DYNAMIC MODEL AND CONTROL FOR BIPED ROBOT

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1. INTRODUCTION

One challenge in motion control of bipedal walking is the high nonlinearities of dynamics and the inaccuracy of the parameters in biped models. The goal of the control law in this paper is to accommodate signal control so that the positions of each joint must track down the trajectory designed in the previous Motion planning section. This control law computes necessary torques to accommodate dynamics model so that the actual angles at each joints track the angles of the designed trajectory with a minimum error. The problem can be described as follow:

After obtaining angles θ from the dynamics model of the biped robot in absolute co-ordinate system:

$$M(q)\ddot{q} + V(q,\dot{q}) + G(q) = t \quad (1)$$

We convert them into movements in generalized co-ordinates at each joint; q is relative angle between links.

$$M(q)\ddot{q} + V(q,\dot{q}) + G(q) = t \quad (2)$$

At this moment, we have a state vector $\begin{bmatrix} q \\ \dot{q} \end{bmatrix}$ which expresses the state of an object. We also express referential vector of input signal $\begin{bmatrix} r \\ \dot{r} \end{bmatrix}$, this vector was defined from the motion planning section. We build the closed- loop control system of the object to generate the vector of tracking error $e(t)$ between the input signal and feed-back signal. The goal of the control law is to provide a signal t so that the signal of tracking error is going on for Zero, $e(t) \to 0$

Another challenge is the control of biped during Double Phase. About the general overview, we see that motion of a biped robot with Double phase has the advantage that it is more convenient to realize the stable motion and can fulfil more tasks than that only walking with Single phase. However it becomes more difficult when controlling a biped Double phase than that of the Single phase. Motion of a biped robot during Double phase can be described as the motion of dynamic system under holonomic constraints. However, in the case of using natural coordinate system, if we do not well in tracking down designed motion trajectory during the control, the constraints are difficult to be satisfied. Generally, approaches require to have an accurate estimation of dynamics model or to simplify the model. In simplification of the model, we can ignore some aspects, regardless of dynamics loading capacity. The interaction of parts and pre - unknown noise signals. As we know, it is difficult to obtain an accurate estimation of physical parameter of complicated models with the interaction of parts of a robot and under the force of gravity. Besides, the effect of noise loading capacity by friction on the system cannot be ignored. In this paper, the writer uses a robust damping control technique so-called RDC which was mentioned in reference book [2]. A RDC control model was built to apply to a biped robot so that it is not necessary to have estimated parameters. This control provides error compensative control signal based on the pre- designed motion trajectory and the data of measurement of velocity and the position of each joint. In addition, the parameters of this control model are built so that they can be adjusted easily.

2. BUILDING RDC CONTROL MODEL

2.1 Dynamic Equations and Hypotheses

We see that, in both of single phase and double phase, dynamics equations can be described as the following equation:

$$M\ddot{q} + C\ddot{q}_r + F + t_d = t_R \quad (3)$$

In equation [3], F is a vector which describes the effect of gravity and friction force, t_d is respective torque which describes the effect of noise on Biped robot. In order to be convenient for solving the problem, we give 2 hypotheses as follow:

Hypothesis 1: (noise signal effects on covered Biped): Noise signal changes respect with time t_d in the dynamics equation of covered manipulator. It is described by a mathematical expression that is $\sup\|t_d\| \le t_N$; here t_N is a positive constant.

Hypothesis 2: (effecting of gravity and friction force is also covered):

The vector $F\left(q, \dot{q}\right)$ is covered by $\left\|F_2\left(q, \dot{q}\right)\right\| \le x_2 + x_3\left\|\dot{q}\right\|$, here, x_2 and x_3 are positive constants.

With these hypothesises we can build RDC control method. Note that the dynamics equations was converted to use them in the generalized co-ordinates at each joint, q is relative angle between links. The control calculates and provides torque t_r to ensure the stability and accurate movements for the joints of the robot.

2.2 Building RDC Control

Choosing and defining Lyapunov function for the Biped Robot as follows:

Review the equation (3); we define tracking error and derivation of the tracking error as follows:

$$e = q_{rd} - q_r \qquad \dot{e} = \dot{q}_{rd} - \dot{q}_r \quad (4)$$

We also define more extra parameters from tracking error and derivation of the tracking error.

$$r = \dot{e} + ke \quad \text{With k>0} \quad (5)$$

We rewrite the dynamics equation (3) with the extra parameter r as follows:

$$M\dot{r} = -t_r + (Mk - C)(r - ke) + F + t_d = t_r \quad (6)$$

Here, F is effect of the friction and gravity force on the model. To build the torque control for the model, the writer chooses Lyapunov function as follows:

$$V = \frac{1}{2} r^T M r \quad (7)$$

We also note that matrix M is positive define because M itself is inertial matrix of masses of the model (the elements of the matrix were made by inertial torque around different shafts of the masses). In addition, because of the limited angles of the robot; we have more features of Matrix M.

$$M_{\min} I_p \le M(q) \le M_{\max} I_p \quad (8)$$

M_{min} and M_{max} are positive constants depending on features of mass of the model; I_p is the unit matrix p× p.

