Design and Test of Lower Part Humanoid Dancer Robot to Do Foot Lifting Move of Remo Dance

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***Abstract* — Robot technology has developed very rapidly, especially humanoid robot technology. Humanoid robot has been used for various types of functions in various fields, including in the world of military, medical, industrial, and even in common use through commercial sales. Dancer Robot is one type of robot used to perform certain dance. Performed dance depends on the type of robot. There are dances performed by wheeled robots in groups, and there are also dances performed by humanoid robots. This study carried out design and testing of humanoid dancer robot's lower part to do foot lifting and other basic movements of dance. In foot lifting, the lower part of robot must be able to maintain balance and hold the load from the upper part so the robot does not fall. The distance of lifted foot also must have sufficient height from the floor. Based on robot design, the length of upper legs are 93.62 mm and lower legs are 93.00 mm. Robot able to make stance up to 8.5 cm wide from left to right leg and capable to do foot lifting with height 6.5 cm from the floor without falling.**

Keywords— dancer robot, humanoid robot, robot design

I. Introduction

Development of robotic technology is advancing very rapidly, especially the development of humanoid robot. Humanoid robot has been used for various types of functions. Among them are in the military, medical and industrial worlds. Even humanoid robot is commonly used as hobby through commercial sale. In the military field, for example, there are developed humanoid robots which are able to jump and carry out movements that were once considered impossible.

Dancer Robot is one type of robot used to perform certain dance. The dance performed depends on the type of robot. There are dances performed by wheeled robots in groups, and there are also dances performed by humanoid robots. In general, dancing difficulty will affect how the robot is designed. Wheeled robots dance with simultaneous movements and give a beautiful composition. Because of that, the robots are designed to have a good level of communication. They have to be able to communicate with each others instantly so that the group movements become compact and beautiful. This design of course balanced with good robot movement.

In humanoid dancer robot, movements that flexible and similar to movements of human dancer are form of challenge when designing robot. Robot must be able to adopt fps (frames per second) that are high enough. This high fps will make robot movements become flexible and similar to the original human dancer's movements. Humanoid robot which used as dancer robot was designed by Fahd et al. [1]. Their robot was designed to be able to walk like human and perform dance movements. In addition, the capabilities needed from humanoid dancer robot depend on the type of dance to be performed. For example in Remo Dance originating from East Java province of Indonesia, there are movements that commonly cannot be carried out by ordinary humanoid dancer robot. In Remo dance, there is a movement called *sabetan* movement that requires the robot to lift one of its foot high. If the robot did not properly designed, then this movement would not be able to carried out.

Reference [2] is an example of hobby robot which its mechanical platform cannot be modified. It has short upper leg and short lower leg. When do foot lifting, its height is not high enough. Similar to [2], Nao robot in [3] is a hobby robot with short leg and has limitation when do foot lifting. Because of that, we need to make a new robot platform which able to do foot lifting properly.

This study did design and testing of the lower part of humanoid robot. Those were carried out in order to be able to do foot lifting movement. In a foot lifting movement, the lower part of robot must be able to maintain balance and hold the load from the upper part. The design of robot must also have proper center of gravity (CoG) so that when robot do walking or foot lifting, the robot does not fall. Therefore, there was a need for an analysis process so that the motors which robot used, mechanical structure, and the program from robot's lower part able to make a foot lifting movement on Remo dance.

II. Hardware Structure

The hardware structure in this study is divided into how to design a mechanical structure of the robot and how to place the robot servos in order to represent a humanoid robot.

A. Mechanical Design

In general, the structure of lower part of humanoid dancer robot similar to common humanoid robot. Humanoid robot itself adopts its structures from anatomy of human body. So that the lower part of the humanoid robot basically mimics anatomy of lower limbs, namely hip, legs, and feet. Lower limb have joints or relationship between bones. The lower limb bones in humans are pelvic girdles, pelvis, femur, patella, tibia, fibula, tarsal bones, metatarsal bones, and so on [4]. These bones are connected to each other an become joints in the lower limb, namely hip joint, knee joint, and ankle joint [4]. These joints are adopted on a humanoid robot so that their positions becomes locations of servo motors which determines the DoF (degree of freedom) of designed robot.

