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ENHANCED HUMANROBOT COLLABORATION VIA IOT ROBOT SKIN IN FUTURE TELEHEALTHCARE

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ABSTRACT

With the fourth revolution of healthcare, i.e., Healthcare 4.0, collaborative robotics is spilling out from traditional manufacturing and will blend into human living or working environments to deliver care services, especially tele healthcare. Because of the frequent and seamless interaction between robots and care recipients, it poses several challenges that require careful consideration: 1) the ability of the human to collaborate with the robots in a natural manner; and 2) the safety of the human collaborating with the robot. In this regard, we have proposed a proximity sensing solution based on the self-capacitive technology to provide an extended sense of touch for collaborative robots, allowing approach and contact measurement to enhance safe and natural human-robot collaboration. The modular design of our solution enables it to scale up to form a large-area sensing system. The sensing solution is proposed to work in two operation modes: the interaction mode and the safety mode. In the interaction mode, utilizing the ability of the sensor to localize the point of action, gesture command is used for robot manipulation. In the safety mode, the sensor enables the robot to actively avoid obstacles

INTRODUCTION

Healthcare 4.0 is ushering in the fourth revolution of healthcare, powered by increased automation, mechanization, and digitization in healthcare services. This revolution is driven by advancements in cyber-physical systems, which have evolved from the manufacturing sector and are now being integrated into healthcare applications. In this new era, healthcare robots are transitioning from traditional manufacturing environments to human-centered healthcare settings, where they will coexist with humans to assist with healthcare services. These robots are designed to operate in dynamic, unstructured environments such as hospitals and homes, delivering healthcare while interacting directly with patients and medical staff. However, this shift comes with significant challenges. Human-centered environments are inherently complex, with varying human behaviors and uncertain situations that are difficult to predict and program. This complexity makes it particularly challenging for robots, especially those with limited machine intelligence, to safely and efficiently interact with humans. Mistakes in interpreting human actions or environmental changes can lead to unintended and hazardous robot behaviors, posing safety risks to people in these environments. Ensuring safe and reliable human-robot interaction is crucial for achieving human-robot symbiosis in Healthcare 4.0. The functional safety of healthcare robots is of paramount importance, as their actions must be predictable and controllable, particularly in scenarios involving direct interaction with humans. Five main strategies have been proposed to improve the functional safety of robots: 1) environment monitoring using cameras and intelligent floors, 2) proximity perception for speed and separation monitoring, 3) tactile sensing with deformable or cushion-like materials, 4) feedback mechanisms for robot joints and links, and 5) power and force limiting in robot control systems through proprioceptive sensors. These approaches can be categorized based on where the sensing components are located: off-robot, on-robot, or in-robot systems. Off-robot methods rely on external cameras and sensors to monitor the robot’s environment, but they limit the flexibility of robots by restricting their movement within a predefined space. On-robot methods, such as robot skin, are gaining popularity due to their flexibility and ease of deployment. Robot skin is an innovative solution that allows robots to sense proximity to humans and other objects directly from the robot's surface, enhancing safety while maintaining flexibility. Existing studies of robot skin can be broadly classified into contact-based tactile-sensing systems and pre-contact proximity-sensing systems. While tactile-sensing systems provide detailed feedback during interactions, they cannot prevent collisions from occurring. Consequently, the focus has shifted toward developing proximity-sensing robot skin, which can detect human presence before contact is made, preventing potential accidents. Various sensing technologies have been explored for this purpose, including capacitive, optical, inductive, and triboelectric sensing. Among these, capacitive sensing is particularly attractive due to its low cost and ease of deployment. However, the scalability of capacitive robot skin,

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particularly for large-area applications, and its environmental sensitivity are areas that need further exploration. In addition, many existing studies have focused on local validation of robot skin in terms of its ability to detect human presence and improve robot safety, but there is a lack of research on how these systems can be scaled up and integrated with larger robot platforms. To address these challenges, this work aims to develop a large-area robot skin system that is scalable, flexible, and integrates seamlessly into healthcare robots. This robot skin will improve functional safety by providing real-time proximity sensing and enabling the robot to react to its environment, preventing collisions and accidents.

