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3D printed Dancing Humanoid Robot "Buddy" for Homecare

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***Abstract*— This paper describes a 3D printed humanoid robot that can perform dancing and demonstrate human-like facial expressions to expand humanoid robotics in entertainment and at the same time to have an assistive role for children and elderly people. The humanoid is small and has an expressive face that is in a comfort zone for a child or an older person. It can maneuver in a day care or home care environment using its wheeled base. This paper discusses on the capabilities of the robot to carry and handle small loads like pills, common measurement tools such as pressure and temperature measurement units. The paper also discusses the use of IP camera for color identification and an Arduino based audio system to synchronize music with dance movements of the robot.**

I. INTRODUCTION AND LITERATURE

Research on humanoids or human-like robots for use in assistive device or rehabilitation for children and elderly has increased recently. The effectiveness of humanoids for the therapy of some disabilities is promising than human interaction in rehabilitation, particularly in autism research for children [1]. The other application of humanoids is to assist elderly people to live comfortably and independently adapting like pets in homes. The robots will be able to do simple assistive household works such as bringing small utensils to users, or performing some chores, or monitor their health and also as a socially interactive companion. Hence, it is important to research and study more the acceptance and use of social robots for elderly and children. A social robot interacts with human via human social cues such as facial expressions [2], [3],[4]. Several human-like and animal-like robots have been shown to be effective in the rehabilitation field of children and elderly. One of the few is Keepon [5], which dances to musical tunes and has shown effective therapeutic tools for children with autism and elderly. Keepon uses actuators for synchronized movement to rhythmic sound beats attracting the attention of a subject in the therapy. Tanaka et al. [6], [7] created dance sequences for QRIO humanoid robot in the presence of children, in a playroom and observed a considerable change in attention of the children.

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Children and the elderly showed interest towards the dog-like robot of Sony, the AIBO [8], [9] when it socially interacts or dances. Shamsuddin et al. [10], observed that the implementation of NAO robot has significantly changed the autistic behavior of children during a direct child and robot interaction, and also in a classroom environment. Dautenhahn et al. built a humanoid robot Kaspar [11], [12], a minimally expressive robot and proved the effectiveness of the humanoid to enhance the attention of autistic children. Several more [13], [14] have shown similar work and have proven the effectiveness of social robots in the rehabilitation of children and elderly, building the case for the necessity of studying these robots. Some other robots which are also used in day care or home care are car-o-bot [15], Robo MD [16], TeCaRob [17] and PaPeRo [18]. The aim of this paper is to expand our prior efforts in the area, [19] towards a complete independent mobile humanoid robotic system for home care. Previously, we have presented an interactive robotic system so called Buddy shown in figure 1, which was designed mainly for rehabilitation of children with psychiatric disabilities but normal kids are also interested in the robot. This paper shows more capabilities of the robot such as dancing, color detection and lifting loads that might encounter in daily activities. This paper is divided into eight sections starting with hardware used in the humanoid system, their description and advantages for the advancement of assistive device or system. Next, the ability of the robot to mimic human-like movements similar to a ballet dance is described. Later, the paper describes the methodology used to play audio and also how to track color using the camera. Finally, we discuss the stress analysis and experimental data of load carrying capacity of the robot arm.

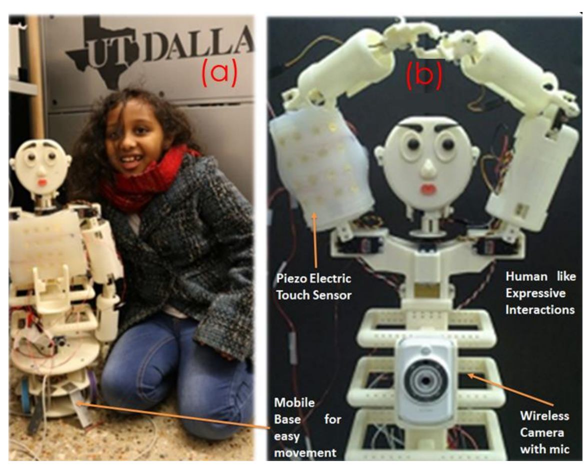

Fig. 1: Humanoid Buddy (a) with an 8-year old normal child and (b) the humanoid parts and raising hands gesture. (Parental consent form was obtained for the photograph of underage child next to the robot).

