# Stair Climbing Task of Humanoid Robot by Phase Composition and Phase Sequence

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***Abstract* – A goal of this work is to propose an algorithm that generates extended Task of humanoid robot to endure a large variety of performance. In this approach, it is likely that using "Task" library, which is constructed by previous Task is effective method to generate extended Task of humanoid robot according to environment change. It could be realized by method adopting "Phase" transition, defined as "Phase Sequence". Also, it would realize to plan a Task that required for humanoid robot in environment change using re-composition and re-using of constructed Phase without motion experiments and planning from scratch. We have been applied a previous Phase of step ascending and walking Task based on strategy of actual motion for humanoid robot Task, stair climbing. In the connection of two Tasks, we adopted third-order bezier curve, which can be transformed desired trajectory using modifying its control parameters. Furthermore, appropriate Task transition operation for Phase Sequence method was applied by re-composition of Phases as variation of designated environments. As a result, extended Task, stair climbing, was realized by recomposing of two fundamental Tasks. In conclusion, a proposed Task generation algorithm was verified.**

***Keywords* – Humanoid robot, Stair climbing, Motion composition, Phase Sequence.**

## I. Introduction

Motion generation algorithm of humanoid robot is important theme. However, it is difficult to achieve desired motions, which is defined "Task", on humanoid robot performance due to complicated link structure of body. Although human body consists of multiple joint, he or she can execute numerous behaviors in various space conditions since it is capable of managing to capricious change by acquired empirical skill, which he learned for a long time. Normal human motion consists has many divided motion components. As using strategy above mentioned, if we could take advantage of this aspect for generating Task of humanoid robot, it would be an effective method because a Task can be decomposed by fundamental Task.

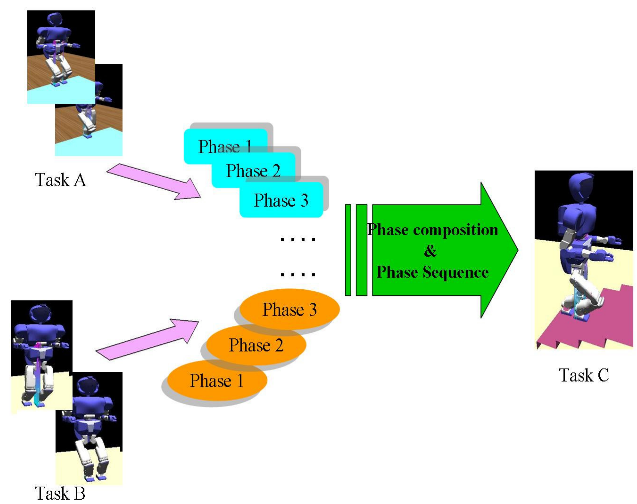



Fig.1.The overview of method for extended Task generation, such as stair climbing by Phase recomposition and Phase Sequence.

Some researches of humanoid robotics that generate motion have been explored [1-3]. These works mainly has been described motion planning of restricted situation of circumstance. However, it should be considered the algorithms that how can humanoid robot in human space, demanded for extended Task according to variable environments, realize generation.

To advantage of our approach is distinguished from above research. We develop the method that adapt to changing desired environments for human's behavior. A more and broadly useful approach would be exploited for appropriate Task generation of humanoid robot without actual motion experiments and Task planning according to variation environments from scratch.

This derived from concept that some Task is categorized into fundamental Tasks [4]. For example, stair climbing Task is composed by two Tasks, such as walking and ascending step as shown in figure 1. If the humanoid robot and real environmental conditions are the same as that of pre-planned motion, then it is can be taught by human behavior as following pattern. As for many humanoid robot has to modify a pre-planned program about motion generation according to changeable environments.

So, we propose the extended Task generation method by re-composition and Phase connection, which based on constructed actual capturing and transformed data of fundamental human motions in advance. This study was conducted as follows.

(1) Extended Task for stair climbing would be referred two Tasks, ascending step and walking based on transformed data from capturing system previously.
(2) These Tasks classified into smaller one or the other motion unit called "Phase".
(3) We define motion composition operation as "Phase Sequence", which was transformed into a humanoid robot using three-order bezier curve by transferring of designated position of Task in environments.
(4) To generate extended Task, Phase can be recomposed by parameter modification of bezier curve, and connected by Phase Sequence.

In our study, we show that validity of extended Task generation, such as stair climbing, using recomposition of preparing Task in library and Phase Sequence.

