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MangoBot: Companion Robot to Help Improve Brain Health

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Abstract

Mental health disorders such as depression, anxiety, and Attention-deficit/hyperactivity disorder (ADHD) affect millions of individuals worldwide. To address these challenges effectively, innovative solutions are needed that provide timely, accessible, and personalized support. This paper presents *MangoBot*, a prototype robotic companion that integrated 3D-printing, programming, animation, and AI-generated music. The development of *MangoBot* was motivated by research highlighting the therapeutic benefits of art forms like music and animation, alongside the emerging robot-assisted therapy. Many existing humanoid robots lack the ability to adapt to individual needs. *MangoBot* fills this gap by offering an open-source platform that enables extensive customization. This flexibility allows for the integration of AI and diverse technologies to generate personalized content and enhance human-machine interaction. Designed for children and teens dealing with anxiety, depression and concentration challenges, *MangoBot* serves as a personal companion to support emotional well-being. *MangoBot* was developed by a team of five middle school students mentored by their parents and coaches. *MangoBot*'s 3D-printed humanoid body is powered by a Raspberry Pi and utilizes Tkinter for the graphic user interface, DeepFace for facial recognition, and Sono-AI for music generation. *MangoBot* can play personalized music, animate eye movements, and even dance, offering an engaging and interactive experience tailored to the emotional needs of users. The design process was iterative, with continuous improvements based on feedback from neuroscientists, counselors, healthcare professionals, and users. Early qualitative analyses revealed positive responses from children, who demonstrated a strong connection to *MangoBot* during short-term engagements at robot competitions, STEM conferences, and other outreach events like technology and career days. This project demonstrated that humanoid robots, particularly those that are affordable and customizable, have significant potential to support mental health and well-being. *MangoBot* represents a promising step toward bridging a critical gap in mental healthcare, offering personalized, interactive support for those in need.

Keywords: Companion robot, Artificial Intelligence (AI), AI-generated music, Brain health, 3D printing, ADHD, Animation, Physical movement

1. Introduction

Mental health challenges, including depression and other mental illnesses, affect many people worldwide. Inspired by the team members' personal experiences, the team aimed to extend support to individuals, particularly children, facing similar struggles. Initially, the team proposed 12 unique ideas, which were eventually narrowed down to two concepts over a month: a robot that can dance to improve mood, and an online therapist that can play music. Ultimately, the team combined these ideas into MangoBot, a robot companion that plays music, dances, and features an interactive display and an animated screen.

Numerous studies in literature have explored the use of various art forms, such as music, cinema, and drama, to improve mental health. For instance, Keisari and Palgi (2017) employed drama therapy to enhance the interaction of individuals with Alzheimer's disease, using techniques like role-playing, dramatic dialogues, and playback theater. Savorani et al., (2013) utilized cinema therapy for patients with dementia, involving video treatments where characters on screen shared similar conditions, offering new coping strategies. Sakamoto et al., (2013) conducted music therapy for patients with severe Alzheimer's disease, where they actively listened to music while clapping, singing, or dancing, leading to improved emotional states and reduced caregiver burden.

Robot therapy has also been explored as a means to improve mental health. Tsiakas et al., (2016) studied the use of robot and music therapy in a game called "Name that Tune" to enhance attention spans in patients with Alzheimer's disease. Liu et al., (2024) employed robot-assisted rehabilitation combined with music therapy for stroke patients, improving physical rehabilitation and alleviating fatigue while promoting positive emotions and self-management. Humanoid robots like NAO, Pepper, and KASPAR offer additional benefits due to their human-like appearance, enhancing user attention and social engagement. KASPAR is a doll-like robot - which uses simplified interactions - that is made to help children with Autism to understand that other people see different perspectives from them, Wood et al., (2019). NAO is a similar-sized humanoid that has multiple touch sensors in the head, hands, and feet. With an editable program, this humanoid can dance, speak, and recognize faces and objects, Geminiani et al., (2019). Pepper is a child-sized, interactive humanoid robot, enhanced from NAO. Equipped with a tablet, Pepper can display additional content and present a wider range of content compared to NAO. The general-purpose humanoids, NAO and Pepper, have both been used in robot therapy for medical conditions, such as Autism, ADHD, and Alzheimers, Fridin et al., (2011), Geminiani et al., (2019), Amato et al., (2021). However, these existing humanoid robots lack full development capabilities for users, such as expanding with additional sensors, altering base libraries, or incorporating new technological advances like AI.

