Analysis and Design of Eye-based Expression and Geometrical Gait for A Four-DoF Toddler-Bipad System

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Abstract—*The paper focuses on "Toddler-Bipad" which is a four degree entertainment robot developed mostly for the development of human-machine interaction. The robot will originally be used for the entertainment of the kids. However, this will form a bridge between the human and the machine as all the actions of this bot will be controlled through voice-control. Also, this buddy bot will have the provision for expressing various emotions as per the instruction received. As we are relying mostly on robots, therefore humans are required to get acquainted and adjusted with these machines to make their life more smooth and comfortable.*

I. Introduction

In this thrilling frontier of robotics, we are witnessing astonishing progress as cutting-edge technologies blend seamlessly with human ingenuity. Engineers and scientists are crafting robots that not only perform repetitive tasks with precision but also exhibit remarkable adaptability and intelligence. The future of robotics is not just about machines, it's about creating symbiotic relationships between humans and robots. Imagine household robots that can clean, cook, and organize your home just by listening to your requests, or industrial robots that can adjust their operations instantly based on verbal instructions from workers, enhancing productivity and safety. By integrating technologies like Siri, Alexa, and Google Assistant, voice-controlled robots are becoming an integral part of smart homes, factories, and even exploration missions. This convergence of voice control and robotics is transforming the way we interact with machines, making technology more intuitive and accessible, and paving the way for a future where human-robot collaboration enhances every aspect of our lives.

The paper describes the development process of a four-degree entertainment robot "Toddler-Bipad" which will be explicitly used for the entertainment of the kids. However, this will form an educational platform to study the human-machine interaction for further development and innovations. This innovative bot, with its 4-degree freedom of movement, can skillfully navigate forward and backward while also showcasing a range of lifelike expressions. Picture giving it a command to move forward, and it cheerfully obeys, or asking it to show a surprised face, and it responds with a captivating expression. Although its physical actions are simple, limited to moving in two directions, its personality shines through its expressive capabilities. This blend of motion and emotive interaction makes the bot an enchanting companion, perfect for entertaining guests, interacting with children, or simply adding a touch of futuristic charm to your home.

II. Literature Review

This paper contributes to the study of a sociable humanoid robot which can express its emotion and contribute to the development of human-machine interaction. It also explores the role of the emotion based sociable robot in human society. It is a robot which will be explicitly used for both training and research purposes. However this robot's movement will be restricted to 4 Degree of Freedom (DoF) for initial development. Additionally this bot will be able to show various emotions based on the voice commands received from the user.

Many researches have been conducted related to such development of miniature robots. In paper **[1]**,the development of humanoid robot HRP-3 is presented. HRP-3, which stands for Humanoid Robotics Platform–3.Robots with human-like mobility on uneven terrain and the ability to use tools offer significant advantages in various applications, including disaster response and industrial settings. These robots can operate in wet and hazardous environments due to their water-resistant design, and they interact naturally with humans using advanced sensors and voice commands. However, their high cost and the need for specialized knowledge and frequent calibration limit their widespread adoption. Additionally, their limited battery life requires regular recharging, and they still lack the speed and agility of human workers.

In paper **[2]**,a new humanoid robot—WABIAN-2— that can be used as a human motion simulator.The WABIAN-2 robot is designed to enhance human-like interactions and assist in various care applications.WABIAN-2 mimics human walking with pelvic freedom for natural foot movements, using advanced sensors and control systems for balance and stability. Its human-like lower body design allows for natural movements, while sensors for vision and hearing make it responsive to gestures and voice commands. This makes it suitable for healthcare, elderly care, and personal assistance applications. However, development and maintenance expenses may limit its adoption, and it might struggle with intricate tasks and interactions. Potential wear and tear could affect its reliability, and considerations regarding employment dynamics, privacy, and human relationships are significant. Additionally, battery life and mobility limitations may restrict its capabilities.