II. HUMANOID BUDDY HARDWARE

The humanoid robot has an on-board wireless camera and microphone, with a mobile base, ultrasonic distance sensor, touch sensors and on-board battery. It has 15 DOF, 580 mm tall and 925 mm arm span. The detailed hardware and characteristics of the robot will be briefly discussed in this section that allows us to demonstrate various dancing movements. Figure 1 shows the size of the robot in comparison with an 8-year old child sitting next to the robot. The most important aspect of this robot is that all the structural parts are 3D printed enabling one to recreate again for use in home care.

A. Servo Actuators

Figures 2 and 3 show all the different types of servo actuators used at different locations of the humanoid Buddy, which are selected based on size limitations and load capacities. The servo motors actuate the arms, the head and the eyebrow, and the lips. DC motors with encoders are used for maneuvering the base for locomotion. Most of the selected servo actuators have metal gear, which have a longer lifetime than the plastic geared servo actuators. Some servo motors have plastic gear but are sufficient to manipulate small loads, which are further discussed in the section 7.

B. DCS 942L camera

Buddy is equipped with DCS 942L camera (inset of Fig.2). The camera has an aperture of F2.8 with fixed focal length of 3.15 mm, 1/5 VGA progressive CMOS sensor and exposure time of 1/3.75 to 1/14640 sec. It also has 4X digital zoom, built-in microphone, PIR motion sensor, 5 meter Infra-red (IR) illumination distance, minimum illumination of 0 lux with IR LEDs on, built in infrared cut removable (ICR) filter module and angle of views of (H) 45.3, (V) 34.5 and (D) 54.9. These features just show how the DSC 942L is properly suited for continuous monitoring of both audio and visuals information remotely through WIFI [20] and can be observed and also interact using the built interface and two-way audio interactions.

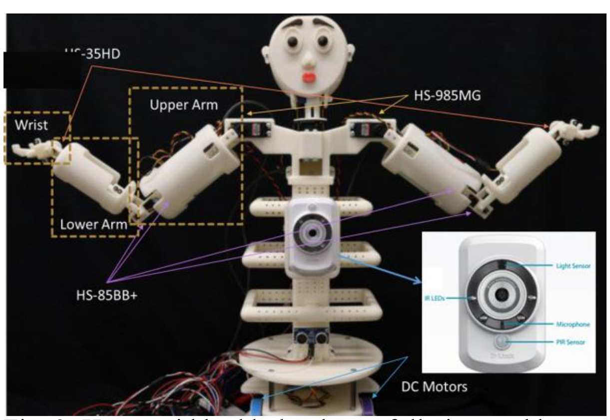

Fig. 2: Humanoid buddy hardware full view and base.

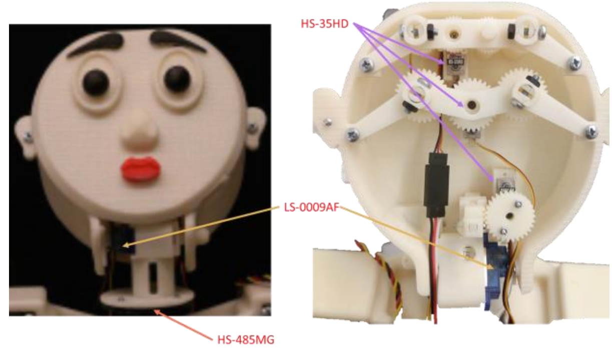

Fig. 3: Hardware Neck and Head

C. Schematic Layout

Figure 4 shows a schematic layout of the humanoid Buddy, which is a small baby-sized robot mimicking a 3 months baby in height. The schematic layout in figure 4 shows where the servo actuators are located and the relative angular movements.

Servo Motors	Max Angle °	Min Angle °
θ_{1L}	0	180
θ_{1R}	0	180
θ_5	0	60
θ_6	0	180
θ_9	36	72
θ_8	0	180
θ_7	0	180
θ_{3R}	18	90
θ_{3L}	18	90
θ_{2R}	132	180
θ_{2L}	132	180
θ_{4R}	0	180
θ_{4L}	0	180