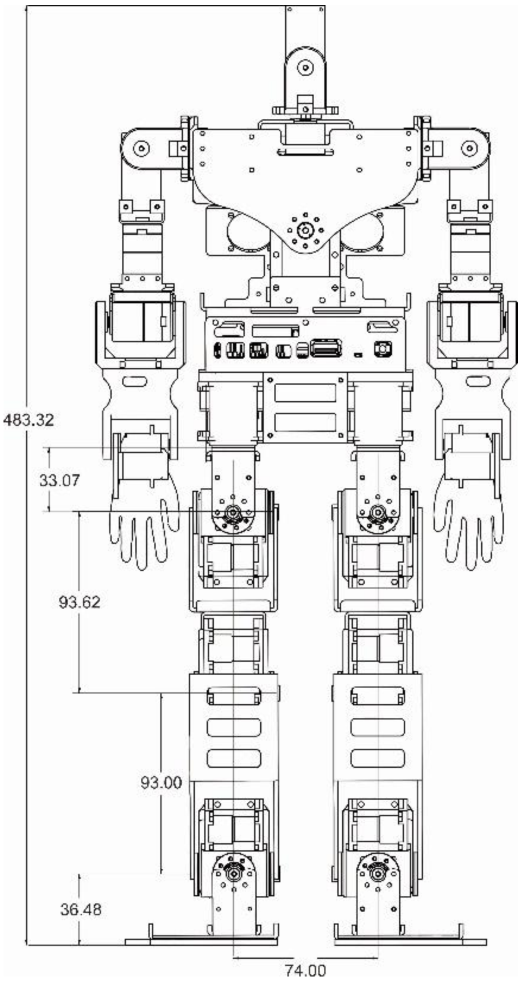

Fig. 1. Robot Dimension

The designed humanoid dancer robot is shown in Fig. 1. The robot is designed to have a height up to 483.32 mm. Lower parts of the robot are approximately 256.17 mm long, calculated from the floor, and the width between feet is approximately 74.00 mm calculated from the center of each foot. The length of upper leg of robot is 93.62 mm while the lower leg is 93.00 mm so it has a ratio of 1: 0.99. This design is close to the average value of lower leg and upper leg ratio of human, namely 1: 1.03. The soles of robot are designed in rectangular form and elliptical angle. Those soles are given rubber-type bearings on their long side to make the walking process easier.

B. *Placement of Servo Motors*

Fig. 2 shows the robot's mechanic when viewed from the side. From the figure, there is a prominent part which is a servo motor that is positioned in such a way. By adopting joint position on human body, the robot is designed so that the servo motors are placed in those positions. Fig. 3 shows the location and position of servo motors at the robot lower part. Servo motor on the lower part is 12 pieces. Hip joint in humans is ball and socket type so that it has 6 degrees of freedom. The robotic hip joint is represented by servo 1, 3 and 5 on the left leg while on the right leg is represented by servo 2, 4, and 6. The knee joint is represented by servo 7 on the left leg and servo 8 on the right leg. Knee joint is a hinge joint type so that it only has 1 degree of freedom. The ankle joint is represented by servo 9 and 11 for the left foot while the servo 10 and 12 represent the right foot.