In paper **[3]**,the authors have developed a robot called "Robovie" that has unique mechanisms designed for communication with humans.The next generation of humanoid robots offers impressive advancements in communication and mobility.These robots feature advanced speech recognition and synthesis for natural conversation, complemented by human-like gestures with articulated arms and hands. A mobile base equipped with sensors allows for efficient navigation and obstacle avoidance, while multi-modal sensing with cameras, microphones, and tactile sensors enhances their interaction capabilities. Despite these innovations, costly development and maintenance limit their accessibility. Additionally, humanoid robots still struggle with complex interactions, face durability issues affecting reliability, and raise ethical concerns regarding employment and privacy. Technical limitations, such as battery life, also impact their overall capabilities.

In paper **[4]**,a mechanism, system configuration, basic control algorithm and integrated functions of the Honda humanoid robot is presented.Cutting-edge humanoid robots are revolutionizing automation with their advanced capabilities.These robots can walk, run, and climb stairs with remarkable balance and agility, thanks to sophisticated sensors and AI for autonomous navigation and obstacle avoidance. They engage in natural conversation through speech recognition and synthesis and perform complex tasks with dexterous hands and precise manipulation. However, their limited operational time and struggles in dynamic settings remain significant challenges. Additionally, improvements are needed in natural language processing, and high development and maintenance costs hinder widespread adoption. Mobility and transport challenges further limit their practical applications.

III. System Architecture Design

A. Component Description:

This toddler robot uses Arduino Nano which is a compact microcontroller board based on the ATmega328P. The small size and versatile functionality makes it ideal for controlling the miniature robot and engaging the various sensors and actuators.

Additionally it uses some arduino cables, typically a USB to mini USB cable, is used to connect the Arduino Nano to a computer for programming and power.

Moreover, the robot contains servo motors which are responsible for the movement and the positioning of the robot joints. Each servo motor offers precise control of angular position, making them suitable for achieving the four degrees of freedom required in the robot.

For the sound output, PAM8403 which uses a low power audio amplifier module is used. The module operates efficiently with a minimum power consumption.

A speaker connected through the PAM8403 is used to emit the sound signals. It plays a critical role in enhancing the interactivity of the robot.

To show various emotion based visual representations, it uses an OLED display. This display is known for its high contrast and low power consumption.

The plastic sheets serve as the structural material for the robot. It is lightweight, easy to cut and shape and provides sufficient strength to support the components and withstand the movement of the servo motors.

Lastly a battery is placed which acts as the primary power source for the robot. It needs to supply sufficient voltages and currents to run the arduino nano, servo motors, OLED display and the PAM8403 to make the robot fully functional.