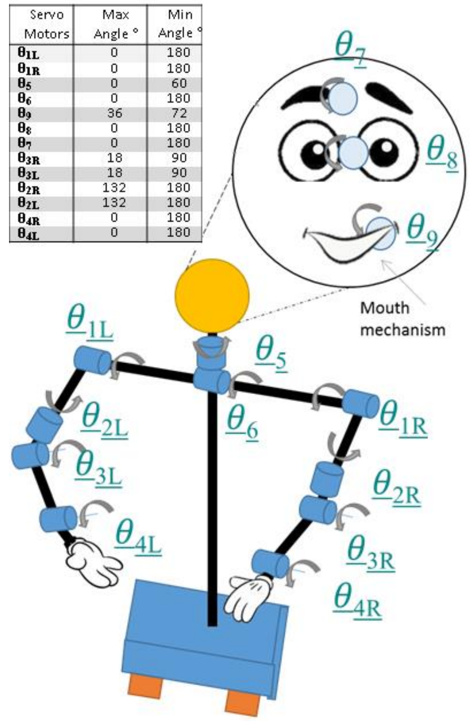

Fig. 4: Schematic diagram of the robot and the head mechanisms along with the minimum and maximum servo position of the joints.

D. Maximum and minimum values of servo motors (without obstruction)

The simplistic representation in figure 5, show the different possible angles of the humanoid, which we considered while coordinating the dance moves for the robot. Ballet dance presented in this paper is provided as a supplementary movie [22]. This is just one of the feasible dances and other can also be made in similar way.

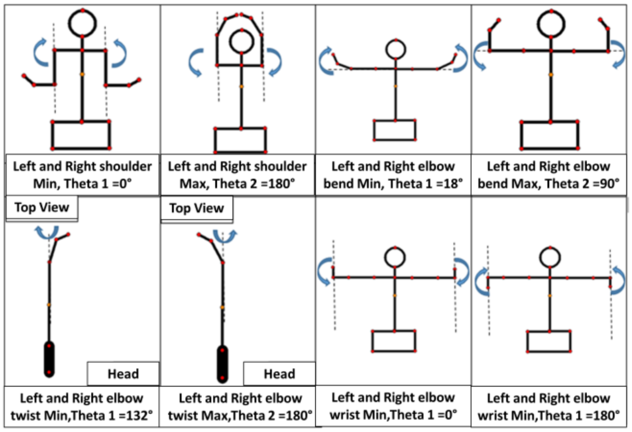

Fig. 5: Simplified diagram of Buddy gestures (max and min).The corresponding angles are show in figure 4.

III. BALLET DANCE SEQUENCE OF THE SERVO MOTORS

In figure 6, we see a different servo actuation of Buddy during the ballet dance move with corresponding actuated servos in time domain. The corresponding snapshots of the robot are shown in figure 7 when the ballet dance sequence is implemented. It was observed that the ballet dance move is very well accepted by all types of audience from young to old people for entertainment.

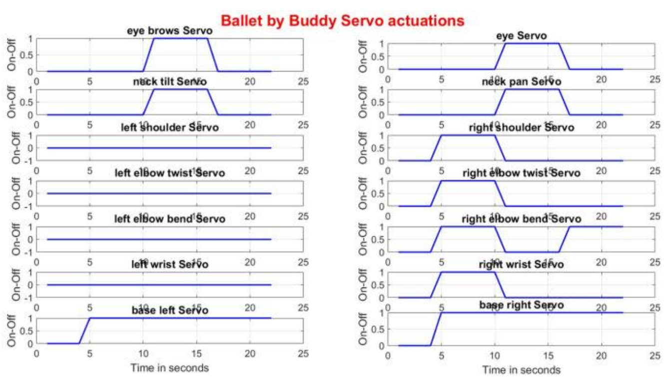

Fig. 6: Servo motor actuation sequence during ballet dance. Different graphs show the on and off time of each servo represented in figure 4

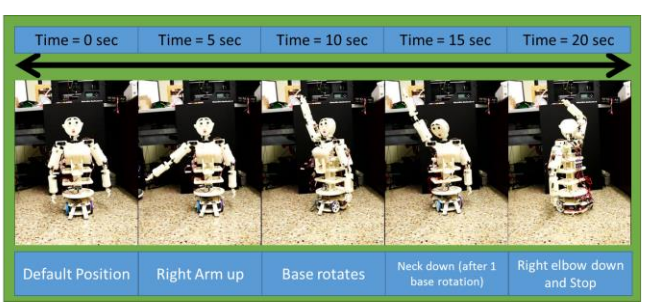

Fig. 7: Photograph of the ballet dance of the robot in 1 cycle that was obtained from video recording.