## II. MOTION ANALYSIS

The humanoid robot consists of rigid links that are connected to several revolute joints, which permit relative motion of neighboring link structure. Since, the type of performance by the form of contact with the ground, a transition movement in humanoid robot would be restricted within joint angle and kinematics configuration. However, it is difficult to define a motion patterns. Toward this problem, the motion to determine the humanoid robot motion based on analysis of human motion was considered. Such a technique also has the advantage to generating Task that adapt to environments or condition for a humanoid robot. The development method is described by the posture of actual humans.

### A. *Phase and Phase Sequence*

A behavior of human indicates that there are as almost endless variety of means. In this paper, when the fundamental motion characteristics of all theses kinds are considered as shown Figure2. Motions can be classified as essentially one or the other, or a combination of individuals. So the step in ours analysis, we classified into smaller fundamental motion unit "Phase" which contain the information that investigated turning point and desired position by trajectory planning based on extracted data from human.

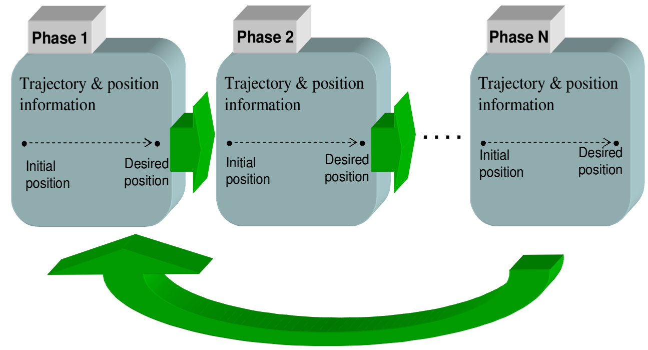



Fig.2.Exemple of performable Task by Phase and Phase Sequence

The classified Phases were linked to each other with order for generating the objective Task. We define what this is "Phase Sequence" method for application, which is were made since then [4,5]. A motion composed of related Phase was define as "Task".

### B. *One step ascending Task*

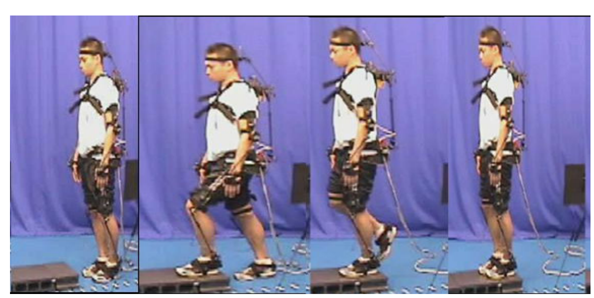
Figure 3 shows the snapshot of actual human motion and step ascending Task of humanoid robot, which is consists of fundamental four Phases individually. Also, this trajectory result of Task is described as figure 4.

-Phase 1 can be defined the initial period of ascending Task for humanoid robot from a stationary posture to the start ② of the COG(Center of Gravity).

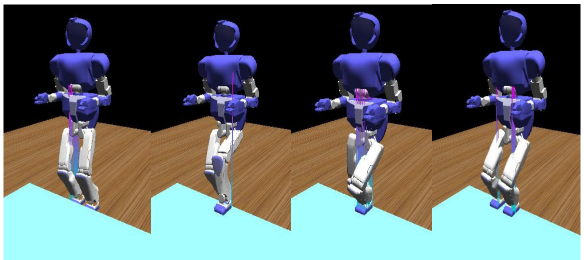
-Phase 2 describe left leg swinging and it move from ground to the above footpace according to desired trajectory in figure 4(d), which is determined by extracted data from actual human motion.

-Phase 3 is period of the COG movements and contact with on stair. The body of humanoid robot is bent forward to area ③ ascending to COG trajectory in order to maintain stable posture ④. It is state of ready shift the next Phase.

-Phase 4 is the final Phase of Task. This Task can be considered the period that is starting of the right leg swing motion occur in order to ascend according to desired trajectories of right leg in figure 4(d), similar to Phase 2. In this Phase, COG return to initial posture ⑤ ⑥ and step ascending Task is stop.