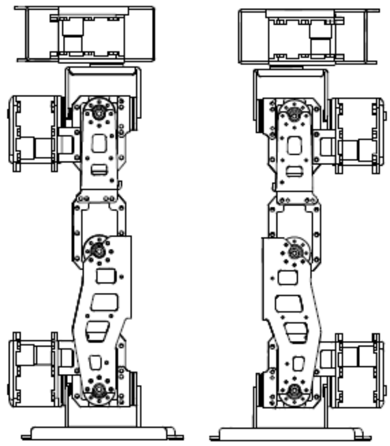

Fig. 2. Side View of Robot's Mechanic

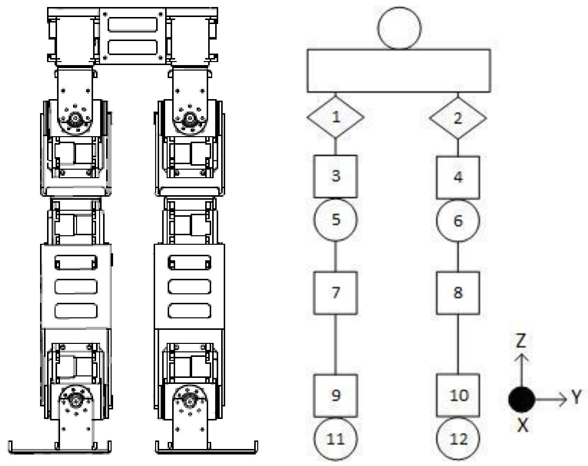

Fig. 3. Servo Motors Position on Lower Part Robot

These servo motors control the movement of each joint. In this study the servo motor used was motor MX-28T which was controlled by CM-730 controller. Servo motor MX-28T is a product from Robotis. Robotis is a company engaged in hobby robots, where robotis produce actuators and servos. These servos can be developed to make various variations of robot. Thus, user can be creative in developing their robots. Servo motor MX-28T is also used in development robot made by Robotis, namely Robotis OP2 which is a further development of Robotis OP. Robotis OP2 uses 20 servo motors MX-28T as actuator [6]. The specifications of the MX-28T are shown in Table 1. The MX-28T servo has an input voltage of 12 V, with dimensions of 35.6 x 50.6 x 35.5 (in mm). It is equipped with PID control algorithm and have feedback in the form of position, temperature, load, input voltage, etc. Those feedback will make MX-28T being able to be designed in such a way in order to provide good movement performance.

The lower part of robot consist of hip, upper leg, lower leg, and sole which are made using aluminum with a plate thickness of 2 mm. This aluminum is processed and formed using laser cutting machines, welding machines, and bending machines so that it becomes robot parts. These robot parts are then assembled into one using screw and nut. The servos are then attached to these parts so that they become joints on the robot. In the end, process of combining aluminum parts and servos will give robot shape shown in Fig. 1.

TABLE 1. SPESIFICATION OF MX-28T [5]

Item	Specifications
MCU	ST CORTEX-M3 (STM32F103C8 @ 72 [Mhz], 32Bit)
Position Sensor	Contactless absolute encoder (12Bit, 360 [°])
Motor	Coreless (Maxon)
Baud Rate	8,000 [bps] ~ 4.5 [Mbps]
Control Algorithm	PID control
Resolution	4096 [pulse/rev]
Backlash	20 [arcmin] (0.33 [°])
Operating Mode	Joint Mode (0 ~ 360 [°]) Wheel Mode (Endless Turn)
Weight	MX-28AR/AT : 77 [g], MX-28R/T : 72 [g]
Dimensions (W x H x D)	35.6 x 50.6 x 35.5 [mm]
Gear Ratio	193 : 1
Stall Torque	2.3 [Nm] @ 11.1 [V], 1.3 [A] 2.5 [Nm] @ 12 [V], 1.4 [A] 3.1 [Nm] @ 14.8 [V], 1.7 [A]
No Load Speed	50 [rev/min] @ 11.1 [V] 55 [rev/min] @ 12 [V] 67 [rev/min] @ 14.8 [V]
Radial Load	1 30 [N] (10 [mm] away from the horn)
Axial Load	1 15 [N]
Operating Temperature	-5 ~ +80 [°C]
Input Voltage	10.0 ~ 14.8 [V] (Recommended : 12.0 [V])
Command Signal	Digital Packet
Protocol Type	TTL Half Duplex Asynchronous Serial Communication with 8bit, 1stop, No Parity RS485 Asynchronous Serial Communication with 8bit, 1stop, No Parity
Physcial Connection	RS485 / TTL Multidrop Bus
ID	254 ID (0 ~ 253)
Feedback	Position, Temperature, Load, Input Voltage, etc
Material	Full Metal Gear Engineering Plastic (Front, Middle, Back), Metal(Front)
Standby Current	100 [mA]

III. SOFTWARE STRUCTURE

Like the neuromusculoskeletal system in the human body, robot is also equipped with a nervous system that is represented by electronic circuits and programs. Electronic circuits and programs are designed to provide signals to servo motors in each lower part of the robot to move as desired. This humanoid dancer robot designed using a mini PC as main processor that gives a signal to CM-730 to drive certain servo. CM-730 itself is a controller equipped with a3-axis gyroscope and a 3-axis accelerometer, and has ports to control up to 13 servos. Sofware structure is explained as how the system work which presented in control block diagram and how the program in lower part robot is designed.