Motivated by this limitation, the team developed MangoBot, a humanoid robot with open-source full development capabilities. AI can significantly contribute to robot-assisted therapy by automating personalization procedures, generating personalized songs, pictures, and videos based on prompts, and training facial expressions and mood sensing for improved human-machine interaction.

MangoBot is built around two Raspberry Pi computers. Raspberry Pi is an affordable, small, lightweight, single-board computer costing under $50 USD. It features multiple input interfaces, including Universal Serial Bus (USB), High-Definition Multimedia Interface (HDMI), and General- Purpose Input/Output (GPIO) pins, making it versatile for various projects like robotics and home automation projects.

Tkinter is a standard Python library used to create Graphical User Interfaces (GUIs). When used with Raspberry Pi, it allows developers to design interactive applications with virtual buttons, labels, and other widgets, enabling users to control hardware or visualize data through a simple, intuitive interface. The team's research has been organized around three main hypotheses which are:

- Hypothesis 1: The integration of AI, 3D-printed parts, suno.ai for music generation, and Raspberry Pi for control and interface will enable the team to create an effective personal companion robot prototype for mental health support.
- Hypothesis 2: An iterative development process involving middle school students will lead to significant improvements in the design and functionality of the personal companion robot.
- Hypothesis 3: Incorporating advanced AI capabilities, such as emotion recognition through DeepFace and an embedded camera, the team will enhance the robot's ability to provide personalized mental health support.

It is important to note that the selected technologies of Raspberry Pi, 3D-printing, and AI-generated music, either individually or collectively have the ability to innovatively address specific needs of children and younger adults for purposes of mental health and personal well-being. A few of the functions the team had envisioned would include the following details.

To begin, the technologies of 3D-printed parts used in concert with Raspberry Pi have the capability to assist with interactive learning activities, such as guiding the user through cognitive exercises or educational games. The

Raspberry Pi can handle the processing and display of these activities, providing a user-friendly interface which keeps the user engaged and focused.

For users who need help with focus, such as those with ADHD or cognitive impairments, the robot can generate and play music designed to enhance concentration and cognitive function. The AI can adjust the music in real-time based on the user's level of engagement and productivity, ensuring that the music remains effective.

The AI can help establish a daily routine for the user, incorporating regular music therapy sessions. The Raspberry Pi can manage these routines and provide reminders, ensuring that the user remains engaged and motivated. This structured approach can be particularly beneficial for individuals struggling with depression.

The AI will eventually be able to analyze the user's emotional state through voice recognition and facial expression analysis. By integrating AI with the suno.ai music generating technology, the robot can create and play personalized, non-copyrighted music that is tailored to the user's current mood and needs, whether it is calming music for relaxation or upbeat tunes for focus.

The AI can learn from user interactions over time, improving its ability to select and generate music that best suits the user's preferences and therapeutic needs. This continuous learning process ensures that the robot becomes more effective in providing personalized therapy.

1.1 Summary of Research Objectives

The team co-constructed the following 4 Research Objectives during their iterative design meetings:

- Research Objective #1: Build a prototypical companion robot using adaptive AI, 3D-printing of parts, and a Raspberry Pi Graphical User Interface.
- Research Objective #2: Test the companion robot prototype for User Interface applications and connectivity.
- Research Objective #3: Create an AI-generated music library with more than 50+ AI-generated songs for use by users in a customizable fashion.
- Research Objective #4: Operate the companion robot's arms to replicate dancing movements which are overlaid with the songs from the suno.ai generated music library.

