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Motion Creating System for A Small Biped Entertainment Robot

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Abstract

SDR-4X is a small biped entertainment robot with expanded capabilities for a variety of motion performances. We developed the SDR Motion Creating System and the Whole Body Adaptive Motion Control for SDR. This software system makes it easy to produce creative motion performances that include stable biped walking and dance steps synchronized to music. The Motion Creating system is composed of two parts: the Motion Editor used to edit upper body motion and whole body motion, and the Foot Trajectory Editor used to create stable lower body motion. Once the upper and lower body motions are created, the system allows the motion designer to inspection the whole body motion before applying it to SDR-4X. The process of creating a fast-paced dance performance is introduced as an attractive application of this software system.

1. INTRODUCTION

We have built a small humanoid entertainment robot SDR-4X (Sony Dream Robot, a prototype) which does motion performances that are dynamic and elegant. It achieves these performances using newly developed robot actuators, the Intelligent Servo Actuator (ISA) and a control system called Whole Body Cooperative and Real-time Integrated Adaptive Motion Control [5][6]. To support motion control for SDR-4X, we have developed a software system for creating motion, the SDR Motion Creating System. The SDR Motion Creating System runs on PC computers.

The purpose of this study is to develop an environment for engineers, designers and artists – other than robot specialists – to produce creative motion performances for SDR-4X. The Motion Creating System has a rich user interface especially suited to creating and editing a variety of motions, including stable biped walking and motion performances synchronized to music. Because the Motion Creating System uses the same Gait Pattern Generator and Motion Stabilizer as the SDR-4X robot, the system produces behavior that works correctly on the physical robot.

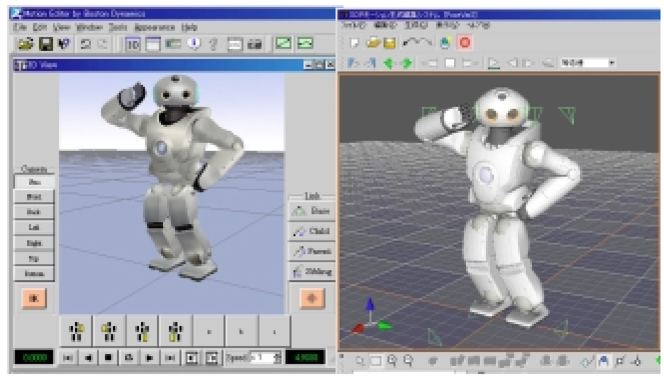
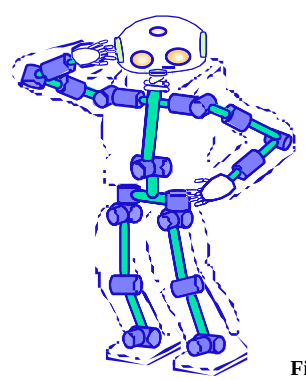


Fig. 1 SDR Motion Creating System

2. Robot Platform

Fig. 1 shows an attractive pose of SDR-4X created by the Motion Creating System. SDR-4X with a 58 cm height and 6.5 kg weight, has 28 DOF in its major joints. Each leg has 6 DOF, the trunk has 2 DOF, each arm has 5 DOF and the neck has 4 DOF. In addition, each hand has five independent fingers (**Fig. 2**). SDR-4X has been designed not to injure humans and also not to be injured itself when it falls over. Safe design includes a joint structure that eliminates pinch points between joints that might trap a user's hands and fingers (**Fig. 3**). The 3D model of SDR-4X used in the Motion Creating System conforms to this safe design.



Height: 580 [mm]
Weight: 6.5 [kg]
Joints: 38DOF
Head: 4DOF
Body: 2DOF
Arms: 5DOF × 2
Legs: 6DOF × 2
Fingers: 5DOF × 2