A. Control Block Diagram for Lower Part of Robot

In the lower part of robot, control block diagram is shown in Fig. 4. The block diagram of this robot is similar to [2], where there are a main controller and a sub controller. In this humanoid dancer robot, the main controller is the Fit-PC2i Intel Atom Z350 1.6GHz and the sub controller is CM-730. The main controller communicates with the CM-730 sub controller. The subcontroller works as a gateway to actuators.

The subcontroller communicates with servo motor MX-28T using dynamixel protocol. Dynamixel protocol by default is type 1.0 which is TTL Half Duplex Asynchronous Serial Communication with 8bit, 1stop, No Parity. The use of CM-730 as a subcontroller makes it easy for user to program the movement of each servo. User do not need to position each servo at a certain angle. User simply enter the ID of servo to be controlled, the value of change in angle, angular velocity, and even the desired torque through CM-730. The CM-730 can be programmed by using a main controller which is Linux-based mini PC. Mini PC is run to send a command to CM-730 through a more user friendly program. By this program, the process of arranging servos on each robot joints to do dance movements can be done easily.

B. Program for Lower Part Robot

Lower parts robot namely upper leg and lower leg are programmed to perform Remo dance movements. These movement are in the form of walking, dance movements such as *Tanjak Tancep* and *Sabetan*, and other movements. *Tanjak Tancep* is a movement with legs forming a stance position, then one leg (left or right) makes a moving motion that is like jerking feet to the floor for several times. While *Sabetan* is a movement where the robot's lower leg is lifted as high as possible to the knee joint and performs a *sabet* motion (wagging the scarf).

The walking movement consists of walking steps, namely stance phase and swing phase. This movement is quite common in walking robot but programmer needs to pay attention to balancing process when composing this movement. When do walking, the upper part of robot eventually need to make a certain angle in order to keep the balance. For example the upper part programmed to be leaned forward when walking. *Tanjak Tancep* movement is one of the special movement in remo dance, this movement is performed by open widely both feet. When this movement performed, the servo on hip joint works. After that, the servo on ankle joint do *gejug* (servo on ankle joint moved for a certain period).

Movement in Remo dance that requires more analysis is *Sabetan* movement. According to the definition of *Sabetan* movement described earlier, this movement is a movement where robot do foot lifting while maintaining balance. When lifting a leg, there is a transfer of center of gravity which must be maintained so that the robot does not fall. The servo motor MX-28T on each joint is positioned at a certain angle so that the process of lifting the foot reaches its maximum point without falling. This process is carried out through a step by step motion test which has been programmed directly by positioning the servo on hip and knee joint. Through several trials, the maximum value of the angle can be found and then programmed to servo motors of hip and knee joints.

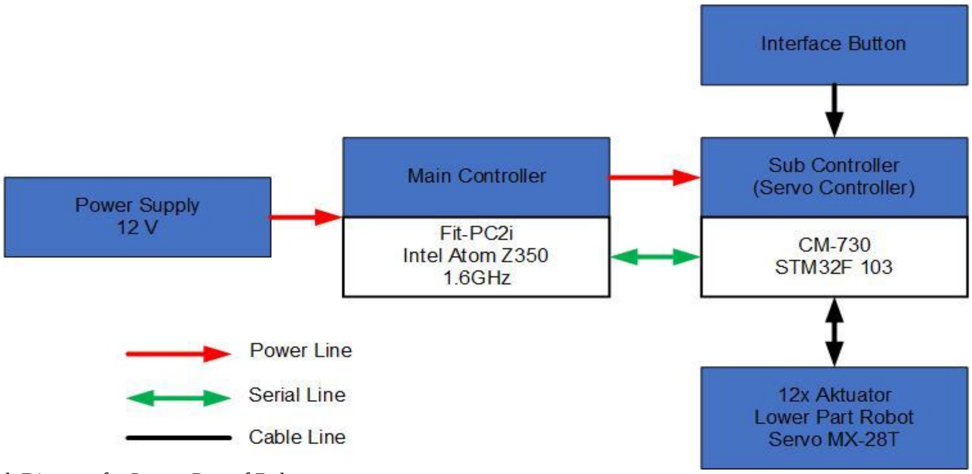

Fig. 4. Control Block Diagram for Lower Part of Robot

IV. Experiment and Results

This study aimed to test the ability of designed humanoid dancer robots to do foot lifing. In general, testing starts with how robot do walking. The robot must be able to balanced its body and able to carry out walking movements step namely stance and swing phase. The walking movement step starts from lifting the foot, swinging forward, putting the foot down, maintaining balance and then repeat those four processes with other side of foot. Fig. 5 shows the results of walking movement step testing of designed humanoid dancer robot. From the experiment, robots capable to walk well.