This research is worthy of investigation in an effort to add to the body of knowledge on less expensive personal robot companions using AI. The intended impact is to address gaps in mental health support and well-being, especially for a number of possible users troubled by anxiety, stress, and lack of focus.

The paper is structured into five sections. Section 1 provides an introduction and background. Section 2 reviews related studies on the therapeutic impact of music on aspects like learning, emotions, and physical movements, establishing the rationale for MangoBot's design. Section 3 details MangoBot's system design and architecture, covering hardware like the Raspberry Pi and 3D-printed body, as well as software implementation for functions like music playback, user interface, and motor control. Section 4 discusses the iterative development process, incorporating feedback, and plans for integrating technologies like ROS and facial emotion detection. Finally, Section 5 concludes by summarizing MangoBot's innovative features as a personalized robotic companion leveraging music therapy, robotics, and AI for emotional well-being and brain health management.

2. Related Studies on the Impact of Music on Human

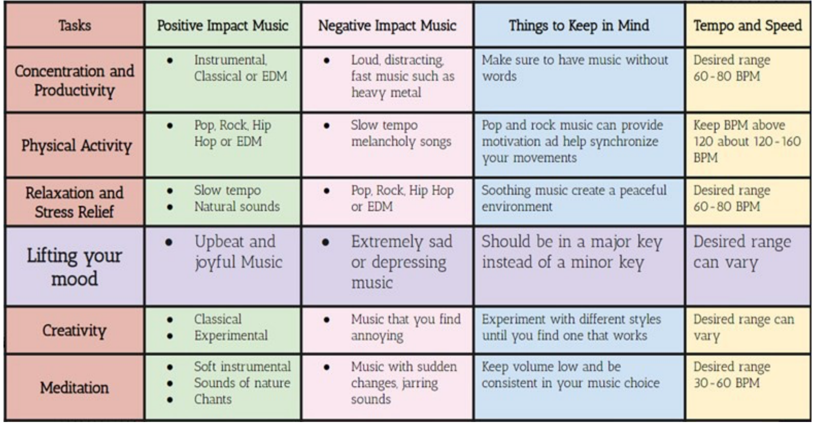
2.1 Research on Music's Impact on Enhancing Learning and Cognitive Functions

Music can shift brain states, enhance learning and memory, and promote brain plasticity. It activates various neural circuits and releases neurochemicals, influencing neuron activity. The frontal cortex, involved in understanding context and making predictions, is activated when listening to music. Music also engages brain areas responsible for arousal, memory encoding, and emotional responses, such as the amygdala, para-hippocampal formation, cortex, and hippocampus. Huberman, A., (2023). By evoking strong memories and emotions, music creates a rich and complex experience, fostering a propensity for action and evoking the activation of various brain circuits.

2.2 Research on Music's Impact on Emotions

Listening to music activates the premotor and motor circuits in the brain, increasing motivation. It can evoke empathy, even without lyrics, by creating a sense of understanding and connection with others. Music has a powerful impact on emotions, capable of uplifting moods, evoking a sense of lightness, and alleviating anxiety. The auditory system and brain circuits that respond to music have a strong ability to evoke emotional states, Huberman, A., (2023).

Table 1. Music with positive impact for different tasks (based on Huberman, 2023)



Tasks	Positive Impact Music	Negative Impact Music	Things to Keep in Mind	Tempo and Speed
Concentration and Productivity	• Instrumental, Classical or EDM	• Loud, distracting, fast music such as heavy metal	Make sure to have music without words	Desired range 60 - 80 BPM
Physical Activity	• Pop, Rock, Hip Hop or EDM	• Slow tempo melancholy songs	Pop and rock music can provide motivation ad help synchronize your movements	Keep BPM above 120 about 120 - 160 BPM
Relaxation and Stress Relief	• Slow tempo • Natural sounds	• Pop, Rock, Hip Hop or EDM	Soothing music create a peaceful environment	Desired range 60 - 80 BPM
Lifting your mood	• Upbeat and joyful Music	• Extremely sad or depressing music	Should be in a major key instead of a minor key	Desired range can vary
Creativity	• Classical • Experimental	• Music that you find annoying	Experiment with different styles until you find one that works	Desired range can vary
Meditation	• Soft instrumental • Sounds of nature • Chants	• Music with sudden changes, jarring sounds	Keep volume low and be consistent in your music choice	Desired range 30 - 60 BPM