The humanoid performed the ballet dance for over 600 audiences in an invited event at the AMC NorthPark, Dallas, TX during the movie screening of Terminator 3 (Terminator Genisys), and received wide acceptance by all types of audience and made them more interested in the coupled engineering and entertainment aspect of the robot.

IV. AUDIO INTERFACING OF ARDUINO FOR DANCE

In order to synchronize the music with dance movement, we designed a subsystem to play music. Nowadays, Secure Digital (SD) card is one of the popular portable memory. We used SD card to save music files. Advantages of SD card are availability and cost effectiveness. We also used a MicroSD shield board to connect the SD card to our controller, Arduino Uno. The Serial Peripheral Interface (SPI) is used as communication protocol to read data from the SD card. FAT32 was used for file system because it is recognized by many devices and operation systems. Thus, users can easily copy their music into the memory.

Currently, the robot uses an open source library, which can play the .wav format with 44100 Hz and 16-bit stereo quality. Although, the input file is stereo channel, the library plays music in mono channel as well. The library reads music file in the root directory of the SD card. This library takes control of PWM pin. Therefore, a speaker was connected to this pin through an amplifier. In the future, we will develop new library to read more file format.

V. COLOR RECOGNITION USING THE CAMERA

One of the subsystems of the Buddy robot is recognition of objects with a solid color. This subsystem captures images of a scene and identifies different colored objects assigned by a user. As mentioned in Section II (B), the camera sends image through a Wi-Fi to a computer to provide monitoring of the environment. We used this image as an input of our subsystem to find the objects. In this way, we used Computer Vison Toolbox of MATLAB software and the algorithm shown in figure 8.

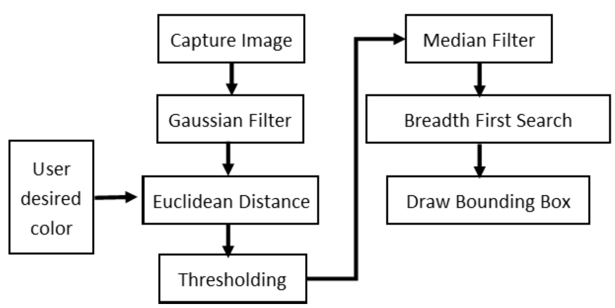

Fig. 8: Flowchart of color recognition

Colors in digital image are determined with vectors, which belong to a color space. There are many color space such as RGB, HSV, HSL, YCbCr, and so on. Buddy's camera captures RGB images. In this paper, we used Euclidean distance to determine how much pixel's color is similar to user-defined color. In the following paragraph, we describe the details.

The camera images always have noise. This noise makes change to the color of the pixels. If we use a noisy image and directly find the Euclidean distance, the result will have several false objects. In order to decrease noise, we used a digital low pass filter. It is assumed that Buddy needs to find objects in the environment with Gaussian noise. Although it is not always true, our experiment shows acceptable results. After filtering an image, the Euclidean distance of color of each pixel with desired color is calculated and saved in a matrix, which is same size with one channel of input image. Then, if the Euclidean distance of each array is greater than a threshold, we write zero on that array, and if it is less than or equal to this threshold, we write one. Comparing a matrix with a threshold and writing zero or one is called thresholding. Sometimes, thresholding produces many noise. To remove these noise, we used a median filter. The result of the above steps is a matrix with one where the color is similar to desired color and zero otherwise.

After determining which pixels are belonging to desired color, we combined the neighbor pixels to find objects. We used Breadth First Search (BFS) algorithm for traversing the matrix and numbering each objects. Then, we draw a bounding box around each object to show to user. Figure 9 (a) and (b) show how the algorithm shown before is used to find green and blue objects. Figure 9(c) shows the implementation of color recognition using our robot.

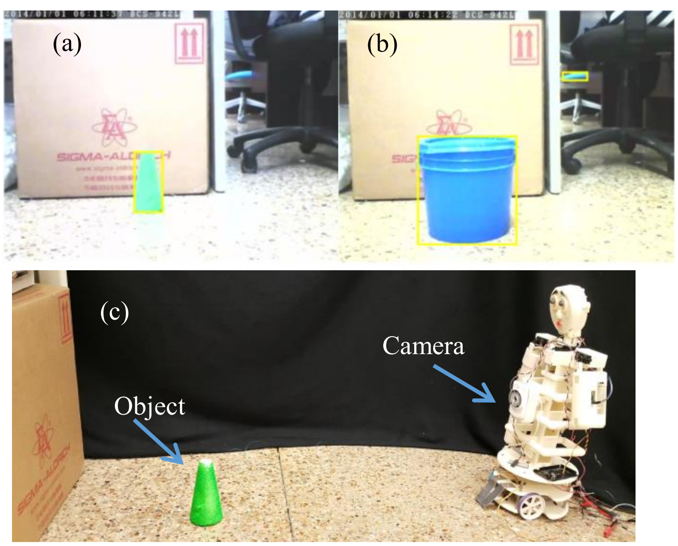

Fig. 9: Finding colored objects, (a) green object, (b) blue objects and (c) experimental setup for color recognition.