LITERATURE SURVEY

A) Z. Pang, G. Yang, R. Khedri, and Y.-T. Zhang, "Introduction to the special section: Convergence of automation technology, biomedical engineering, and health informatics toward the health care 4.0," IEEE Rev. Biomed. Eng., vol. 11, pp. 249–259, 2018, doi: 10.1109/RBME.2018.2848518.

The paper *"Introduction to the Special Section: Convergence of Automation Technology, Biomedical Engineering, and Health Informatics Toward Healthcare 4.0"* explores the concept of Healthcare 4.0, which is a transformative revolution in healthcare, analogous to the ongoing Industry 4.0 revolution in manufacturing. Healthcare 4.0 is characterized by the integration of cyber-physical systems (CPS) with healthcare services. This involves the use of the Internet of Things (IoT), big data analytics, artificial intelligence (AI), robotics, and cloud computing to improve healthcare delivery, services, and outcomes. These technologies enable more efficient processes, personalized treatments, and patient-centered care, thus redefining the entire healthcare value chain from medical equipment production to patient care and even logistics. The authors propose that Healthcare 4.0 will lead to a more proactive and personalized healthcare system where early prediction and prevention of diseases are key goals, ensuring more effective treatment outcomes. This section emphasizes how automation, AI, and biomedical engineering intersect to address challenges in healthcare. It identifies the need for reliable, low-latency communication systems, effective use of healthcare robotics, and improved human-robot interfaces to ensure the safety and efficiency of healthcare processes. These advancements are expected to create systems that can predict and prevent diseases, ensuring that treatments are tailored to individual needs, resulting in more widespread and effective healthcare delivery. The paper also points out the significant hurdles that remain, including the integration of these technologies into existing healthcare infrastructures, the safety of human-robot interactions, and the legal frameworks that will be necessary to support these advancements. Key areas of focus for the ongoing research include the design of new healthcare systems, robotics, and AI solutions to meet the needs of modern healthcare, especially in areas like wearable technologies, home care, and disease diagnostics.

B) G. Yang et al., "Homecare robotic systems for healthcare 4.0: Visions and enabling technologies," IEEE J. Biomed. Health Informat., vol. 24, no. 9, pp. 2535–2549, Sep. 2020, doi: 10.1109/JBHI.2020.2990529.

The paper *"Homecare Robotic Systems for Healthcare 4.0: Visions and Enabling Technologies"* by G. Yang et al. delves into the potential of homecare robotic systems as key enablers of Healthcare 4.0, a movement that seeks to modernize healthcare by leveraging emerging technologies such as robotics, artificial intelligence (AI), and the Internet of Things (IoT). The authors outline how these technologies can be integrated into homecare settings to provide enhanced patient care, particularly for elderly and chronically ill individuals, in order to reduce hospital visits and provide continuous, remote healthcare monitoring. The paper highlights the convergence of automation and healthcare, envisioning a future where robots support independent living, assist with daily tasks, and provide crucial monitoring and diagnostics remotely. The paper categorizes various enabling technologies for homecare robots, including sensory systems, AI algorithms, communication technologies, and robotic actuators. It discusses the role of artificial intelligence in improving decision-making, enabling robots to adapt to the complex, dynamic environments of home care. The integration of AI in robot systems would enable them to monitor patients' conditions, provide feedback to caregivers, and alert medical professionals in case of an emergency, ensuring a safer and more efficient homecare environment. Additionally, the authors examine various challenges and limitations such as robot design, user acceptance, privacy issues, and the need for standards and regulations in the healthcare space. The overall vision of the paper is to explore how homecare robots, empowered by Healthcare 4.0 technologies, can assist in creating a more personalized, efficient, and accessible healthcare system, helping bridge the gap between hospital-based care and home-based care.