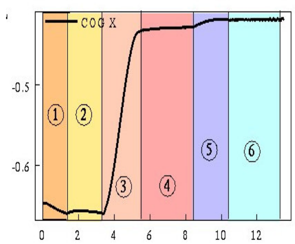


(a) Human step ascending



(b) The Task of step ascending for humanoid robot

Fig.3 The snapshot of human and humanoid robot step ascending Task

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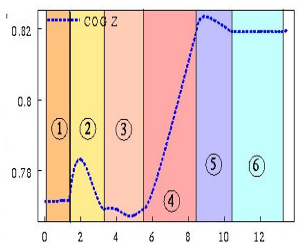


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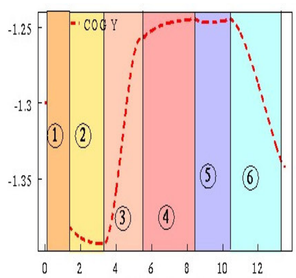


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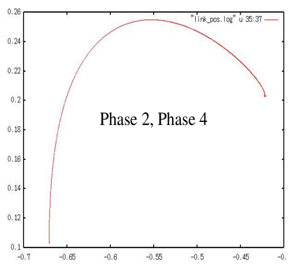



(d)

Fig.4 The prepared trajectory of step ascending Task for humanoid robot

### C. *Walking Task*

Figure 5 shows the snapshot of actual human motion and humanoid robot walking Task, which is compose of iterative fundamental four Phases preparing trajectory results shown as figure 6.

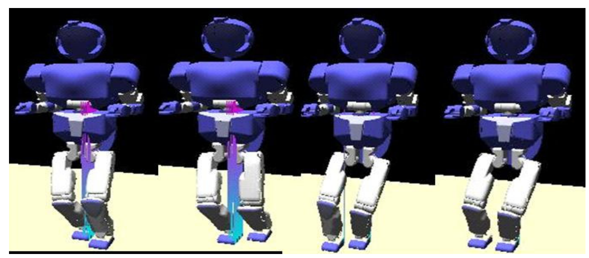
-Phase 1 describes the period of beginning from a stationary position on double foot for stability to the starting of the swing leg motion. Because the lower-limb starts to move forward, a new Phase in which the lower-limb is in front of the forwarding-moving COG.

-Phase 2 is the period of motion extending from swing of leg to supporting the upper body with both legs. The left lower-limb is in contact with the ground while transferring forward of COG, and the left leg is propelled forward to the desired lift-off position. Moreover, we can determine the length of stride according to parameter adjusting of third-order bezier curve.

-Phase 3 is definition period that stance occurs between Phase 2, and the starting of the left lower-limb swing, similar to Phase 1.

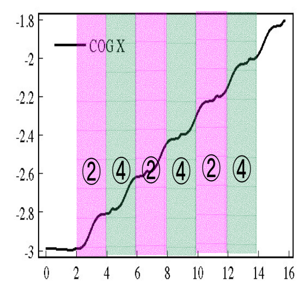
-Phase 4 is final Phase in the walking Task. The COG transfer moves forward from supporting leg to single leg, which examined as Phase 2. The end of this Phase is the returning position for Phase 1.

(a) Human walking



(b) The Task of walking for humanoid robot

Fig.5 The snapshot of human and humanoid robot walking Task

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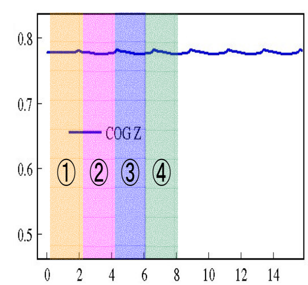


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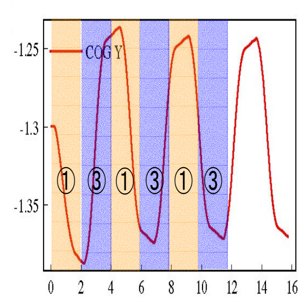


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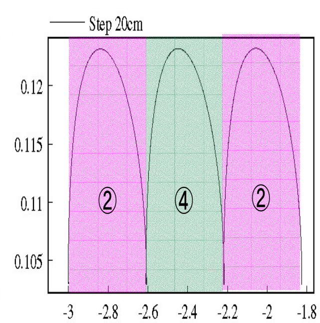


(d)

Fig.6.The prepared trajectory of walking Task for humanoid robot

## III. A METHOD OF TASK GENERATION

The Task definition is associated with the objective motion set of trajectories, which realize work or attain a desired position in environments. It is necessary to consider the capability of an operator to transfer these Tasks into the humanoid robot using real environment variables. In particular, the autonomous Tasks that can be used to achieve work by following human motion patterns must be adaptable to the Phase composition method, and there must be flexibility in the transition between Phases. In order to obtain a Phase Sequence from a set of Phase transitions, a method of planning the desired trajectories using kinematics transformation from motion configuration, bezier curves, and transition recognition is required.