VI. STRESS ANALYSIS OF THE ARM

One of the most important aspects of 3D printed robot is the load carrying capacity of the robot for carrying tools for measuring like temperature, pressure etc. To evaluate the load bearing capabilities, finite element analyses were performed. The wrist servo motor is HS-35HD ultra nano servo motor, which has a stall torque of 0.8 kg/cm at 4.8V and the elbow servo motor is HS-85BB premium micro servo motor which has the torque of 3 kg/cm. The stress analysis for static load was conducted at 300 g load, which was the maximum observable weight the arm can carry. The weights of the parts were obtained from SolidWorks material library using ABS material and cross-checked by measuring the printed parts and found to be very similar with negligible difference. SolidWorks 2014 was used to simulate the stress distributed in each part when the maximum possible weight or load is lifted. The meshing for all parts was done using the default mesher of Solidworks. Figure 10 (a) and (b) show the von Mises stress (max 2.758 MPa) and displacement (max 0.0635 mm) of the wrist for 2.942 N load. Figure 10 (c) and (d) show the von Mises stress (max 52.92 MPa) and displacement (max 6.359 mm) of the lower arm at 3.14N applied load and figure 10 (e) and (f) show the von Mises stress (max 46.65 MPa) and displacement (max 1.974 mm) of the upper arm at 3.68N.

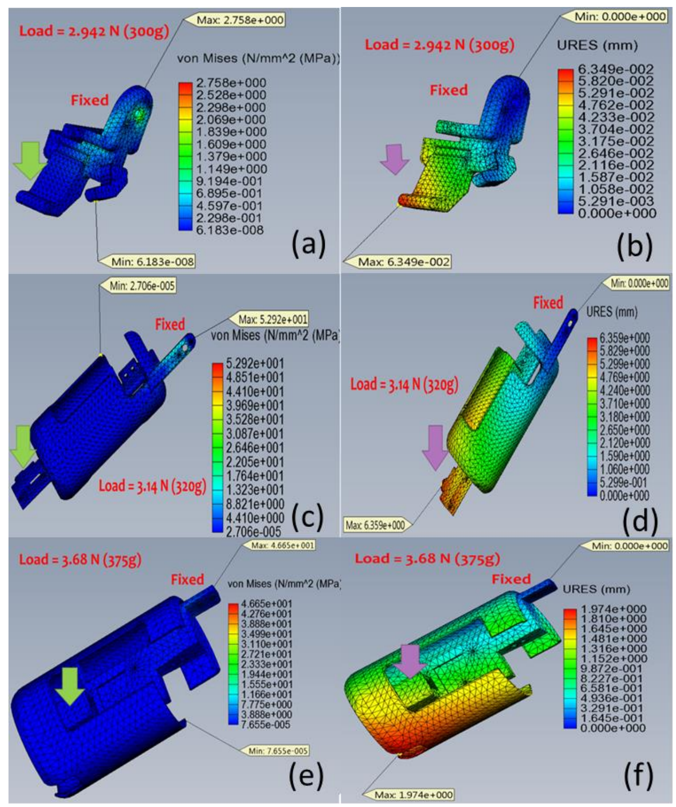

Fig. 10: Stress analysis of the robot arm part, (a) wrist -von Mises stress, (b) wrist - displacement, (c) lower arm - von Mises Stress, (d) lower Arm - displacement, (e) upper arm von Mises Stress, and (f) upper arm - displacement.

The figure 10 shows the stress analysis results based on respective loads applied on consecutive parts including the weights of the former parts, the fixed location and the load locations are shown in the figure. The load locations are the starting point of the parts (arrows in the figure). The stress analysis has shown that there is some high stress in the lower arm and upper arm due to complicated geometry (thin and slender structures in the arm) and other stress concentration points, which needs modification to carry higher load. The strength of common ABS material is 31 MPa [21] and therefore the applied load 300 g is higher. To carry higher load the thin structures and the geometry should be modified. However, the robot will not be subjected to higher loads, which will be discussed in the next section.