Fig. 2 Configuration of SDR-4X

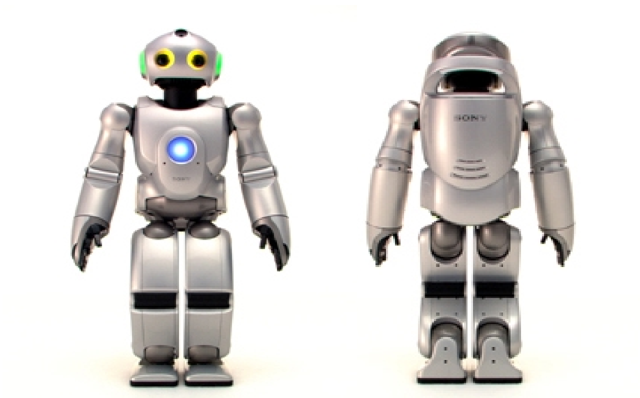


Fig. 3 Standing Pose of SDR-4X

The physical SDR-4X has the embedded and integrated motion control system named 'Real-time Integrated Adaptive Motion Control System' [8], which can generate gait patterns in real-time and stabilize the bipedal motion using the ZMP equations and whole-body motion stabilization. These controls are integrated in one software module called 'Locomotion Engine', which receives gait commands, joint angles of the upper body and the position/orientation of the pelvis from other software modules every control cycle, and generates the reference angles to all the joints. To adapt to unknown uneven terrains and external forces, Locomotion Engine can also take in the sensor values to stabilize the whole body motions. The motion creating system is designed to cooperate closely with this physical control system.

3. Basic Configuration of the Motion Creating System

The Motion Creating System is mainly composed of Motion Editor and Foot Trajectory Editor. The Project Manager is managing software that transfers data and manages the file system (**Fig. 4**). The Foot Trajectory Editor includes two major functions for creating motion data for control of SDR. One function is the Gait Pattern Generator and the other is the Motion Stabilizer. **Fig. 5** shows the motion creating procedure for SDR. Once the motion design concept is fixed we can start to run the Motion Editor through the Project Manager. The Motion Editor has a capability to create and edit the upper body motion and/or the whole body motion by setting poses and transitions between poses. Both forward kinematics and inverse kinematics are used to create and modify attractive poses for SDR. The created motions are replayed and observed in the 3D Window. The gait pattern, the lower body motion for biped walking, is produced by Gait Pattern Generator in the Foot Trajectory Editor. Once the user has created upper body motion data using the Motion Editor and lower body motion data using the Foot Trajectory Editor, the two sets of motion are merged. The merged whole body motions are evaluated by the Motion Stabilizer to see if they are stable and if they can be applied to SDR's motion control.

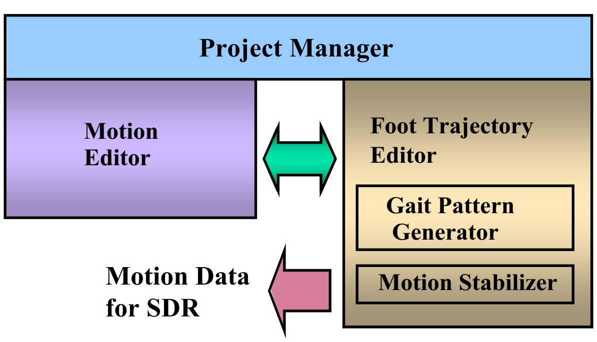


Fig. 4 System Configuration of the Motion Creating System

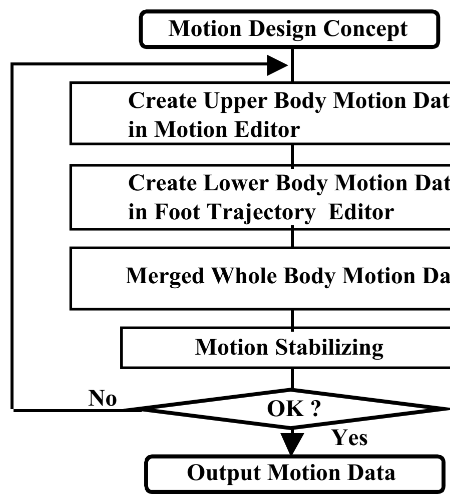


Fig. 5 Motion Creating Procedure

4. Motion Editor

4.1 The Timeline Editing

The Timeline is comprised of some function buttons, some controls for manipulating time and multiple tracks. The multiple tracks include a number of Motion Tracks, a Joint Limit Error Track and an Audio Track. Motions for different parts of the body can be organized by using separate Motion Tracks. Each track is associated with a different group of body joints such as neck joints, right arm joints, left arm joints, and so on. If more than one track specifies the same joint, the track on top has priority. The 3D window displays the prioritized data from all the tracks (**Fig. 6**).

