Two-Level Behavior Control of Virtual Humans

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SUMMARY

The digital human modeling is considered in terms of intelligence agents with regard to human behavior in virtual environment. The human modeling systems are classified. The problems of high-level control of virtual human's behavior and methods of low-level positioning control are shortly described.

Keywords: human behavior, human body modeling, posture control.

1.0 INTRODUCTION

Currently modern methods and means from the field of informatics and artificial intelligence (AI) are actively engaged in the solution of the problem of automation of ergonomic researches and man-machine systems design. Any complex system design can't be performed without CAD/CAM means and the modern trends of human utilization during design phase require attraction of special software for human body modeling, its motion control and interaction with environment.

At first the idea of virtual anthropomorphic objects modeling appeared in 70th in astronautics, aviation and vehicle construction because of necessity of human factor utilization during such a systems design. It was very crucial for the expensive systems to simulate the human-connected parameters at the design stage. At the first place were the tasks of systems' safety and comfortable working conditions modeling – cockpit layout, simulation of sortie into space, etc. Before now the systems of virtual anthropomorphic objects modeling existed as an isolated units, but at present the dynamic spatial human body models are demanded in different scientific and industrial fields: human behavior modeling for the design and technology choice during hand welding, assembling of large-scale products, accessibility analysis of large parts mounting areas, comfort analysis of transport means, muscle strength analysis for the trauma exclusion during working process, clothing modeling, sportsman training, animated cartoon, etc. Accordingly, computer modeling of the human body structure and form, its animation and behavior simulation within virtual environment is currently the most vital task.

Software and technical means for human body and behavior modeling are now created and refined within virtual reality and AI concepts, whose theories, methodologies, mathematical instruments are closely interpenetrated.

2.0 CLASSIFICATION OF THE HUMAN MODELING SYSTEMS

As for the software systems for human body modeling and behavior simulation in virtual environment, it's possible to see about their qualitative evolution and development towards features and implemented

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functions intellectualizing. The following classification, that doesn't intend to be unique or complete, according "intelligence" criterion can be considered:

1st group – Static Systems – the simplest systems appeared at the end of 70ties. They allowed observing the human positions at the workplace from different viewpoints. The first such systems are the BOEMAN (USA) [1], developed by BOEING firm, CREWSTATION GEOMETRY EVALUATOR (USA) system, ERGOBIM (Russia) [2], COMBIMAN (USA) [3], etc. Within that system it's possible to visualize human body in key projections. Static models allowed to change arbitrary the human body measurements, to verify the visibility and reach conditions.

2nd group – Kinematics Systems – actual systems, which allow to generate and visualize human body motion, interact with extern CAD-systems. The examples of such systems are SAMMIE (USA) [4], MAN 3D (France), SAFEWORK (USA), REGGIE, CAR MODEL [5], CREW CHIEF (USA), MANEKEN (Belarus) [6], CBMAN (Belarus) [7].

3rd group – Dynamic Systems – in addition to kinematic systems consider mass-inertia attributes of the human model elements, the strength that is necessary to perform different motor actions. The examples of such systems are ADAMS/ANDROID (USA), MANNEQUIN (USA-Canada], etc. The successful application of the dynamic systems for the working place design for the different-purpose objects motivate the development of CASHE (EU-USA-Canada) modeling system [8]. This system is oriented for the military object design. The researches in the field of virtual reality and broad area of their application produce more and more perfect dynamic models of human body. The famous systems of this kind are HUMANOID (Holland-Switzerland) [9], JACK (USA) [10] and RAMSIS (Germany) [11,12].

4th group – Intelligent Dynamic Systems – are appropriated for complex motions modeling and intelligent behavior simulation of virtual humans in dynamic virtual environment. Intelligent behavior assumes interaction with environment (independent analysis and collision avoidance, interaction with another virtual humans, etc.), hypothesis generation, their evaluation and decision making, cumulative experience and temporal factor accounting, etc. The information about finished works in this group of systems is absent. According to some publications different centers carry out the researches in described above direction: Pennsylvania, Michigan, Louisville, Illinois universities (USA), Biocomputer NASA center, University in Kassel (Germany), etc.