VII. EXPERIMENTAL ANALYSIS OF LOAD CARRYING CAPACITY

Experiments were performed on the humanoid by mounting a known weight and recording the movement of the mass using a video camera. The angular position of the shoulder joint was measured by varying the mass. Calibrated weights were hung on the palm of the arm using thread with negligible weight and then the servo arm was actuated while keeping the servo arm at 0 position, to perform an arm lift from default angle of 330 to angle 1150 as shown in no load condition in figure 11a. Other loads are shown in the pictures in figure 11. The angular positions (lifting capacities) of the robot for various loads were recorded and the results are presented in figure 12. In figure 12, we can see that the angle reduces to zero gradually as we increase the weights. As the weights were added, the angle to which the arm can lift also reduced, and at 500 g, it could not lift the weight anymore. Considering the dynamic motion and the load, we can see that the arm could not lift beyond 300 g significantly. From the experiential results, 200 g is a good weight after considering the angle the arm can lift and the static load discussed in the finite element analysis.

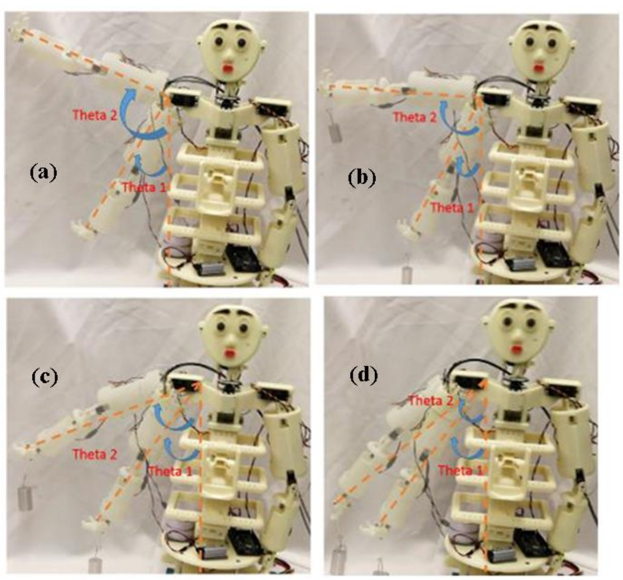

Fig. 11: Photograph of load carrying capacity of the robot during experiment, (a) 0 g, (b) 100 g, (c) 200 g and 300 g load.

VIII. CONCLUSION AND FUTURE WORK

This paper presents a 3D printed small and affordable human-like robot that can serve as an assistive device or co-robot and at the same time entertain users. We briefly described the hardware, feasible movements, ballet dance synchronization, implementation of audio through open source Arduino board, color recognition of using the camera and finally the load carrying capacity of the arm. The 3D printing enables the flexibility and customizability according to the need of the subject. The audio synchronization with the dance makes it more lovely, whereas the color detection can help in checking the health condition of the subject by doing more work in color recognition. The important factor for the 3D printed robot, which is the load carry capacities of the arm were, determined both experimentally and theoretically. It was shown that the robot can easily handle commonly used objects and help users in fetching and providing tools like thermometer, heart monitors etc. The future works include further characterization and implementation in laboratory settings and home care environment. Future work also includes implementation artificial intelligence and characterizations of movements.

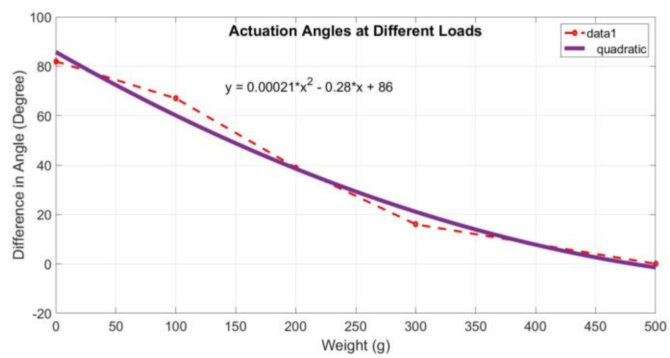

Fig. 12: Experimental results of actuation angles of the shoulder joint of the robot at different loads at the tip

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[22] A video of the robot is included that shows a ballet dance movement and load lifting capacity of the shoulder in the paper.