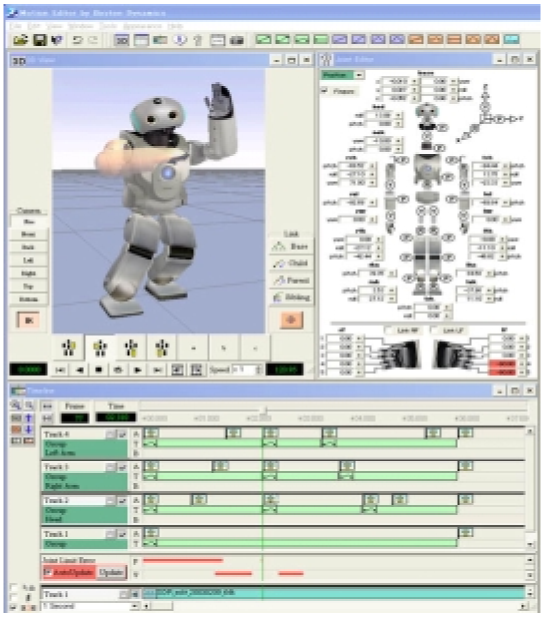


Fig. 6 Motion Editor

4.2 Poses and Interpolations

One way of editing with the motion editor is to create poses, then interpolate across poses. A large variety of motions can be easily created by setting poses and interpolating them on each track. This approach is simple to use, even when it produces complicated joint angle trajectories. The Motion Editor has several interpolation functions, such as linear, polynomial, and cubic spline. Each smoothly connects distributed poses together into one continuous motion. Poses include all of SDR's joints, but only the joint angles enabled on the motion track influence the resulting motions.

4.3 Angle Limit and Angular Velocity Limit

The complicated joint angle trajectories created on the Timeline may sometime exceed joint angle limits and joint angle velocity limits of SDR. It is important for the motion designer to have a means of detection such limit violations so they can fix them. The Motion Editor's Angle Limit check and the Angular Velocity Limit check provide visual feedback at all points along the timeline where a violation exists. The limit values of all joints are set in a Limit Setting file.

4.4 Motion Blend

The motion designer sometime wants to create a chain of motions combined smoothly from one motion at one time to another motion at another time. The Motion Editor has various blend functions for this purpose. The Linear Blend function has a linearly increasing/decreasing ratio applied to combine the overlap between two motions. Other functions, such as the teepee and igloo functions provided smoother blends between the motions, smoothing both the positions, but also the velocities and accelerations at the boundaries.

4.5 Pose Editing

The Motion Editor has two types of copy functions for manipulating joint angle values. One is Mirror Copy and the other is Symmetric Copy. Mirror Copy enables the motion designer to copy each symmetrical joint angle value at the selected joint. For example, if the motion designer selects the right arm, each joint angle value of right arm will be copied to the corresponding joint angle of the left arm. Symmetric Copy performs a similar function, except it copies in both directions. For example, if right and left arms are selected, the joint angle values of each arm will be swapped.

4.6 Joint Editor

The Joint Editor displays 38 joint, including fingers and their joint angle values in the Joint Editor Window. There are two methods for editing joint angle values. One is the direct typing of joint angle values and the other is through use of a pop-up slider. Multiple sliders can be displayed at the same time to simplify pose creation. The Joint Editor Window can also display angular limit violations.

4.7 Direct Editing

Pose Edit Mode allows the motion designer to work directly in the 3D View to modify the joint angles and pose of SDR (**Fig. 7**). When a joint is selected, each of the DOFs of that joint are indicated with a graphic ring handle. Pose editing requires mouse-clicks and mouse-drags on this ring handle.

IK Edit Mode allows the motion designer to directly manipulate the end position and orientation of a limb or chain in the 3D-View window (**Fig. 8**). The resulting pose of this operation using Inverse Kinematics and/or Pose Edit Mode is represented in the Timeline.