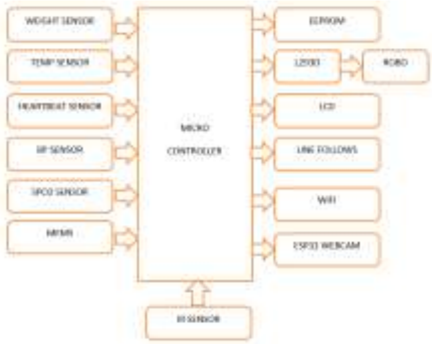
C)H. Lv, G. Yang, H. Zhou, X. Huang, H. Yang, and Z. Pang, "Teleoperation of collaborative robot for remote dementia care in home environments," IEEE J. Transl. Eng. Health Med., vol. 8, pp. 1–10, 2020, doi: 10.1109/JTEHM.2020.3002384

The paper *"Teleoperation of Collaborative Robot for Remote Dementia Care in Home Environments"* by H. Lv et al. explores the potential of using teleoperated collaborative robots (cobots) for remote care of individuals with dementia in home settings.

The authors investigate how these robots can assist caregivers in monitoring and interacting with patients remotely, providing an effective solution to the growing challenge of dementia care, particularly given the increasing number of aging populations worldwide. The paper emphasizes the importance of creating a safe and comfortable home environment for dementia patients, where teleoperation enables caregivers to remotely assist with everyday tasks, monitor the patient's health, and ensure their well-being without requiring constant physical presence. The research focuses on the development and deployment of collaborative robots that can work alongside human caregivers to enhance the quality of life for dementia patients. These robots are designed to be user-friendly and capable of performing a variety of tasks, such as reminding patients of daily activities, helping with mobility, and even offering emotional support. The paper also addresses technical challenges related to the implementation of teleoperation, including the need for reliable communication systems, real-time control, and safety features to ensure both patient and caregiver safety. The authors discuss the collaborative aspects of these robots, where they complement the efforts of human caregivers rather than replace them, ensuring that the patients receive personalized care while maintaining autonomy in their home environment. The paper ultimately demonstrates the potential of collaborative robots as a valuable tool for dementia care in the era of remote healthcare and emphasizes the importance of integrating these technologies into broader healthcare systems to ensure a more effective and sustainable approach to managing dementia.

IMPLEMENTATION

BLOCK DIAGRAM



DESCRIPTION

POWER SUPPLY

A **regulated power supply** transforms unregulated AC (Alternating Current) into a stable DC (Direct Current). It guarantees consistent output despite variations in input. A regulated DC power supply is also known as a linear power supply, it is an embedded circuit and consists of various blocks

- **Regulated Power Supply Definition**: A regulated power supply ensures a consistent DC output by converting fluctuating AC input.
- **Component Overview**: The primary components of a regulated power supply include a transformer, rectifier, filter, and regulator, each crucial for maintaining steady DC output.
- **Rectification Explained**: The process involves diodes converting AC to DC, typically using full wave rectification to enhance efficiency.
- **Filter Function**: Filters, such as capacitor and LC types, smooth the DC output to reduce ripple and provide a stable voltage.
- **Regulation Mechanism**: Regulators adjust and stabilize output voltage to protect against input changes or load variations, essential for reliable power supply

SENSORS

Sensors are used for sensing things and devices etc. A device that provides a usable output in response to a specified measurement. The sensor attains a physical parameter and converts it into a signal suitable for processing (e.g. electrical, mechanical, optical) the characteristics of any device or material to detect the presence of a particular physical quantity. The output of the sensor is a signal which is converted to a human-readable form like changes in characteristics, changes in resistance, capacitance, impedance, etc.

HEARTBEAT SENSOR

Heartbeat sensor provides a simple way to study the function of the heart which can be measured based on the principle of psycho-physiological signal used as a stimulus for the virtual- reality system. The amount of blood in the finger changes with respect to time. The sensor shines a light lobe (a small very bright LED) through the ear and measures the light that gets transmitted to the Light Dependent Resistor. The amplified signal gets inverted and filtered, in the Circuit. In order to calculate the heart rate based on the blood flow to the fingertip, a heart-rate sensor is assembled with the help of LM358 OP-AMP for monitoring the heartbeat pulses.