From the equation (8), after having the result of derivation both sides of equation (8), we can see the equation below :

$$\dot{V} = r^T \{ -t_r + Mkr + (C - Mk)ke + F + t_d \} \quad (9)$$

We can also rewrite (9) as follows:

$$\dot{V} = r^T \{ -t_r + Mkr + (C - Mk)ke + F \} + r^T t_{d_2} \quad (10)$$

From this result, we have a transformation process as follows:

$$r^T \{ -t_r + Mkr + (C - Mk)ke + F \} \le -r^T t_r$$
$$+ \|r\| \left(M \left\| \ddot{q} + k(r - ke) \right\| + C \left\| \dot{q}_{rd} + ke \right\| \left\| \dot{q} \right\| + x_2 + x_3 \left\| \dot{q} \right\| + t_N \right) = r^T t + \|r\| \Delta^T j \quad (11)$$

Vectors Δ and j were defined as follows:

$$\Delta^T = (M, C, x_3, x_2 + t_N) \quad j^T = \left(\|q_{rd} + k(r - ke)\|, \left\| \dot{q}_{rd} + ke \right\| \left\| \dot{q} \right\|, \left\| \dot{q} \right\|, 1 \right) \quad (12)$$

According to the transformation above of choosing Lyapunov function of control law, the remaining work is to build a control which provides a torque t_N so that the system has robust-stable status. We can choose the torque control law as follows:

$$t_r = k_{pr} + k_2 r \| j \|^2 \quad (13)$$

Here $k_{pr} \ge 0$, $k_2 \ge 0$ are constant factors of gain of the controller, the vector j was defined at (12) We can have conditions in order to prove the stability of the control. Substituting (13) into (10) we have :

$$\dot{V} \le k_{pr} r^T r - k_2 r^T r \| j \|^2 + \|r\| \Delta j$$

$$\le -k_2\|r\|^2\|j\|+\|r\|\|\Delta\|\|j\|$$
$$\le -k_2\left(\|r\|\|j\|-\frac{\|\Delta\|}{2k_2}\right)^2+\frac{\|\Delta\|^2}{2k_2}$$
$$\le -k_2(\|r\|\|j\|)^2+\|r\|\|j\|\|\Delta\|-\frac{\|\Delta\|}{2k_2}$$
$$\le -k_2\|r\|\|j\|^2+\|r\|\|j\|\|\Delta\|-\frac{\|\Delta\|}{4k_2}+\frac{\|\Delta\|^2}{2k_2}$$
$$\le -k_2\left(\|r\|\|j\|\right)^2+\|r\|\|j\|\|\Delta\|+\frac{\|\Delta\|^2}{4k_2}$$
$$\le -k_2\left[\left(\|r\|\|j\|\right)^2-\frac{\|r\|\|j\|\|\Delta\|}{k_2}-\frac{\|\Delta\|^2}{4k_2}\right]$$

$$\le -k_2\left[-\left(\|r\|\|j\|\right)^2-\frac{\|r\|\|j\|\|\Delta\|}{k_2}-\frac{\|\Delta\|^2}{4k_2}+2(\|r\|\|j\|)^2\right]$$
$$\le -k_2\left[-\left(\|r\|\|j\|+\frac{\|\Delta\|}{2k}\right)^2+2\left(\|r\|\|j\|\right)^2\right]$$
$$\le -k_2\left[2\left(\|r\|\|j\|\right)^2-\left(\|r\|\|j\|+\frac{\|\Delta\|}{2k_2}\right)^2\right]$$
$$\le -k_2\left[\left(\sqrt{2}-1\right)\|r\|\|j\|-\frac{\|\Delta\|}{2k_2}\right]\left[\left(\sqrt{2}+1\right)\|r\|\|j\|+\frac{\|\Delta\|}{2k_2}\right] \quad (14)$$

Let see (14), using (8) and (12) we have $\|\Delta\|$ as a limited value. Therefore we can apply Lyapunov and LaSalle [3] theory to solve the problem. If we chose a suitable value k2 $\dot{V}\le 0,\forall r$ and $V\to\infty$ when $\|x\|\to 0$. And we also have a largest set of invariable which is coordinate origin $e=0,\dot{e}=0$, therefore the phase trajectory trend to the coordinate origin asymptotically and globally when $t\to\infty$. In other words, tracking errors trend to the coordinate origin when $t\to\infty$. Based on this feature we apply it to the Biped Robot model.