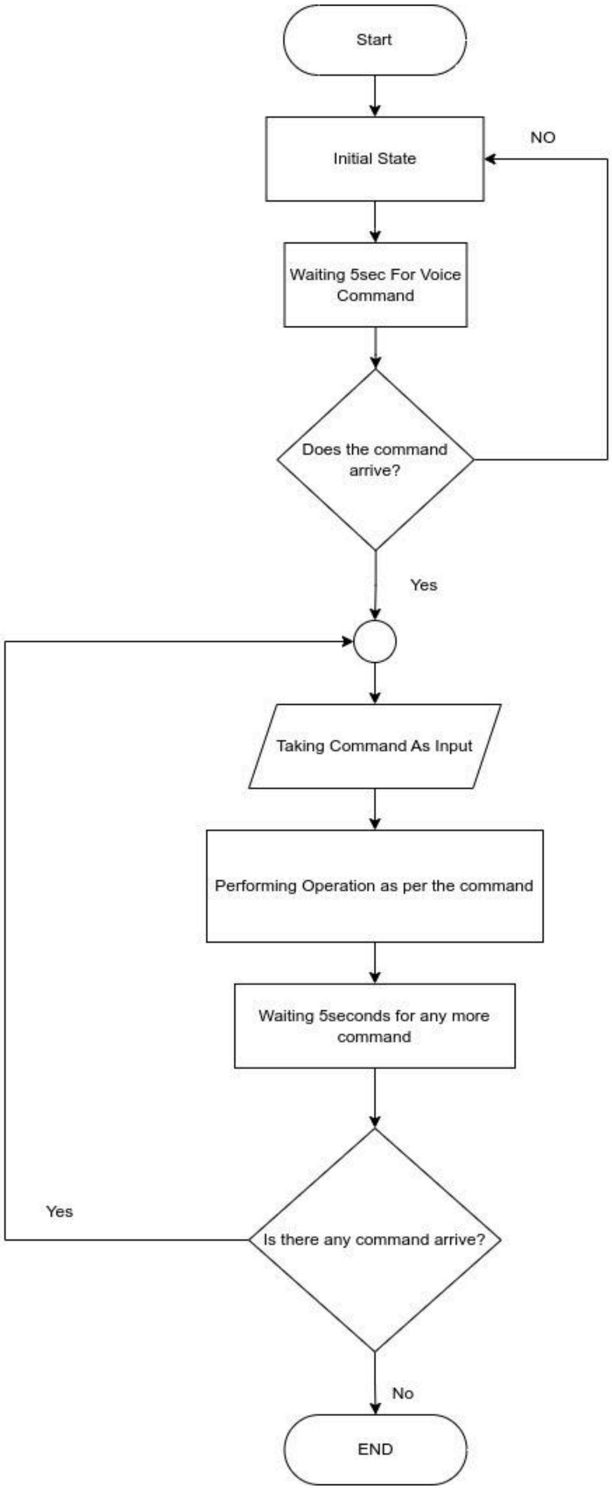

Fig-1:Workflow Diagram

B. Workflow Diagram:

At the initial state, the bot stays in idle and waits for the voice command for 5 seconds. If it does not receive any command then it will return to its idle state which is the initial state. Once it receives the command from the user, it takes the command as input and performs the operation as per the command received. After performing the operation,it will again wait for 5 seconds to receive commands. If it receives any command then again it will take it as input and perform the operation based on the command. Otherwise, it will go back to its initial state.

C. System Architecture

The system architecture outlines the process for developing the “Toddler-Bipad” starting with planning and design to identify core functionalities and performance metrics. It proceeds with designing the robot's structure to accommodate components like microcontrollers, servos, audio systems, displays and power supplies. Following component selection, the hardware assembly involves constructing the bot’s body and securing all components. Software development includes installing necessary libraries, coding for functionalities and developing bluetooth communication to process voice commands. Movement control programming and algorithms enable smooth motion, while facial expressions are created and displayed on an OLED screen. Finally, voice output is integrated using text-to-speech functionality and audio systems.

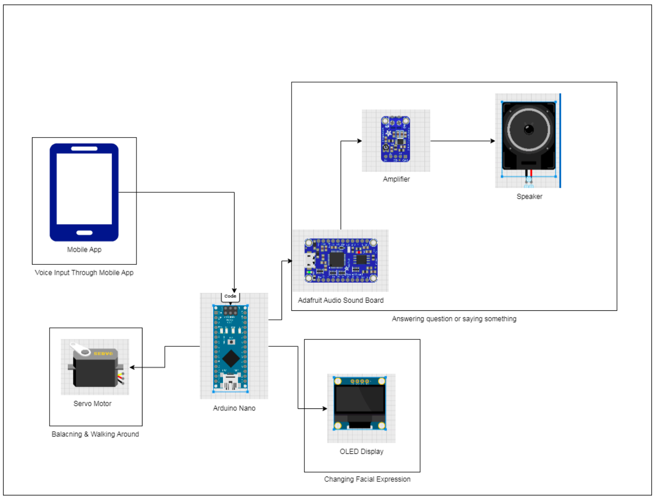

Fig-2: System Architecture

D. Circuit Diagram

The circuit diagram for the "Toddler-Bot" illustrates the electrical connections and component integrations necessary for the bot's functionalities. It includes an Arduino Nano as the central microcontroller, connected to high-torque servos responsible for limb movements. An OLED display is used for facial expressions, while a PAM8403 amplifier and a small speaker handle voice output. The power supply is managed by a rechargeable Li-Po battery, ensuring sufficient power for all components. The diagram emphasizes proper wiring and secure connections to facilitate effective communication between components, enabling smooth operation of the bot's movements, voice responses and facial expressions.