The next experiment is flexibility test. Because humanoid robot has many joints that are represented by a servo motors, humanoid robot also should be as flexible as human. In hip joint, human have to do continuous training so that flexibility of the hip can be realized. This test is carried out to see how far the robot can widen their feet, or in other word to test how *Tanjak Tancep* movement is done by the robot lower part. Fig. 6b shows how far the robot's stance (widen its feet) can be done.

After robot can do *Tanjak Tancep* movement, the next experiment was the testing of foot lifting movements. In this test, all servo motors on the lower part of dancer robot are programmed to be able to produce highest distance of foot from the floor without falling. Fig. 6c and 6d show the testing process. The lifted foot used in this test is right foot. When do right foot lifting, the left foot becomes a support so that the left foot servo is in charge of balancing the robot’s body. The right foot becomes the side which is lifted so that the ankle, knee, and hip joint of right leg are positioned to produce the highest distance from the floor. This test will show how well the design in this robot when perfomed the dance movement. The choice of servo type, mechanical design, and the program used to drive servo motor determine how high the robot's feet can be lifted. This height show how good *Sabetan* movement from this Remo dance can be performed properly.

(a) (b) (c) (d)

Fig. 5. Test of Walking Movement. (a) Preparation of right leg swing phase. (b) Swing phase with right leg. (c) Swing phase with left leg. (d) Standing phase.

(a) (c) (d)

(b)

Fig. 6. Flexibiltiy and foot lifting test. (a) Stand condition. (b) Stance phase to test how far leg widen. (c) Front view of foot lifting test. (d). Side view of foot lifting test

The results of this study are shown in Table 2 and Table 3. Table 2 shows the result of *Tanjak Tancep* movement experiment where legs can extend up to 8.5 cm when performing *Tanjak Tancak* movement. This distance are quite far and show the degree of robot flexiblity. If the servo motors off, the leg could widen more where the distance between legs is 34 cm (maximum).

Table 3 shows the result of testing the *Sabetan* movement (foot lifting). From Table 3, it can be seen that the humanoid dancer robot is able to do foot lifting properly. The height of lifted foot even up to 10% of the leg length. When trying higher than that height, robot unable to maintaining balance and fall. The highest foot lifting movement from this designed robot is 6.5 cm from the floor. One of the reason this design has such performance is because the robot body uses a mini PC as the main controller. By using a mini PC that is placed in the abdomen of dancer robot, the abdomen become heavier than the other parts. Because of this, when

TABLE 2. RESULT OF TANJAK TANCEP MOVEMENT EXPERIMENT

Movement	**Feet Widen (cm)**
Tanjak Tancep	8.5
Maximum	34

TABLE 3. RESULT OF FOOT LIFTING MOVEMENT EXPERIMENT

Foot Distance from Floor (cm)	**Result**
1	succeed
2	succeed
2.5	succeed
3	succeed
3.5	succeed
4	succeed
4.5	succeed
5	succeed
5.5	succeed
6	succeed
6.5	succeed
7	failed

foot lifting movement make robot reaches a certain tilt condition, the robot's center of mass shifts. This shift can make humanoid dancer robot unable to maintain its balance and fall.

V. CONCLUSION

From this study it can be concluded that mechanical and electrical design of humanoid dancer robot can function properly. In general, designed robot capable to perfom common functions of a humanoid robot. Designed robot able to do walking movement and able to do foot lifting according to the design of to be performed dance movement. But when do walking movement, the selection of material for soles must be considered in order that robot remains balanced when walking and does not fall easily. The material can be a rubber type or other similar type that is not easy to slip or too sticky so that the walking process of a humanoid robot can be performed well.

Robot with a length design of upper leg is 93.62 mm and lower leg is 93.00 mm can do stance movement up to 8.5 cm wide and able to do foot lifting with 6.5 cm high from the floor without falling. Thus, the designed robot are able to carry out basic movements of Remo dance. In the next study, it is expected that the control system of the robot will become more automatic so that it can shift the CoG. By shifting the CoG automatically, the robot will prevent the fall by positioning the servo motors at each robot joints.

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