According to our analysis by means of Internet more then 30 organizations in Europe and as many firms and universities in USA and Canada are engaged in virtual systems design including human body modeling, its animation and human-like behavior simulation.

3.0 OBJECTS, ACTORS, AGENTS

In described above classification we can see about some analogy with evolution stages of "intelligent agent" concept, that appeared in early 90-ties in relation to artificial intelligence (AI) field. "Object" "actor" "agent" – is the process of evolution of the key concept of the modern trends of decentralized and distributed AI.

According to terminology of M. Minsky [13], such as object-oriented programming (OOP), objects are the elements of programming systems, specified by the interaction structure and mechanisms. Object has its name, proper data and procedures. It can include its embedded structure and compose from several smaller units or belong to larger object. At the same time the objects can't analyze their behavior, determine the nature of connections with other objects.

Actors, according to G. Agha [14], are the developed, interactive, concurrently operated objects, which interact by asynchronous messages routing and don't possess the property of message analysis.

Program systems that claim to be the "actor" must include three components: knowledge of its operational environment; knowledge about other actors; variety of data and operation alternatives. These components determine the local actor behavior under the corresponding message entry.

According to OOP and "weak" agent definitions by M. Wooldridge and N. Jennings [15-17], the main distinction of intelligent agent from actors and objects lies in the higher level of autonomy and activity during goal achievement. In decentralized AI along with traditional notion of agent exists the anthropomorphic agent concept. Coming back to computer modeling systems classification, we can see with some limitations, that virtual objects, simulated by intelligent dynamic systems, can be treated as programmable anthropomorphic intelligent agents.

4.0 HIGH-LEVEL BEHAVIOR CONTROL

At present the most tasks, related to realistic motions modeling and anthropomorphic objects locomotion in virtual environment can be considered as resolved. The actual researches are concentrated on the vesting of virtual anthropomorphic mannequins with intelligent mental abilities and transition to high-level control of their behavior. In high-level control context the behavior means both mental activities and complex motions. Modeling of virtual "human" interaction with environment, memory, emotions and behavior unpredictability compose the complex of tasks, which after their solving permit to treat the virtual anthropomorphic mannequins as the anthropomorphic intelligent agents.

High-level behavior control consists of anthropomorphic agents' (VAA) animation by means of instructions, which include only the general plan of activities and movements, and controlling animation system must itself add the details. The example of such an instruction for VAA is following: "Take the object A from the location B and remove to the location C". It's apparent, that high-level control must employ low-level functions and operations. For this purpose the behavior primitives' library must be created in the form of appropriate database. Each of such behaviors must include the list of possible consequences in order for high-level control system to consider them in global VAA behavior scenario. Among the set of consequences the behavior primitives must contain priority-ordered list of application conditions, which allow to provide multivariate decision in target instruction specification. This list of conditions can be defined through the system of production rules or other methods of AI. A set of consequences together with the list of application conditions are the requirement for the VAA mental and autonomous behavior support, that is related to decision making about local activity. The subsystem of VAA location planning within high-level control system must to a great extent consider the spatial organization of the world, what greatly minimize useless and incorrect VAA movements. This subsystem can be performed with effective algorithms of VAA collision avoidance with other objects of virtual environment. Such algorithms in turn require high-level knowledge about environment, which is typically created by CAD-systems or using virtual reality modeling language (VRML). Distinctive (or key) objects of the virtual environment must automatically (ideal) or interactively be recognized by the system. As an example of such objects let consider: doors, instruments, machine tools or other elements with which the interaction is simulated. The existence of such "primitives" description is the necessary condition for automatic or semi-automatic decomposition of the high-level instruction to smaller mental and perceptual acts. Apparently, the VAA motion in virtual environment isn't always "smooth". Therefore the behavior repertoire must include such motion primitives as crawling, climbing, running, jumping, sliding, etc. These motions themselves are very biomechanically complex and their software support isn't trivial. From the linguistic point of view high-level control system must use natural-language instructions. The overall system must know how to understand and adapt them to virtual environment, automatically decompose to more simple acts considering the behavior primitives set of consequences and application conditions.