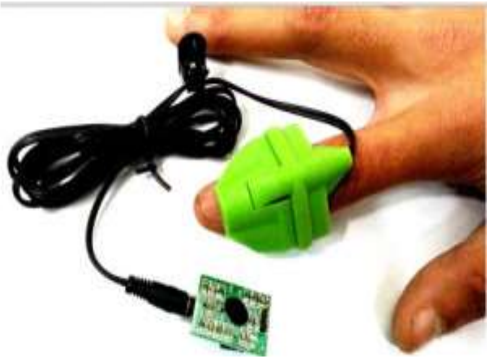
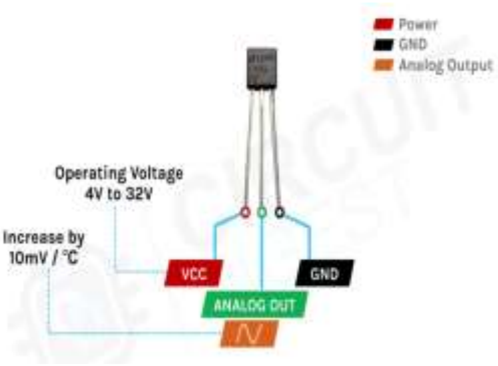


Fig: Heartbeat Sensor

LM35 TEMPERATURE

If you are looking for an inexpensive, accurate, easy-to-use temperature sensor, then LM35 is an excellent choice. It has an accuracy of ±¼°C at room temperature and ±¾°C over a full −55°C to 150°C temperature range. It does not require any external trimming, although the main drawback of this sensor is that it outputs data in analog format, making it very prone to external noise and interference. So, in this tutorial, we will learn how to wire up a **LM35 Temperature Sensor with Arduino** and also we will output the temperature data in the serial monitor window.

LM35 TEMPERATURE SENSOR PINOUT



MEMS SENSOR WORKING AND ITS APPLICATIONS

The term MEMS stands for micro-electro-mechanical systems. These are a set of devices, and the characterization of these devices can be done by their tiny size & the designing mode. The designing of these sensors can be done with the 1- 100-micrometer components. These devices can differ from small structures to very difficult electromechanical systems with numerous moving elements beneath the control of incorporated micro-electronics. Usually, these sensors include mechanical micro-actuators, micro-structures, micro-electronics, and micro-sensors in one package. This article discusses what is a MEMS sensor, working principle, advantages and it's applications

IR SENSOR WORKING AND APPLICATIONS

In the electromagnetic spectrum, the infrared portion divided into three regions: near infrared region, mid infrared region and far infrared region.

In this blog we are talking about the IR sensor working principle and its applications.

What is an IR Sensor?

IR sensor is an electronic device, that emits the light in order to sense some object of the surroundings. An IR sensor can measure the heat of an object as well as detects the motion. Usually, in the infrared spectrum, all the objects radiate some form of thermal radiation. These types of radiations are invisible to our eyes, but infrared sensor can detect these radiations.

Fig: Ir Sensor

RPI –PICO

A Raspberry Pi Pico is a low-cost microcontroller device. Microcontrollers are tiny computers, but they tend to lack large volume storage and peripheral devices that you can plug in (for example, keyboards or monitors).

A Raspberry Pi Pico has GPIO pins, much like a Raspberry Pi computer, which means it can be used to control and receive input from a variety of electronic devices

Raspberry Pi Foundation is well known for its series of single-board computers (Raspberry Pi series). But in **January 2021 they launched their first micro-controller board known as Raspberry Pi Pico**.

It is built around **the RP2040 Soc, a very fast yet cost-effective microcontroller chip packed with a dual-core ARM Cortex-M0+ processor.** M0+ is one of the most power-efficient ARM processorRaspberry Pi PICO board

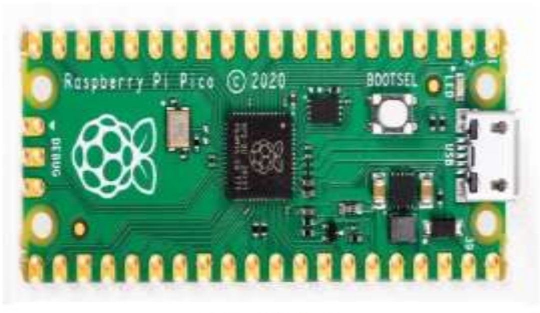


Fig: Raspberry Pi Pico Board

Raspberry **Pi Pico is a small, fast, and versatile board that at its heart consists of RP2040**, a brand-new product launched by Raspberry Foundation in the UK. It can be programmed using MicroPython or C language.