2.3 Building the control during Single phase

2.3.1 Building relative coordinate system qi at joints

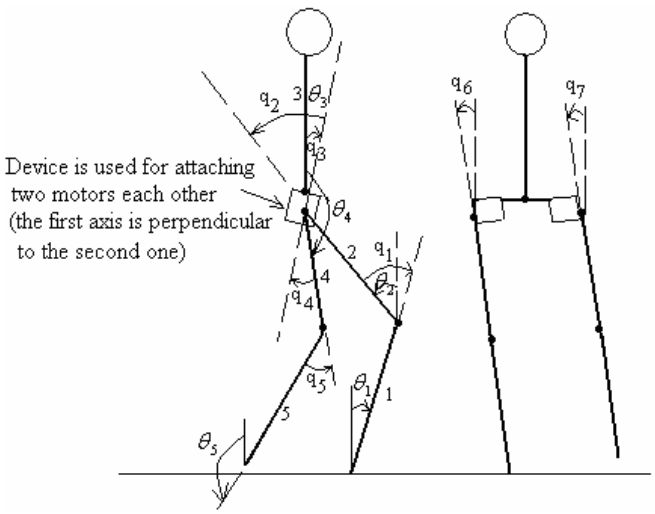

Fig1. The relative coordinates q_i

We studied the absolute angles q at joints in chapter 3 to synthesis the motion gait of the biped robot. The nature of the biped control problem in this case is to control motors which places at joints so that these joint rotate following a desired angle q. Combining the controls of these motors we get the motion gait of the biped robot. So we convert absolute coordinates q to relative coordinates q, q is angle formed between directions of two links. This enables it is easier to control biped robot.

We build the relative coordinate qi between joints as figure 1, qi is relative angle between joint i+1 and i

Following the above method, we find out the relation between q_i and q_i

$$\begin{cases} q_1 = q_1 - q_2 \\ q_1 = q_1 - q_2 \\ q_3 = q_3 \\ q_4 = 180^0 - q_4 + q_3 \\ q_5 = q_4 - q_5 - 360 \\ q_6 = -q_r \\ q_7 = -q_l \end{cases} \quad (14)$$

$$\begin{cases} q_1 = q_1 + q_2 + q_3 \\ q_2 = q_2 + q_3 \\ q_3 = q_3 \\ q_4 = q_3 - q_4 + 180 \\ q_5 = q_3 - q_4 - q_5 - 180 \\ q_r = -q_6 \\ q_l = -q_7 \end{cases} \quad (15)$$

2.3.2 Some graphical results

With the coordinates qi calculated (14) we have some results as follow ($k_1 = 5, k_2 = 130, k_{pr} = 3.4$)

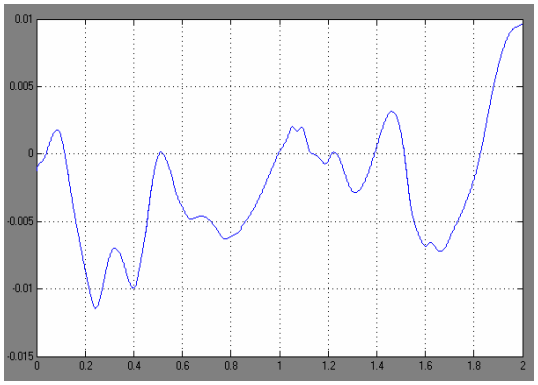

Fig2. The error of the 1st joint (degree/s)

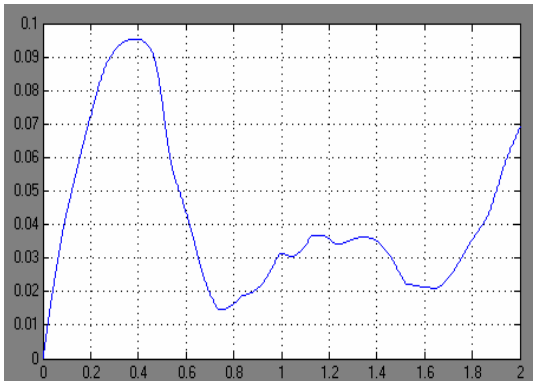

Fig3. The error of the 2nd joint (degree/s)

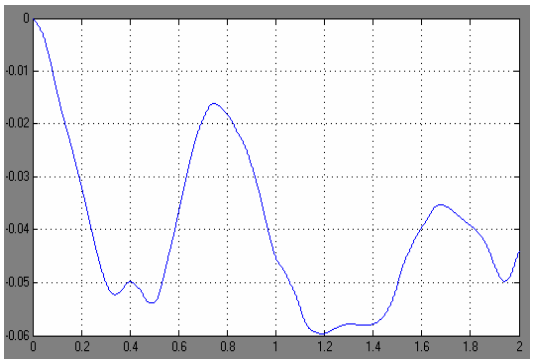

Fig 4. The error of the 3th joint (degree/s)

