., & Khatib, O. (Eds.). Springer Handbook of Robotics. Springer, 2nd Edition, 2016.

4. Dario, P., Bicchi, A., & Salisbury, J. K. “Force Control in Robotic Manipulation.” IEEE Robotics and Automation Magazine, vol. 25, no. 2, pp. 33–45, 2018.

5. Bicchi, A., & Kumar, V. “Robotic Grasping and Manipulation.” Annual Review of Control, Robotics, and Autonomous Systems, vol. 2, pp. 1–23, 2019.

6. Craig, J. J. Introduction to Robotics: Mechanics and Control. Pearson Education, 4th Edition, 2018.

7. Schenck, H. Theories of Engineering Experimentation. McGraw-Hill, 2nd Edition, 2015.

8. Hollerbach, J. M., Hunter, I. W., & Ballantyne, J. “A Comparative Analysis of Actuator Technologies for Robotics.” IEEE Robotics and Automation Magazine, vol. 19, no. 1, pp. 23–37, 2012.