ASIMOV
Educational Framework for the Modeling, Programming and Simulation of Mechanical Manipulators

Anderson Maciel
Departamento de Informática – Universidade de Caxias do Sul
Rua Franscisco Getúlio Vargas, 1130
Caxias do Sul - RS – 95070-560 - Brazil
+55 054. 212.1133
Anderson@nl.com

Gilda Aparecida de Assis
Departamento de Informática – Universidade de Caxias do Sul
Rua Franscisco Getúlio Vargas, 1130
Caxias do Sul - RS – 95070-560 - Brazil
+55 051.286.4708
gaassis@ucs.tche.br

Ricardo Vargas Dorneles
Departamento de Informática – Universidade de Caxias do Sul
Rua Franscisco Getúlio Vargas, 1130
Caxias do Sul - RS – 95070-560 - Brazil
+55 054.212.1133
rvdornel@ucs.tche.br

1. ABSTRACT

This paper describes the ASIMOV, an integrated educational environment for the learning and development of mechanical manipulators. Some of the main methods used for the modeling and visualization of the mechanical manipulators are presented.

1.1 Keywords

Robotics, Computer Graphics, CAD, Mechanical Manipulators.

2. INTRODUCTION

A mechanical manipulator is a programmable machine, that is used in the production line of the industry. Usually, the manipulators are compared to human arm, considering the form and motion capability. The manipulators do not have sensors that allow them to adapt to the environment. Manipulators execute repetitive industry activities, which do not involve making decisions like painting, assembling, loading, etc.

There is a variety of automated tools (software) that help in the design and simulation (test) when building manipulators. Usually, such tools are developed for specific phases in the project and they are not integrated [7]. In such a context, the ASIMOV project was defined. This project presents a proposal to integrate the computational resources, with the goal of to aid the design and simulation of mechanical manipulators. The computational resources integrated in an interactive environment are the following:

- Database of components;
- CAD of manipulators module;
- Simulation module;
- Programming environment module;
- Instruction module.

This work presents the description in details of the methods of modeling and visualization, which are included on the CAD of manipulators module and Simulation module. The Figure 1 represents the general structure of the system ASIMOV. The ellipsis emphasize the context in which this work is included.

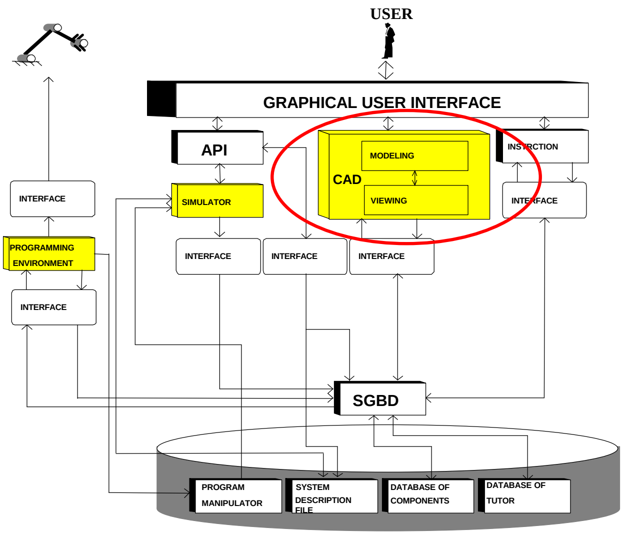

Figure 1

This paper is organized in the following way. The next section begins with an overview of the data structure used. In the section 4 the teaching module is presented. In the section 5 the modeling operations, that are included on the CAD of manipulators module, are presented. The section 6 presents the 3D viewing operations, which are used in the CAD of manipulators module and Simulation module. The section 7 presents an overview of the simulation module. In the section 8 the rendering is presented. In the section 9 the collision detection is described. The section 10 presents the implementation aspects of the system ASIMOV. Finally, the section 11 gives the conclusions of this project.

3. DATA STRUCTURE

This section describes the geometrical structure of the manipulators and the hierarchical structure of the parts of the manipulator.

The primitive objects are obtained from files in the format DXF[1]. The geometrical structure is composed of points, which in pairs form segments. These segments in groups with *n* elements form faces, which are assembled to form convex polyhedrons. Each of these polyhedrons is denominated primitive object (Figure 2).