High-level behavior control is greatly complicated within multi-agent virtual environments, when the coordinated behavior of several VAA is simulated. Single-agent task requires believable reaction to some high-level instruction. For multi-agent tasks the problem of VAA coordination arises. Such coordination must be generally executed at the following levels: physical, task and cognitive. Physical level assumes spatial location coordination of the VAA group in goal achievement, determining timing parameters, strength and workload distribution. Task coordination requires augmenting the task knowledge base with information on multi-agent tasks. This leads to the instructions' specification (undesirable) or to the raising demands to the instruction interpreter, since high-level instructions can't be too specific. Cognitive coordination between VAA involves the possibility to determine or abort the leadership role of some agent, initiate activity, keep it moving along, interrupt or abort it, etc.

5.0 MOTION CONTROL OF SYNTHETIC CHARACTERS

Motion control methods define the way of character animation and differ in the type of information used in animation. According to this information motion control methods may be divided into three categories: geometric, physical and behavioral [28].

Geometric methods refer to the methods, fully controlled by animator: rotoscopy, shape transformation, parametric keyframe animation. Typically the animator provides a lot of geometric data corresponding to a local definition of the motion. Character motions are locally controlled.

Physical methods provide a realistic motion by using kinematics and dynamics. The animator should determine physical data corresponding to the complete definition of a motion. Typical physical motion control methods animate articulated figure through forces and torques applied to limbs. As trajectories and velocities are obtained by solving equations, character motions are globally controlled.

Behavioral methods take into account the relationship between each object and the other objects. The control of animation may be performed at a task level. As a behavior motion control method any method may be considered, consisting in driving the behavior of a synthetic character by providing high-level directives indicating a specific behavior without any other stimulus.

There is no general method applicable to complex motions, only a combination of various techniques may result in a realistic motion with a relative efficiency.

Task-level animation system must schedule the execution of motor programs to control characters, and the motor programs themselves must generate the necessary pose vectors. According to Lozano-Perez's [29] description, task planning may be divided into three phases:

1) World modeling, which consists of describing the geometry and the physical characteristics of the objects.
2) Task specification, defined by a sequence of model states using a set of spatial relationships or a natural language interface.
3) Code Generation, which consists of several types of output: series of frames, value of parameters for certain keyframes, script in an animation language or a command-driven animation system.

In each case the correspondence between the task specification and the motion to be generated is very complex.

Most positioning algorithms in computer animation are principally concerned with motion. For postural control the motion is not so important because the principal goal is a static posture. The interactive postural control process consists of placing the figure in a sequence of postures closely spaced in time and space, giving the illusion of motion. In our research the inverse kinematics algorithm has been used for posture determination. The function defined as a linear combination of kinematic constraints is minimized using nonlinear programming algorithm.