### *A. Trajectory planning for Task*

Many of biped robots are able to perform on condition such as stair, irregular terrains and standing-up. In addition, their lower-limbs have various foot motion patterns that fit within a human's actual ground space. These can be used to avoid obstacles and enhance maneuverability [6-7]. With trajectory planning, the humanoid robot determines a suitable motion of the lower-limbs before actually performing motion by interpolating on-line human motion data during the swing and supporting Phases. If the lower-limb trajectories are designed to attain a specified goal, we can choose a set of constraints of its motion configuration properly.

### *B. Adopting the bezier curve*

Generating Tasks for humanoid robot, it trace the path of a describing desired end effector, which were determined by motion configuration and convert these data into a kinematics transformation after dividing the motion into Phases. In the Task, it is necessary to interpolate from position to next position during the Phase to allow the humanoid robot to transit more skillfully. As interpolation algorithm, we were adopted a third-order bezier curve. This provides suitable smooth shape for end effector for the end effector of the humanoid robot by adjusting the control vectors and anchor parameters.

In general, the parameters for a third-order bezier curve can be expressed as $P = (P_0, P_1, \ldots, P_{n-1}, P_n)$. Here, $P_1$ to $P_{n-1}$ are the control points, while $P_0$ and $P_n$ denote anchor points (one is initial position, $P_{initial}$ and the other is the desired end position, $P_{end}$ in Phase). Therefore, trajectory generation by a third-order bezier curve consists of four points: two control and two position points. The control points are associated with shape of trajectories, which pull the curve vector in a given direction. Also, all of trajectory present with two points without description of via points. The interpolation equation using a third-order bezier curve is

$$X(t) = \sum_{i=0}^{n} B_{n,i}(t) P_i \qquad (\, i = 0, \ldots, n\,) \tag{1}$$

where,

$$B_{n,i}(t) = \frac{n!}{(n-i)!\,i!} t^i (1-t)^{n-i} \tag{2}$$

Eq.(2) describes the Bernstein polynomials, where $t$ is an interval ranging from 0 to 1. The polynomials for a third-order bezier curve are obtained by substituting $n = 3$. Substituting Eq.(2) into Eq.(1), $X(t)$ becomes

$$X(t)=(1-t)^3P_0+3t\,(1-t)^2P_1+3t^2(1-t)\,P_2+t^3P_3 \tag{3}$$

Then, the Eq.(4) can be rewritten as a four-dimensional matrix form:

$$X(t) = [1 \;\; t \;\; t^2 \; t^3\,] \begin{bmatrix} 1 & 0 & 0 & 0 \\ -3 & 3 & 0 & 0 \\ 3 & -6 & 3 & 0 \\ -1 & 3 & -3 & 1 \end{bmatrix} \begin{bmatrix} P_0 \\ P_1 \\ P_2 \\ P_3 \end{bmatrix} \tag{4}$$

Here, the vector $P_0$, $P_1$, $P_2$ and $P_3$ denotes the control and anchor points of a third-order bezier curve.

## IV. APPLICATION OF TASK

In order to generate Task widely, the data that gleaned from human motion strategy needs to re-use. It means previous data of motion by capturing system to generate new Tasks so that certain requirements should be met. Furthermore, an extended Task for application can be re-generated newly through the Phase Sequence and its composition method. This section describes stair climbing Task for humanoid robot using proposed method.

### *A. Task Library*

We captured several subjects different motion sets for Task generation of humanoid robot using capturing system in real space. Although, humanoid robot would be demanded for many kinds of motion planning by programming according to capricious environments, it is hard to determine the Task that does exactly what humanoid robot wants because the acquired data from capturing experiments have limitation of quantity for Task.

To solve this problem, we adopt the Task library that can be constructed by individual preparing Phase. Extended Task, but not used capturing data, can be generated by Phase recomposition and reusing of library. Many number of Task in library as example would show in more variety and flexibility for humanoid robot. As library size grows, the ability to perform about an environment would become more and more selective. This library contains in individual Phase data that consists of transformed trajectories by kinematics constraints from configuration between desired position and orientation with interpolation, and recognition threshold for continuous Phase transition. Also, these Phases in Task library must be stored as named through threshold condition. Therefore, the size of constructed library would be keys to the success of an autonomous objective Task.