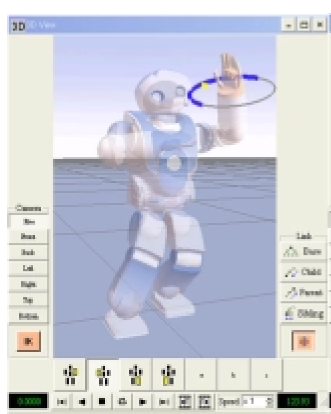


Fig. 7 Pose Edit Mode

Fig. 8 IK Edit Mode

4.8 Characteristic of 3D-View

In addition to permitting direct editing, the 3D-View allows the motion designer to play the motion back and view the results. The motion designer is able to set the start time and end time of the motion playback in the Timeline window, and to loop and adjust the playback speed. The 3D-View has various cameras and camera settings that provide a variety of views. Several camera views can be stored, each with its own camera location, fixation point, field of view, etc. For example, if a fixation point is set to SDR's right hand, when the motion is played the right hand is always fixed in the center of 3D-View. This feature allows the motion designer to observe the created and edited motions precisely. Poses and motions are assets that can be saved in pose and motion data files, and they can be reused effectively across projects as a library of poses and motions.

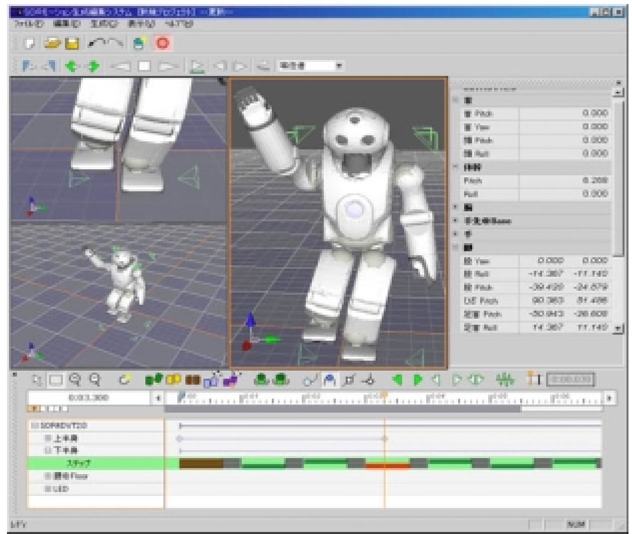


Fig. 9 Foot Trajectory Editor

5. Foot Trajectory Editor

5.1 Gait Pattern Generator and Motion Stabilizer

One of the characteristic features of the Foot Trajectory Editor is that it includes the same gait pattern generator and real-time motion stabilizer as are found in the actual SDR-4X. The gait pattern generator makes a series of trajectories for the position and orientation of the feet from a sequence of gait commands and parameters. The parameters include step length, step cycle and a few other parameters. The real-time motion stabilizer receives the gait pattern, the pelvis movement and the joint movement in the upper body every control cycle, and calculates the corresponding whole body motion that provides stable biped walking based on the ZMP Stability Criterion.

This feature makes it possible to observe the same motions as the ones performed on the actual robot and to inspect the feasibility of the motions on the editing system before testing on the physical robot. The editing system only has to transfer a sequence of gait commands and the key frames of the pelvis and the upper body motions to the control system when specifying motion data, because the controller has the ability to determine the details of the whole body motion itself. These cooperative design policy between the control system and the editing system enables us to reduce the size of the motion data that must be transferred to the robot during loading.

5.2 Design of Gait Pattern

The gait pattern is designed by setting gait parameters assigned to each step. Various walking and dance steps are created from appropriate gait parameters. Gait parameters include the landing position and orientation of the swing leg, step height, step speed and so on. The task of creating and editing the gait pattern involves inputting appropriate gait parameters for each step, and arranging them in the time sequence. The motion designer is not required to specify the detailed trajectories of the leg joints for biped walking, because these are derived from the gait parameters by the software. The designed gait patterns are displayed in a Timeline window and the lower body motion of the robot is displayed in the 3D view (**Fig. 9**).