The components of music, such as frequency, cadence, and lyrics, activate brain circuits and evoke the firing of neurons. Certain sound frequencies release neurochemicals, creating emotional states (Huberman, 2023). Surveys indicate that people listen to music to relax, induce happiness, process emotions (often sadness), and increase concentration. Music that induces happiness tends to be faster, with 140 to 150 beats per minute or higher, often in a major key, and may have positive or nonsensical lyrics. The cadence of music is a critical variable in shifting one's mood (Table 1). Listening to happy music for at least nine minutes can significantly improve mood. Allowing oneself to listen to sad music for a period can be a helpful approach in processing feelings of sadness, using catharsis to amplify emotional expression. Music can shift states of happiness, sadness, and anxiety. A study from the University of Pennsylvania, Graff and colleagues (2019) showed that listening to the song "Weightless" by Marconi Union can reduce anxiety by up to 65% in just three minutes, comparable to the effects of benzodiazepines. Further exploration of music's effectiveness in facilitating emotional processing and expression is warranted.

2.3 Research on Music's Impact on Bodily and Physical Movements

When humans listen to music, their neurons and hormones respond to the frequencies of sound, creating a symphony of emotion within one's body and brain. Listening to music for 10 to 30 minutes per day can lead to significant physiological shifts, such as reduced resting heart rate and increased heart rate variability. Different frequencies and patterns of sound in music can evoke different types of bodily movements. Music can impact one's physiology at a deep level, even below conscious awareness, by modulating one's cardiovascular system and breathing apparatus. Music with a faster cadence, around 140 to 150 beats per minute, can create a heightened state of motivation to move. Music can evoke the release of neurochemicals that shift the body towards being more likely to move (Huberman, 2023).

2.4 Research on AI Generated Songs, Pictures, and Videos

AI is rapidly developing and can help robot-assisted therapy in many ways. First, AI can automate the personalization procedure to accommodate the user's needs. There are, in general, two different ways to personalize the robot to the user, the traditional categorization approach, which groups people with similar backgrounds, and the learning approach, where the robot learns to adapt to the user's needs through multiple training sessions. Second, the more recent AI technologies also create personalized songs (Suno AI), pictures (Stable Diffusion), and videos (invideo AI) according to a text prompt, which could lead to further personalization of the robot. Finally, AI can be used to train facial expressions and sense the mood of the user for better human-machine interaction, Savor et al., (2024).

3 System Design and Architecture

3.1 System Design Overview

Figure 1 shows the system design of the MangoBot. The team first designed the body of the MangoBot using Fusion360 (Figure 2). Later, the team used Raspberry Pi to power MangoBot. The upper Pi controlled the screen on the robot's head, displaying its eyes, while the bottom Pi controlled the MG996R servo motors and a screen on the chest with a user interface for music selection. The robot's body was 3D-printed using parts from *Thingiverse*. Thingiverse is a popular online platform where users can share and download 3D-printable models. It is widely used in the robotics community to find and print parts for various projects. Users can search for specific components, such as robot arms or gears, download files, and print them using a 3D-printer.

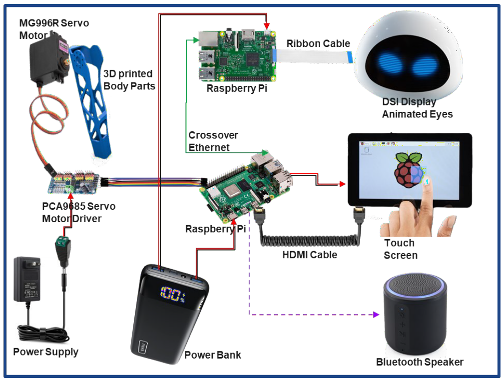


Figure 1. System design of MangoBot

The team employed *TKinter* for the GUI and worked together to assemble the robot, involving tasks like 3D-printing, coding, and assembly.