6.0 LOW-LEVEL POSTURE BEHAVIORS AND HUMAN BODY NOTATIONS

In high-level animation systems the behaviors will include a whole range of activities from reaching, walking, path planning to complex "emotional" interactions between characters. All this high-level, activities are based on the low-level operations, which itself can utilize behavior parameters. When defining a set of behavior rules for objects, we than can more easily control them using more efficient and intuitive language, most of the motion then is generated automatically. In our research we tried to use behavioral control to the static positioning of the articulated figures with inverse kinematic methods. Postures are a very important aspect of human figure simulation. A static and recognizable posture such as stand, sit or supine can be defined by the relative positioning of various parts of the body. The behaviors in our research constitute a powerful vocabulary for postural control. When manipulating the objects the behavior parameters and controls have the direct impact to the final response. Several systems have used the notion of behaviors to describe and generate motion [18], [19]. Behaviors have also been applied to articulated figures [20-23]. In our research we focus on simple but very important postural behaviors. The interactive system for postural control must include manipulation primitives that allow the user to push, twist parts of the body and the behavior controls that direct the body's response. We consider such manipulation primitives as "move foot", "move center of mass", "bend torso", "move hand", "move head" and the different ways of their realization under the impact of implemented behaviors. These behavior parameters and controls are developed according to the existing theoretical studies described in biomechanics and physiology literature.

There are two main approaches to the description of the body and its movement. The first one is based on the skeletal representation of the human body as a set of limbs and joints. This approach includes the Labanotation and the Eschkol-Wachmann notation [24] that are similar in their principles but describe the body in two different ways. In the first case, the movements are associated to the joints that constitute the main entity of description, and in the second case they are associated to the limbs, each of them related to a longitudinal axis.

In Labanotation [25], five different models of description are defined: the direction signs and the revolution signs, that indicate a translation and rotation of the joint, the facing signs that indicate an orientation of the joint, the contacts signs, and finally the shape signs that describe movements of some shape in space (typically some arm movements).

In the Eschkol-Wachmann notation, the movement is specified in terms of the angles given around an axis of the model or a position assumed by a limb.

The Effort/Shape notation is, as opposed to the previous two, based instead on a muscular model of the body [26] and attempts to specify the dynamic characteristics of the movements: tension flow, weight, time, etc.

The differences between these two classes of notations are important: on the one hand the implementation of a skeletal description is easy and allows simple specifications of the movements, on the other hand, a muscular description takes into account physical properties such as mass, force, etc. and is more realistic and complex [27].

7.0 BEHAVIORAL PARAMETERS

For the realistic positioning the human figure must satisfy the number of constraints on its toes, heels, knees, hands, elbows and center of mass. These constraints can be specified through the corresponding kinematic or dynamic expressions. The behavior parameters are the properties of the constraints, which can affect the resulting posture. These parameters describe the objective function of the constraints.

The implemented behaviors allow to control over time the position and orientation of the feet, hand, torso, center of mass and others. The behavior parameters determine the desirable reaction of one part of the body to the translation of the other.

As the behavior parameters for the human foot we can consider the position of the heel and the general foot positions. For the standing figure the two behavior parameters: *keep heel on floor* and *allow heel to rise* control the height of the heel. The *pivot* behavior allows the toes while holding in the same position to rotate through a vertical axis. The *hold global location* behavior fixes the toe orientation in space, while the *hold local location* parameter attaches the foot to the desired object. If the object moves, the foot will follow it and maintain the constant relative displacement from it. The behavior of the foot is activated through the manipulation of any other part of the human body and the selected behavior parameter of the foot affects the resulted motion.

The process of manipulation the human body often requires the maintenance of the hands in particular position. The application of behavior parameters allows to resolve this problem. They provide several standard postures for the hand: *hands on hips* for standing figure, *hands on knees* for sitting figure, *reach the point* behavior moves the hand to a particular point in space, in both position and orientation.

The constraints on the hand are logically separate from the other constraints on the human body. As the human figure is rooted at the toes, there are too many DOFs between the toes and hands. The inverse kinematic algorithm can't resolve such complicated task efficiently. In any case the center of mass and pelvis constraints must have higher priority level in optimization function, invoked to solve the positioning task. Therefore it's much easier to simply localize the movements of the arm and isolate them from the rest of the human body.