OVERVIEW

The paper *"A Digital Twin-Based Large-Area Robot Skin System for Safer Human-Centered Healthcare Robots Toward Healthcare 4.0"* explores an innovative solution to improve the functional safety and performance of healthcare robots, particularly in human-robot interaction (HRI). This work is positioned within the context of Healthcare 4.0, a revolution in healthcare systems characterized by the convergence of advanced technologies like robotics, AI, and cyber-physical systems to enhance patient care and healthcare delivery. As healthcare robots are expected to work closely with humans, ensuring their safety in dynamic, unstructured environments becomes a primary challenge. The paper introduces a novel system combining large-area robot skin with a digital twin infrastructure to address safety concerns and improve the reliability of human-robot interactions. The robot skin developed in this research is based on capacitive sensing technology, which enables proximity detection and touchless interaction between robots and humans. Unlike traditional tactile sensing, which requires direct contact, this robot skin can detect the presence of human hands or bodies in proximity, allowing robots to avoid collisions or adjust their behavior in real-time. This capability is especially important in environments where robots are assisting vulnerable individuals, such as in healthcare applications. The system is designed to be scalable, lightweight, and adaptable to different robot platforms, making it suitable for deployment in various healthcare scenarios. The robot skin's sensitivity ranges from detecting objects as close as 50 mm, with high repeatability and minimal error rates, ensuring precise interaction with patients and caregivers.To further enhance the safety features of the robot skin, the paper integrates a digital twin system. A digital twin is a virtual replica of the physical robot and its environment, enabling real-time monitoring and remote intervention. This feature is crucial for healthcare robots operating in home environments, where caregivers might not be physically present. The digital twin infrastructure allows healthcare professionals to monitor the robot's behavior remotely, providing support if any issues arise. For instance, in case of an emergency, healthcare professionals can intervene by taking control of the robot, ensuring timely responses to critical situations. The integration of this real-time monitoring system provides an additional layer of safety and ensures that the robot functions within predefined safety parameters.In practical applications, the robot skin system can be customized for specific robots, enhancing their ability to interact with patients safely. The system was tested through various experiments, including distance monitoring and reactive collision avoidance, to validate its functionality. The results demonstrated the effectiveness of the robot skin in preventing accidents and improving the overall interaction between robots and patients. Furthermore, the digital twin system allowed for continuous evaluation and intervention, illustrating the potential of combining physical and virtual systems to ensure the safety of human-robot interactions.The research highlights the importance of creating flexible, scalable, and adaptive technologies for healthcare robots, as they become integral components of healthcare delivery systems. By combining robot skin with digital twin technology, the paper offers a comprehensive solution to address the safety concerns associated with robots working in close proximity to humans, particularly in healthcare settings. This work represents a significant step toward the realization of safer, more reliable healthcare robots that can operate autonomously while ensuring patient and caregiver safety. The integration of digital twin technology and robot skin offers a promising path for the development of intelligent, human-centered healthcare robots in the future.

CONCLUSION

In conclusion, the robot skin system with proximity sensing capabilities developed in this work has demonstrated robust and reliable performance in various experimental scenarios. The system has been shown to be insensitive to the type of conductive materials, stable at different approaching speeds, and durable under long-term mechanical bending, making it a promising solution for human-robot collaboration in dynamic environments. Furthermore, the skin's bending sensitivity and environmental stability to humidity and temperature have been validated, enhancing its potential for practical deployment in healthcare robots. The integration of active shielding has also proven effective in mitigating interference, ensuring that the system operates reliably in diverse conditions. These results highlight the versatility and adaptability of the robot skin, positioning it as a key technology in ensuring the safety and functionality of human-centered robots. Additionally, the robot skin was successfully customized and scaled up for large-area coverage on a dual-arm robot, demonstrating its applicability to more complex robotic systems. The inclusion of a digital twin infrastructure has further improved the system's operational safety by enabling remote monitoring of the robot's status, allowing security officers to intervene when necessary. Two experiments on safe collaboration between the robot and humans were conducted, showcasing the system's potential in improving the functional safety of robots in healthcare and other human-centric applications. These findings underline the significant progress made in creating safer, more reliable robots that can operate autonomously in real-world environments, paving the way for the widespread adoption of human-centered robots in Healthcare 4.0.

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