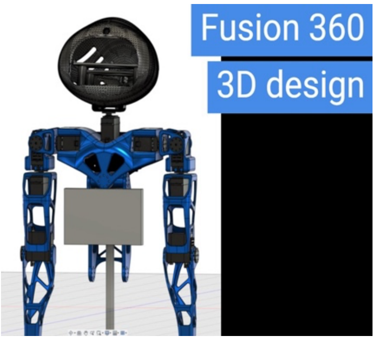


Figure 2. Design of MangoBot in Fusion 360

3.2 Design for 3D-Printing

3D-printing has become a versatile and cost-effective method for generating designs in the 21st century. Two of our five team members had access to 3D-printers, allowing them to assign roles efficiently. They printed different sections of MangoBot and assembled the segments. Initially, the team encountered challenges with the brittle and weak nature of the printed parts, leading to breakage incidents. After discovering the hollow interiors, the team members increased the infill to 100% and reprinted every part. Additionally, the team used a hairdryer to soften the Polylactic Acid (PLA) filament into a malleable state, reducing the likelihood of breakage (Figure 3).

3.3 Coding

The team used Raspberry Pi Python to code MangoBot's functionalities, including playing music, displaying a GUI, and controlling motor movements. Teammates employed TKinter for coding the User Interface, learning how to properly place buttons and assign their actions. Team members also learned how to play music on Raspberry Pi using PyGame, as well as how to animate MangoBot's face and control the servo motors through online guides, YouTube tutorials and support from coaches and mentors. Every team member contributed, whether it was coding the UI, motors, or animations.

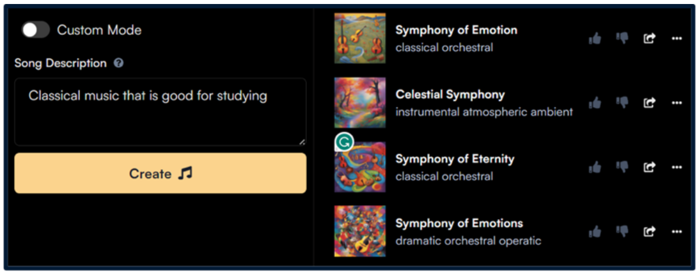
Figure 3. 3D-printing of the MangoBot

3.4 AI-Generated Music

Music is an essential component of this innovation project. To incorporate music into MangoBot, selected team members utilized Suno.ai, an AI tool that generates original songs based on user text prompts (Figure 4). After creating over 150 songs, the team integrated them into MangoBot's Raspberry Pi via a hard drive. The team then coded the robot to randomly reorder and play those songs upon button press, ensuring a diverse and engaging musical experience.

3.5 Overall Assembly

For the overall assembly, the team integrated the hardware and software components. Team members ensured that the movement code would not compromise the robot's hardware by carefully considering the range of motion. The team also combined their code testing modules for movement, music playback, and the UI into a cohesive system. The 3D-printed parts were initially assembled using duct tape and screws, as the screens were integrated and attached.



Classical music that is good for studying

Symphony of Emotion
classical orchestral

Celestial Symphony
instrumental atmospheric ambient

Symphony of Eternity
classical orchestral

Symphony of Emotions
dramatic orchestral operatic

Figure 4. User Interface of Suno.ai for AI generated music

3.6 Ethical Design Considerations

As with any new prototype or invention that seeks to target mental health and personal well-being, there are ethical considerations in the development and implementation processes that should remain most important for designers. Of major concern are issues related to privacy, autonomy, biases, and ethics.

With regard to privacy, the designers must consider that the robot companions will collect sensitive data including emotional states and personal interactions. Ensuring a robust data encryption scheme with secure storage is essential to protect user privacy. In addition to data security there is the issue of informed consent. Users should be fully informed, in advance, about the data being collected, how it will be used and who will have access to it.