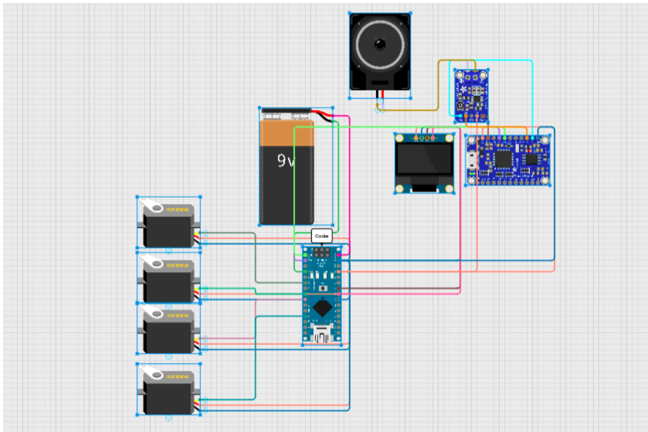

Fig-3: Circuit Diagram

IV. Mechanism

The “Toddler-Bipad” is designed with the primary goal of entertaining children through interactive movements and expressions. Its structure is constructed using durable plastic sheets, and the joints are equipped with servo motors to facilitate smooth and precise movements. The bot features an OLED display capable of mimicking various facial expressions, adding a layer of engagement and realism to its interactions. In terms of mobility, the bot can move both forward and backward, enhancing its dynamic range.

To enable the expression output feature, an input system has been established. This system involves usage of a mobile where specific inputs can be provided to control the bot's movements and expressions. Upon receiving an input, the bot's control system activates the appropriate servos to execute movements and adjusts the OLED display to reflect the corresponding expressions. This setup ensures that the toddler bot responds promptly and accurately to inputs, providing an immersive and entertaining experience for kids.

V. Experimental Result

A. Walking and Movement:

The “Toddler-Bipad” system's walking and movement capabilities are engineered for both stability and natural motion, leveraging a geometrical gait design to optimize its four degrees of freedom. The system's two primary degrees of freedom in the legs allow for forward and backward navigation, while the additional two degrees of freedom ensure the robot can adjust its posture and maintain balance effectively. Actuators within the legs provide the necessary force for movement, executing precise steps based on predefined gait cycles.

To ensure continuous stability, the system sensor is constantly monitoring the robot's orientation and acceleration. These sensors feed real-time data into balance control algorithms, enabling the robot to make instantaneous adjustments to its posture. For example, if the robot begins to tilt, the sensors detect this change, and the balance control algorithms calculate the necessary corrective movements, which are then executed by the leg actuators.

The geometrical gait design is based on mathematical patterns that emulate natural walking, providing a smooth and lifelike motion.

In summary, the Toddler-Bipad system combines precise actuators, real-time balance adjustments, and a carefully designed gait pattern to deliver stable, smooth, and responsive walking and movement capabilities.

B. Facial Expression:

Facial expressions are projected as per the given input from the user through an OLED display. This makes the human-machine interaction much more accurate.

The Toddler-Bipad system utilizes OLED displays for facial expressions, bringing a dynamic and engaging element to its interaction capabilities. These high-resolution OLED screens are used to create lifelike eyes that can display a wide range of emotions, such as happiness, sadness, surprise, and curiosity. The OLED displays offer vibrant colors and sharp contrasts, making the expressions easily recognizable and captivating for users. Controlled by a microcontroller, these eyes can change shapes and movements in response to interaction cues, enhancing the robot’s expressiveness. Algorithms generate appropriate eye movements and shapes for each emotion, ensuring smooth transitions and realistic expressions. This advanced use of OLED technology not only improves the robot's emotional communication but also significantly increases user engagement and interaction, making the Toddler-Bipad system a more relatable and enjoyable companion.

VI. Impact

The development of “Toddler-Bipad” could contribute to the expansion of the consumer robotics market, especially in the entertainment and childcare sectors. As voice-controlled robots with emotional expressions become more popular, companies specializing in robotics, AI and voice recognition technologies may experience increased demand for innovative consumer products.Human-machine interaction is a growing field that spans entertainment, education, healthcare and more. Developing “Toddler-Bipad” will likely lead to further investments in HMI technologies, creating opportunities for research and development and commercial applications in voice control, emotion recognition and machine learning systems.In households, “Toddler-Bipad” could serve as a supplementary form of entertainment or learning for children.As more businesses invest in the production of robots like “Toddler-Bipad”, there will be increased demand for skilled professionals in robotics engineering, AI development, UX design, and software programming.