5.3 Design of Pelvis Movement

Joint angles of each leg are calculated from position and orientation of the pelvis and the feet using inverse kinematics. The design of pelvis movement is accomplished by editing the position and the orientation trajectories of the pelvis according to the time sequence determined by the gait pattern. The trajectory of the leg joints is calculated from the gait pattern and pelvis movement. Pelvis movement is edited by control points and interpolation functions as is described in the preceding section. Editing pelvis movement requires only small changes from the default trajectory of the pelvis as determined from the foot trajectories. The designer can observe the pelvis movement in 3D view of the Foot Trajectory Editor (**Fig. 9**).

5.4 Integration with Upper Body

The trajectory of joint angles in the upper body can be imported into the Foot Trajectory Editor from the Motion Editor, and integrated with the lower body data. The motion data for the whole body of the robot are displayed in 3D view. In the Foot Trajectory Editor it is available to edit the lower body data aligned with the motion of the upper body. In addition, the software module of Gait-Synchronous Arm Motion Generator used in the actual robot is useful if required. It provides a natural motion of the upper body that synchronized with gait pattern.

5.5 Checking Feasibility

Foot Trajectory Editor also has the capability of the effective feasibility inspection of the created motion before applying it to the physical robot. In prior to checking feasibility, Foot Trajectory Editor applies the stabilizer and the gait pattern generator to the motion data created in the processes mentioned above to produce the stabilized whole body motion. This operation is done in the same way as on the physical robot except all the sensor values are neglected. The motion data in the time lines are iteratively extracted every control cycle (dt) from the beginning(t=0) to the end (t=T) of the motion, and are put into Locomotion Engine (**Fig.10**). Receiving them, Locomotion Engine calculates the whole body joint angles, which are inserted into the corresponding time slot in the time line for them. The left and right images of **Fig.11** show the SDR's biped walking motion observed before and after the stabilization respectively.

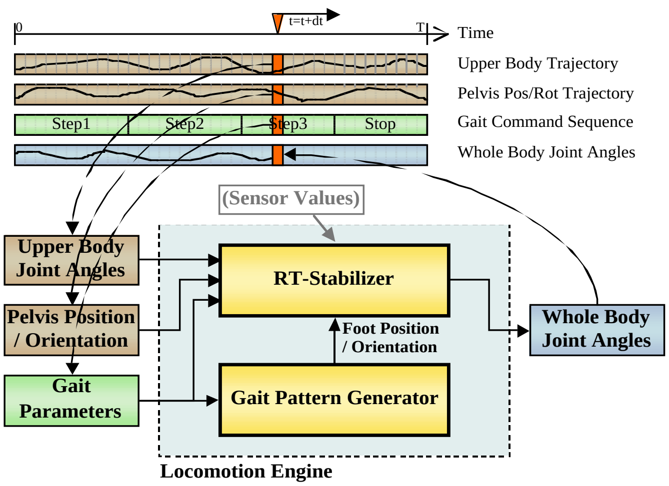


Fig.10 Emulation of the RT-Stabilizing Process on the Control System

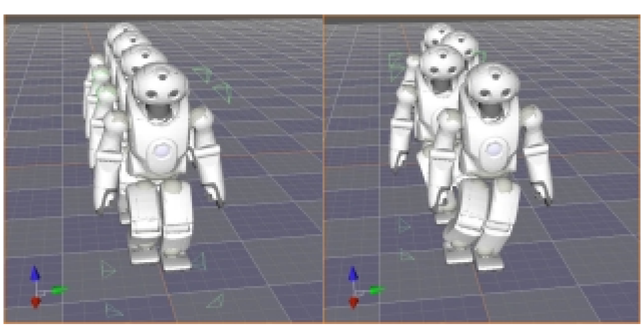


Fig. 11 Motion Stabilization

The stabilized result in Foot Trajectory Editor is completely same as the one on the actual robot without sensor inputs, so it is reasonable to check feasibility of the motion using them. Foot Trajectory Editor utilizes them to detect the invasion upon the limit of the movable range and the angular velocity of each joint. The limit values have some allowances considering the effects of the offset in the joint angles made by the adaptive controls. If the exaggerated shot of the joint trajectory exceeds these limits, a list of detail information is displayed in the editor window.

5.6 Exported Files

Foot Trajectory Editor has a function which outputs the edited motion data to a motion data file, and the data file is transmitted to the robot via Memory Stick. This output data concerning the trajectory of joint angles in the whole body motion contain only the information on control points and equation of interpolations. By this data format, reduction of large data size is realized as compared with the joint angle data of the whole body arranged in the time sequence.