With regard to autonomy**,** users should have control over the robot’s functions as well as the ability to turn off or modify those functions. This ensures that the robot enhances, rather than diminishes, the user’s sense of autonomy. There is a risk that users might become overly dependent on robotic companions, potentially reducing their interactions with human caregivers and family members. Balancing robot use with warm human interactions is important to maintain healthy social connections.

AI is known to have issues related to potential biases in AI algorithms. AI algorithms can inadvertently incorporate biases present in the training data, leading to unfair treatment of certain user groups. Regular audits and updates of the algorithms are necessary to identify these biases. Additionally, the robot should be designed with a degree of cultural sensitivity. The robot’s responses and behaviors should be culturally sensitive and inclusive. This requires diverse training data and continuous evaluation to ensure the robot can appropriately recognize and interact with users from different backgrounds.

Finally, there is the issue of ethics. Two critical concerns come to mind. First, is the issue of deception. Using robots that mimic human emotions and interactions can raise ethical concerns about deception, especially if users are predisposed to fantasy or are not aware that they are interacting with a machine. The other concern is the issue of design accountability. Establishing clear guidelines as to who is responsible for the robot’s actions and decisions is crucial. This includes accountability for any harm or perceived harm caused by the robot, whether that is due to malfunction or misuse. While making improvements to the design these issues must be addressed uniformly and consistently in the iterative design process.

3.7 Qualitative Measures and Consistent Observations

The original idea for MangoBot grew from a sincere desire to help one of their own teammates using music. As such, there was no initial “design of experiment” or data collection plan. The primary focus was to build a robot prototype. The team of 5 middle school students adopted a qualitative analysis approach by looking into different possibilities, and by using new technologies and Artificial Intelligence. The team kept an engineering notebook, and they kept observational notes on the iterative processes they employed in their design-build project. Opportunities for observations came from expert feedback, robotic competitions events, technology outreach, and motivational training sessions provided to younger audiences to inspire interest in fields of Science, Technology, Engineering, and Math (STEM). Below are some of the more consistent observations:

Table 2. Qualitative Measures and Observations (based on Denzin & Lincoln, 2011).

Users/Observers	Observations	Examples and Explanations
Team members, parents, mentors, and coaches	Mood shift from negative to positive (33 instances)	Altered mood, independent of other human interactions, based solely on the robot's presence and interactions
Team members, parents, mentors, and coaches	Desire to touch and interact with MangoBot (65 instances)	Users engage the robot as if it were a living entity
Team members, parents, mentors, and coaches	Desire to make eye-contact with MangoBot (123 instances)	Users engage the robot as if it were a living entity
Team members, parents, mentors, and coaches	Reluctance to terminate interaction with MangoBot (51 instances)	Users are curious and desire to understand the robot's capabilities
Team members, parents, mentors, and coaches	Curiosity about MangoBot's mechanisms and design (75 instances)	Intellectual curiosity about the robot's design and functionality
Team members, parents, mentors, and coaches, healthcare experts, and counselors	Parental curiosity about the robot's efficacy (150 instances)	Perceived need for the robot and hope for successful design outcomes
Younger users (children 7 years and younger)	Frustration due to robot's inability to meet expectations (12 instances)	Frustration from incomplete design and lack of emotional recognition capabilities
Team members and robotic competition judges	Interest in AI integration and design complexity (4 instances)	Comparative assessment of design efficacy and competitive standing
Team members, parents, mentors, coaches, healthcare professionals, and judges	Anthropomorphic design features (75 instances)	Importance of human-like qualities for positive emotional reactions and approachability
Team members, parents, mentors, coaches, small children and teens	Emotional engagement from eye animations (48 instances)	Positive emotional reactions making the robot more endearing and approachable
Team members, parents, mentors, and coaches, healthcare professionals, and judges	Perceived social presence (75 instances)	Sense of companionship and interaction, enhancing acceptance and effectiveness

The team shared these repeated observations in an effort to record their observations and match them with what they saw as the qualitative measures of their nine months of design work. This gives one a better idea of the observations made and what the observers interpreted as the underlying influences in the design environment that contributed to the evolution of the robot's design. While there is no inference of statistical significance, one can intuit the relative weights of the observations based on the number of instances observed over a period of nine months. Any future work involving MangoBot, or its progeny will contain a well-planned data analysis plan.