Positively,the “Toddler-Bipad” may lessen the demand for physical toys,many of which are composed of non-biodegradable materials like plastic. Traditional toys, which are generally discarded, may become less common as kids begin interacting more with digital and robotic entertainment. If robots are made with sustainability in mind, this move towards digital entertainment options could help cut down on plastic waste.The voice control, movement and emotion expression capabilities of Toddler-Bipad require power and its widespread use may result in a rise in overall energy consumption.Toddler-Bipad must be designed using low-energy technology in order to have the least negative environmental impact possible.

Toddler-Bipad,created to interact with kids via vocal commands and facial expressions, may have a big influence on kids' early development. Children may enhance their social, linguistic and cognitive abilities by engaging with a robot that can convey emotions and obey commands. Better learning results could result from this, particularly for kids who might find it challenging to interact with classmates or adults.Toddler-Bipad could provide a kind of emotional support for kids, especially those who could be shy, nervous or autistic, by portraying emotions and reacting to spoken commands. The robot may be used as a therapeutic tool since its capacity to exhibit empathy-like behaviors can promote trust and companionship.

VII. Limitation & Future work

Every innovative creation comes with its own set of challenges, and the “Toddler-Bipad” is no exception. While it offers promising capabilities for human-machine interaction, its design is limited by a few key factors. With only four degrees of freedom, the robot’s movement is constrained to basic forward and backward motions, restricting its ability to perform more complex tasks. The robot can only communicate basic emotions and simple interactions because its emotional expressions are displayed on an OLED display. Although these visual emotions work well for simple interactions, they could not have the depth needed for more complex emotional exchanges between humans and machines.Because of its heavy reliance on voice commands, the Toddler-Bipad might be difficult to operate in noisy surroundings or for users who have speech issues.Despite being compact and effective in size, the robot needs a steady supply of energy to run its motorized motions and display. Limitations on the robot's battery may make it less useful for extended periods of time and require regular charging.Although the robot is capable of basic voice control interactions, it is currently limited in its capacity to handle more sophisticated orders or multi-step tasks. We have not yet implemented advanced human-robot interactions that need contextual understanding and flexibility.Though it allows for mobility, the robot's longevity in harsher situations may be compromised by the use of lightweight plastic sheets in its construction. Wear and tear over time may result in structural flaws, particularly if youngsters utilize the robot frequently.These limitations highlight areas for future improvements to enhance both functionality and user experience.

There are a lot of interesting opportunities ahead for the Toddler-Bipad to grow in terms of features and uses. Increasing the robot's degrees of freedom will enable more intricate movements and improved mobility, making it more adaptable to a variety of settings. This is an important topic for future development. Furthermore, adding more realistic facial characteristics and auditory cues to the emotional expression system will significantly enhance its human-like interaction. The robot will be easier to interact with if voice recognition technology is improved, for as by supporting several languages and being more adaptive to different surroundings and accents. By incorporating sophisticated artificial intelligence, the robot might be able to interpret increasingly complicated commands, learn from interactions, and modify its behavior accordingly. Longer operating times could be made possible in future versions by enhanced power management and energy efficiency. With these improvements, the Toddler-Bipad may go beyond amusement and find new uses in therapy, education, and cutting-edge studies on human-machine interaction.

VIII. Conclusion

To summarize, the Toddler-Bipad represents a significant advancement in human-machine interaction, particularly in the field of entertainment robots meant for children. The robot provides consumers with an engaging experience because of its four degrees of freedom, which allow it to move smoothly and exhibit a variety of emotions through an OLED display. Even while its voice recognition, emotional depth, and mobility are still limited, it offers a solid platform for further advancements. The robot has the potential to move beyond entertainment and into fields like education, rehabilitation, and research as its capabilities are increased by developments in AI, motion, and interaction systems.Ultimately, the Toddler-Bipad serves as an important platform for exploring the future of robotics, where machines and humans collaborate more seamlessly to enrich everyday life.

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