6. Application Development

We are experimenting with creating various motion performances, such as a dance performance, a cappella chorus performance, and an emotional expression performance. In this chapter, the creation process of a fast-paced dance performance is introduced as an application of the described Motion Creating System.

The created fast-paced dance performance includes dance motions performed by 4 SDR robots while they change formations in synchrony with the music for about 2 minutes. First the motion designer loads music into the system. The motion designer starts by creating motions of the upper body using the Motion Editor while listening to music. Then the motion designer creates the dance steps using Foot Trajectory Editor. During this process, the Project Manager manages the motion project, and the synchronization of each editor is maintained by exchanging data upper body and lower body motion data. Therefore, the motion designer is able to edit while considering motion of the whole body. The motion of one SDR robot is created first. Then motion for the three remaining SDRs is created. The reuse of motion data from the 1st SDR robot when designing motions for the remaining three robots greatly simplifies the task. Finally, in order to check the resulting formations, the motion data of the four robots are loaded into Foot Trajectory Editor, and they are observed, checking that the behavior of each robot is as the motion designer expects (**Fig. 12**). **Fig. 13** shows the actual motion performance.

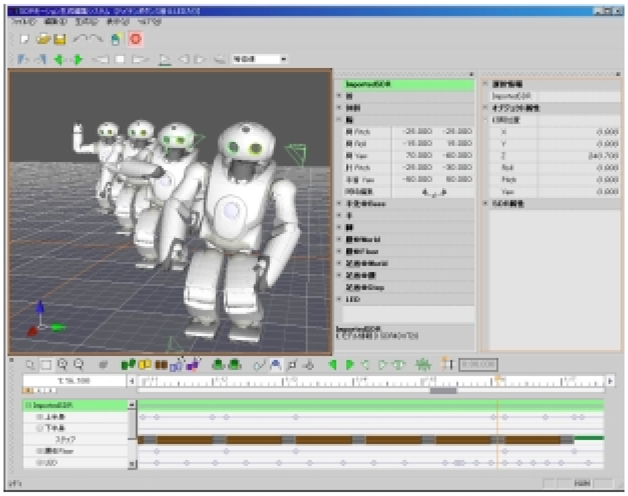


Fig. 12 Designed Motion Performance

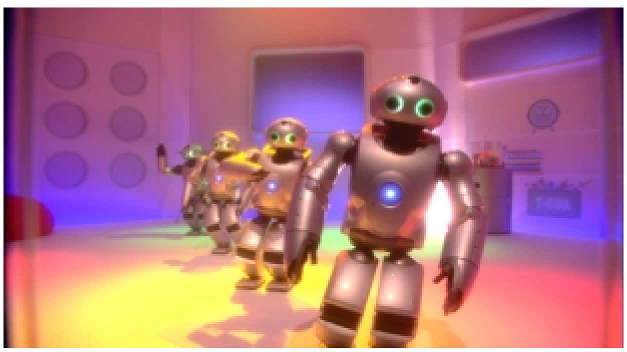


Fig. 13 Actual Motion Performance

7. Summary and Conclusions

We have proposed a small biped entertainment robot SDR-4X. In order for SDR to realize dynamic and elegant motion performances, we developed SDR Motion Creating System. It allows motion creators to develop a variety of attractive motion performances. The Motion Creating System is mainly composed of the Motion Editor and the Foot Trajectory Editor. The Motion Editor allows the user to create and edit upper body motion and /or whole body motion. The Foot Trajectory Editor generates the gait pattern, the lower body motion for biped walking and the stabilized whole body motion. It does so using the Gait Pattern Generator and Motion Stabilizer, the same modules implemented in SDR's motion control system. A 3D view allows the user to see the motions as they are created, modified, and stabilized, in preparation for executing them on the motion control system of SDR-4X. To demonstrate the ability of the software and process to create attractive motions, we applied it to create a fast-paced dance performance for SDR-4X. The development of this motion creating technology for SDR-4X provided a development system for engineers, designers and artists (who are not robot specialists) to produce creative motion performances for a small biped entertainment robot.

8. Acknowledgments

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