8.0 CENTER OF MASS RELATED BEHAVIORS AND THE HUMAN FIGURE ROOT

Balance is the most important human postural behavior. Balance is a generic term describing the dynamics of body posture to prevent falling. The implementation of the balance behavior leads to more natural movements of the human body model. The location of the balance point of a figure depends on the feet position. The location of the balance point can be parameterized with respect to the feet. The derived parameters are available for the behavior functions. Labanotation has a notion for distribution of the weight between the feet. After specifying the distribution of weight, this proportion should remain fixed, even the position of the feet changes during postural manipulations. *Balance point follows feet* behavior can realize these constraints.

As the human body model is hierarchical system, during the process of resolving of positional constraints with inverse kinematic algorithm the problem of figure root choice arises. The positioning algorithm can't move the figure root, it can only manipulate the chains, going out of the root. Therefore one of the additional behaviors must include the possibility to change the figure root. For certain postures of a human figure, different locations of the figure root can be considered as applicable: the feet, the lower torso, and the center of mass. Many systems, that don't have the ability to change the root, choose it at the lower torso. This choice complicates the process of moving the lower torso during balance control. The lower torso on the contrary is the good root choice for the sitting figure. The root behavior function can be designed in order to automatically change the figure root to provide the best control.

9.0 INTERACTIVE SYSTEM FOR POSTURAL CONTROL

Interactive system of postural control includes the following manipulation primitives: move foot, move center of mass, move hand, move head, bend torso, etc. These primitives comprise the verbs in the postural control language. Each of the primitives along with the behavior parameters forms the final human body response. When manipulation with the foot in straightforward manner, its orientation depends upon the selected foot orientation behavior. The moving of the foot causes the change in the balance point location when the *balance point follows feet* behavior is active.

When manipulating with *move center of mass* command, the feet movements can be different depending on selected foot behavior parameter. This command also works on the elevation of the center of mass. So moving the center of mass up and down allows the figure to stand on its toes or squat down. When moving the hand to the particular point the *hold global location* behavior can then be selected in order for the hand to stay in the same place despite the other manipulation commands, applied to the other parts of the figure.

The developing interactive system consists of the several blocks that are iteratively processed. The system repeatedly evaluates the kinematic constraints and executes the behavior functions. It also inquires the user for information about geometric movements or commands to execute which can change the state of the system or parameters of the constraints. Each iteration of the control loop is a time step in a simulated movement process (Fig.1).

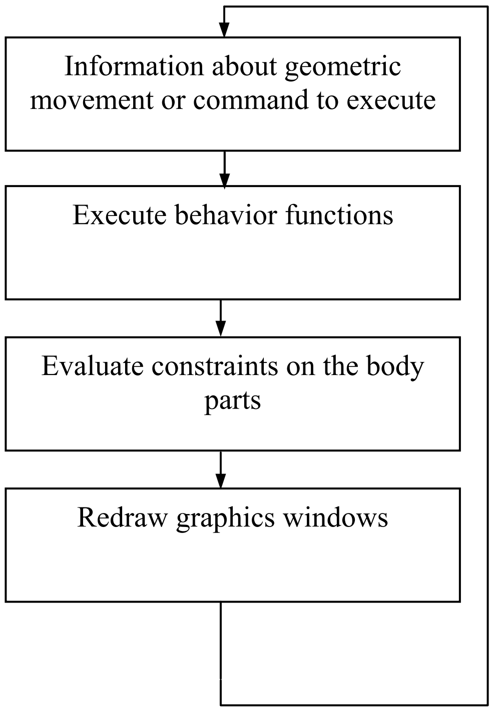

Figure 1: Interactive System Architecture.

10.0 CONCLUSION

The problem of the human body modeling and behavior simulation in virtual environment is considered from the intelligent agents' concept point of view. The main tasks of the high-level virtual human behavior control and the brief description of low level positioning control with the aid of the behavior functions are presented. The introduction of such functions in interactive positioning control system can help to coordinate the manipulations of different parts of the human figure model leading to the natural representations of the figure positioning in space. The further development and use of different behavior functions in the interactive animation systems will greatly facilitate the process of motion modeling.

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