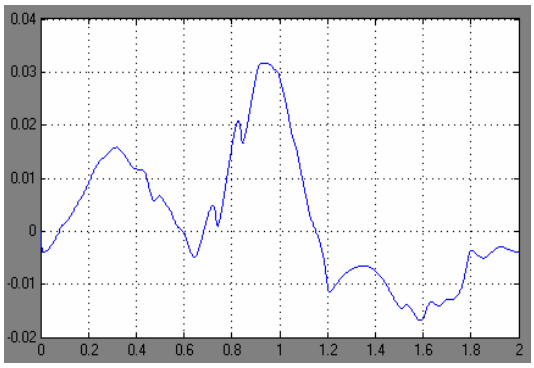

Fig 5. The error of the 4th joint (degree/s)

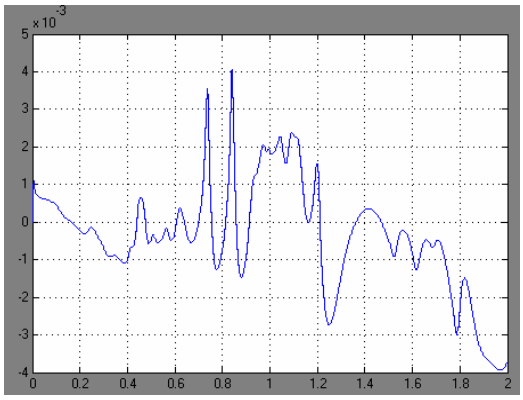

Fig 6. The error of the 5th joint (degree/s)

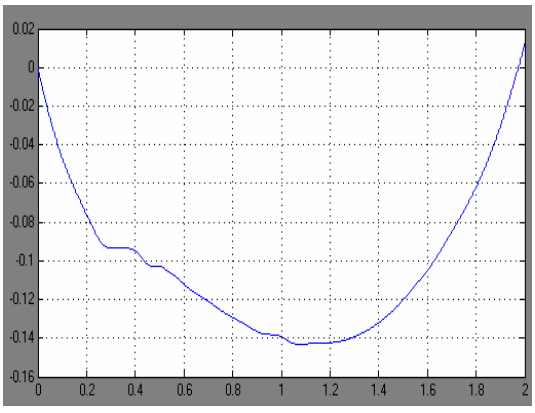

Fig 7. The error of the 6th joint (degree/s)

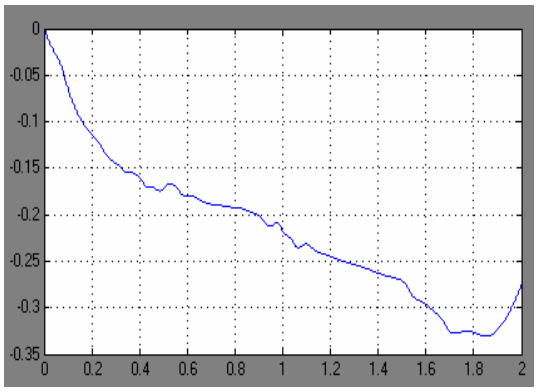

Fig 8. The error of the 7th joint (degree/s)

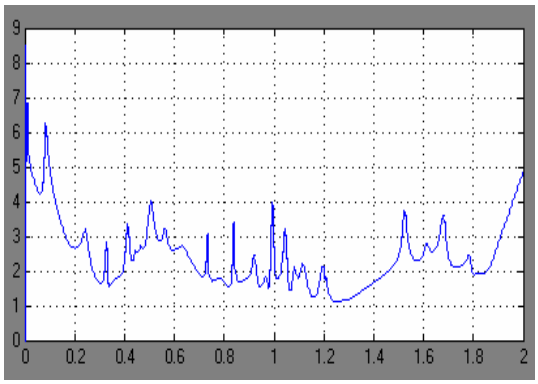

Fig 9. The demonstration of $\|j_2\|$

3.CONCLUSION

According to the demonstration in 2.2 section and the checked together the dynamic mode, we get the quite good results of the error of each joint. However, it is necessary to combine some more flexible control methods in the next research such as Neuron network and fuzzy algorithm or other adaptive control models. The main reason to develop these control model for the biped robot is that we simplified the problem, regardless of the effect of impact in contact with the ground when the swing leg step forward in this research, in this case we have to consider more the effect of the impulsive force from the ground when the swing leg starts contacting with the ground. In addition, we should use some sensor devices (camera, loadcell) in the next research so that we can build a humanoid robot with an artificial intelligence. So, it is necessary to bring out flexible control model for the next research.

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