*B. The Generation of Extended Task*

To realize autonomous Task for humanoid robot in various environments, generating trajectories of each foot is important [6-7]. The desired lifting-off and step height position should be taught by actual human's fundamental motion, ascending and walking, and it operates for Task generation. Moreover, the trajectories are planned using third-order bezier curve because it can be defined by control points, which make it invariant shape. We need only to transform the control points and the compute the new trajectories.

*1. The planning for stair climbing*

In this section, we present the method of extended Task generation, such as stair climbing , through re-composition and re-using of previous constructed Phase that contain a generated trajectories based on modifying parameter of third-order bezier curve and transition, which are allowed during a contact change though position teaching. As seen in figure 7, stair climbing Task can be planned by classification of one-step ascending and walking, iterative leg transferring and COG, as follows.

-Phase 1: The initial posture of COG moves on left leg in order to stable start. This Phase can be considered as same Phase 1 of ascending step, shown in figure 3.

-Phase 2: This period shows swing of leg to one-step. This leg allow predicting desired trajectory according to bezier curve parameter while planning trajectories to position A. One-step stride and height on stair can be determined in this procedure by referring re-using Phase 2 of ascending Task.

-Phase 3: This Phase expressed as a COG transferring on stair due to stable. Also, the trajectories of right leg would be planned by sequence via half of leg step to position A using Phase 3 in walking before shift to position B.

-Phase 4: In practice, the leg transition of stair climbing Task is done by planned trajectory in Phase 3. This leg is modified from leave the ground to another pose, which is about to arrive on the stair adopting parameter of bezier curve.

-Phase 5: The period, performing right COG, is similar to that of Phase 3. The position C can be considered as next step to arrive.

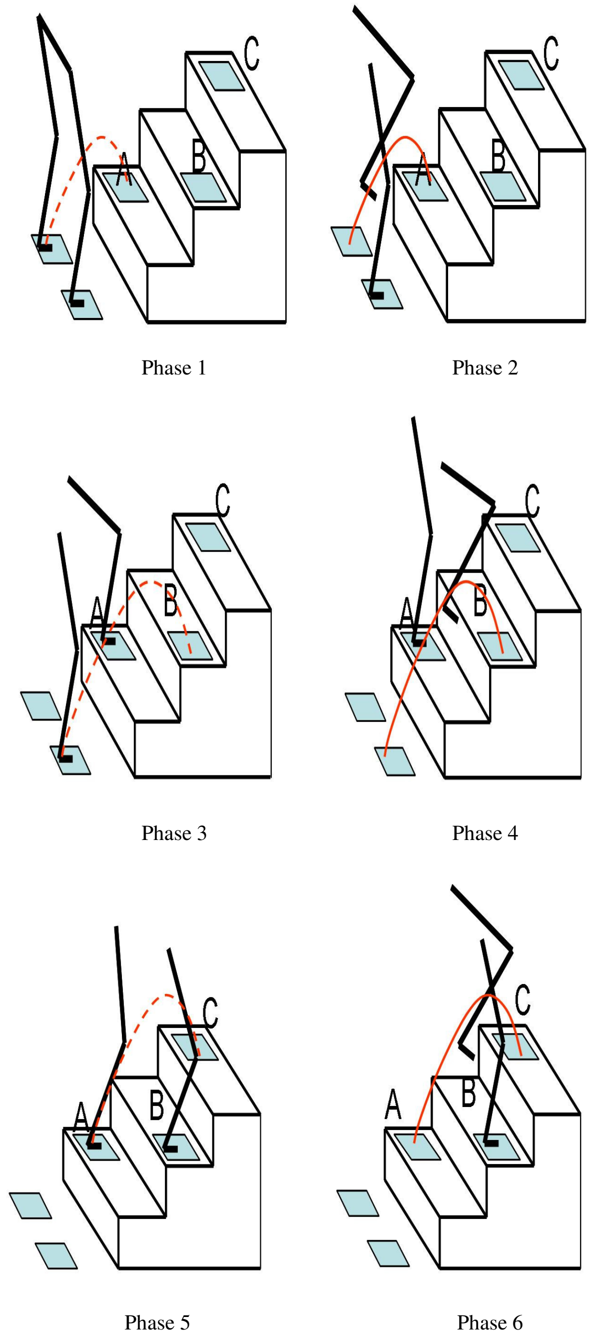


Fig.7 Trajectory planning for stair climbing by Phase division

-Phase 6: This position is final Phase of this Task. Also, left leg transition in this Phase can be referred via half of right leg step to position C re-using Phase 4 in walking. Also, the end of this Phase returns to the starting point for Phase 1.