4. Discussion & Future Work

The development and iteration of MangoBot involved gathering feedback from experts, potential users, and the community. The team engaged with experts at robotics laboratories at the University of Texas at Arlington, collecting insights from professors and graduate students. Their recommendations included integrating facial emotion detection capabilities and enhancing the robot's operating system. Furthermore, active participation at a community center for autistic children highlighted the diverse spectrum of autism severity, prompting a focus on enhancing MangoBot's customization features to meet individual user needs. Additionally, outreach efforts at events such as the Dallas ISD Expo led to suggestions to diversify MangoBot's music offerings and improve animations, and an under-resourced school in the Himalayas led to suggestions of cost-effective products so that more people can use it.

In order to improve the overall functionality and stability, extensive research was conducted on the Robot Operating System (ROS) to explore its potential for enhancing MangoBot's development. ROS is a freely available software development toolkit designed for robotics applications. It provides a standardized software framework for developers across various sectors, supporting them from the initial research and prototyping stages to eventual deployment and production. Following thorough research, the team decided to integrate ROS into its framework, aiming to leverage its capabilities in facilitating the creation of modular, hardware-independent robotic systems with efficient communication between components. Specifically, the team selected ROS 2 Dashing Diademata for implementation due to its advancements in performance, reliability, and security over previous iterations, ensuring a more robust and efficient operation of MangoBot.

Another key development is to integrate emotion detection functions into MangoBot so that it can automatically detect emotion. The team found multiple existing solutions for facial recognition and identified ***DeepFace***, a facial recognition system developed by Facebook's AI research team, as the most promising one. DeepFace utilizes deep learning, specifically convolutional neural networks, to accurately analyze and identify faces in images under diverse conditions. Renowned for its robustness across varying lighting, poses, and facial expressions, DeepFace stands as an effective solution for real- world applications. The team intends to integrate DeepFace into its ROS framework for MangoBot, enabling the robot to detect user emotions and respond accordingly, such as by playing music to assist.

Integrating DeepFace and ROS 2 Dashing into MangoBot holds the promise of significantly enhancing its cognitive capabilities and responsiveness. By incorporating DeepFace's robust facial recognition algorithms, MangoBot could accurately detect and interpret users' emotions, enabling personalized AI-generated music tailored to individual needs. This integration could be facilitated by developing ROS 2 nodes that interface with DeepFace's functionalities, allowing MangoBot to seamlessly process facial data and make informed decisions based on detected emotions. Additionally, leveraging ROS 2 Dashing's enhanced performance and reliability would ensure efficient communication and processing of data within MangoBot's framework, further enhancing its overall effectiveness and responsiveness in real-world scenarios. Through this integration, MangoBot could emerge as a versatile and empathetic robotic companion, capable of providing tailored assistance and support to users.

5. Conclusion

While this project started out as a robotics innovation project for a First Lego League Challenge Team, the team members quickly realized that what they had envisioned and what took shape in the prototype demonstrated greater potential benefits and rewards than they had imagined in a post-COVID environment. The World Robotics FLL judges who assessed MangoBot, regarded it as worthy of a "*Breakthrough Award*." With combined ideas and hard work, the team was able to create a prototype with great promise and enjoyable outcomes. Through gracious professionalism they realized that their invention might be able to address the anxiety, and depression needs of younger children and teens by addressing the gaps in isolated mental healthcare and rarified well-being. The team had both a real- world mission and an emerging real-world solution in mind.

Based on the feedback from numerous sources such as judges, counselors, parents, coaches, mentors, and healthcare professionals the prototype showed great promise as one of the earliest iterations of what had been envisioned. The MangoBot, which costs $400 in materials to create, could be a launching pad for greater achievements and fuller, more nuanced AI-integration. Last but not least, the team had a lot of fun learning from each other in the design and learning process.

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