In summary, stair climbing Task could be classified into six cyclic Phases, which composed by Phase of ascending and walking Task.

## V. SIMULATION RESULTS

The result of simulation for regenerated stair climbing Task based on Phase re-composition and Phase Sequence algorithm. This simulation is tested in 10cm stair height and 25cm stride. Stair climbing Task is generated by referring Task library, which is contains a Phase that consists of motion parameter, position and orientation and threshold value for transition. Also, combining of previous Phase and Phase Sequence from ascending and walking Task was conducted. Its Phase is planned from the arrival and contact on ground position modifying third-order bezier curve. Then, humanoid robot could perform the stair climbing Task as shown in figure 8.

## VI. CONCLUSION

This paper describes a method of extended Task generation for humanoid robot that is capable changing and environment conditions. Our approach is re-composition and re-using of Phase referring the previous data from captured human motion strategy, which is stored in library. The Task is generated by Phase Sequence method that defined as cyclical transition operation of individual Phase. We then modified parameter of third-order bezier curve to allow trajectory planning of Task into humanoid robot in capricious environments. Using this method, generation of extended Task would not require data of actual human motion from capturing system. A simulation result, stair climbing is classified into six Phases, which consists of previous two Tasks, ascending step and normal walking. Adopting Phase Sequence algorithm, this result was verified.

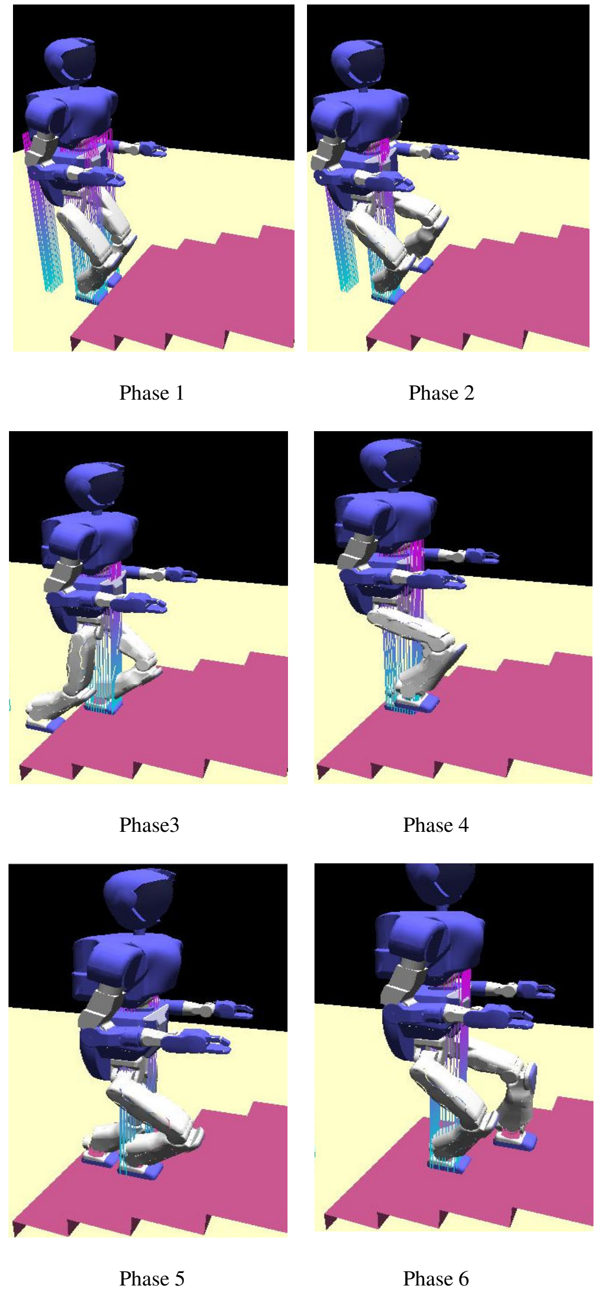


Fig.8 The result of extended Task, stair climbing, according to Phase composition and Phase Sequence method.

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