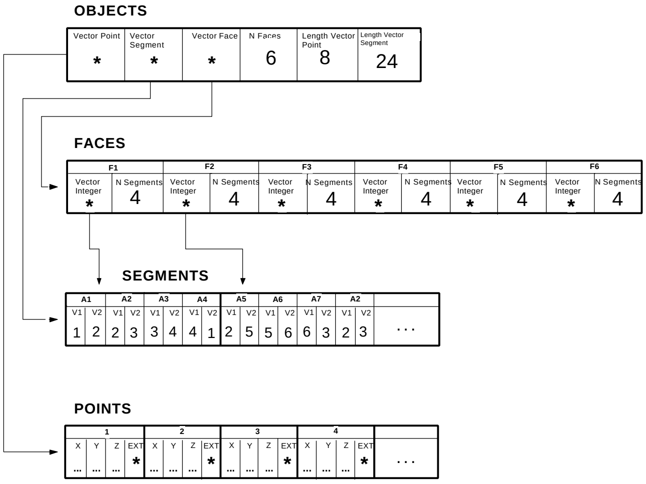

Figure 2

The primitive objects are assembled in groups. Each of the primitive objects of a group is described in the reference Cartesian system of the group. A group is a piece of the mechanical manipulator. The primitive objects of a piece do not have relative movement between them. The geometrical structure of a mechanical manipulator is composed of a limited set of pieces.

The movement of a piece relative to other pieces is defined through the hierarchical structure. The pieces are identified by an integer number. The first piece is fixed in the World reference system. So, this piece does not move and its identifier is 0 (zero).

Most industrial robots are articulated. They are composed by revolution or translation joints. A set of pieces does not define a hierarchy, being necessary to define a set of joints. The identifiers of the joints are integers. The identifier of the first joint is the number *1* (one). Each joint aggregates two pieces. The pieces assembled through a joint are divided in fixed piece and movable piece. The fixed piece presents the shorter value of identifier. The movable piece presents the larger value of identifier. When a joint moves, is the movable piece, and its primitive objects, that move. For example, if the mechanical manipulator represents a human arm and the joint corresponding to human shoulder moves thus the arm moves but the forearm continues firmly fixed, what is not wanted. So, a method is used to relate the joints between them.

The Denavit-Hartemberg notation, originally developed for robotic manipulation, is used to establish the inter-relationship of the joints [3]. Such formalism describes the kinematics of each link relative to its neighbor by attaching a coordinate frame to each link. It means that, each reference Cartesian system of joint is associated to coordinates of the anterior neighbor joint in the hierarchy of joints. Afterward, four parameters are produced. These parameters define a linear transformation matrix, the DH matrix, which establishes the relationship among consecutive joints.

4. TEACHING MODULE

ASIMOV is an educational framework that helps to transmit robotic concepts to the students of Mechanical and Electrical Engineering and Automation.

The teaching of the basic concepts of hydraulics is made through the use of intelligent tutors[6]. Also, it is possible to execute a studying session about the basic concepts of the design and simulation of mechanical manipulators.

To build the intelligent tutor in hydraulics many activities were developed. The first one was the selection and the study of the knowledge domains to be taught by the intelligent tutor. After that, the definitions about the knowledge representation, about the tactics [8] and strategies [9] to teach and about the student modeling were defined. The teaching tactics used by the tutor were defined through an interaction with professors of the course of Mechanical Engineering that teach correlated subjects.

The intelligent tutor of hydraulics contains a hypertext, which has topics about hydraulics organized hierarchically. Also, exercises in different degrees of difficulty were introduced, allowing thus the student to interact with the tutor. The figure 3 shows the main frame of the hydraulics tutor.

Nowadays, intelligent tutors to teach the basic concepts of pneumatics and electricity are being developed.

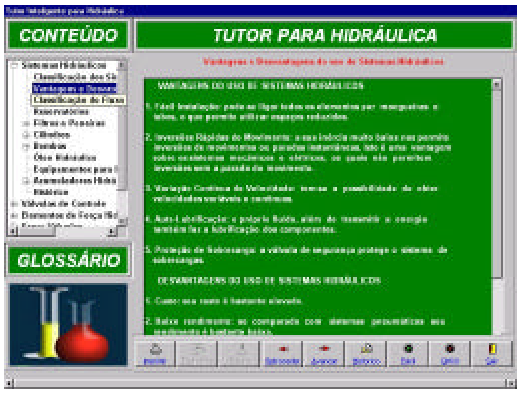

Figure 3

5. MODELING OPERATIONS

In the geometrical building of the mechanical manipulators 3 views originated from orthographic parallel projections (front, top and side) and a view originated from a perspective projection are used. In the perspective view, the user defines the attributes of a synthetic camera for visualization of the mechanical manipulator from different viewpoints on the World.

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[1] DXF - Drawing Interchange File.

The CAD of manipulators module presents mechanisms to selection and manipulation of objects in the stage of modeling. The selection of objects is made with the mouse. The selection of pieces is made through the selection of the reference Cartesian system of the piece. The operations of manipulation implemented are:

- Translation;
- Rotation;
- Scale.

The operations of manipulation can be used to set the position, the dimension and to orientate the primitive objects and the pieces of the mechanical manipulator.

6. VIEWING OPERATIONS

The viewing operations can be divided into two classes:

- Modeling;
- Simulation.

6.1 Viewing at Modeling Stage

In the modeling stage of the mechanical manipulators there is no information about the hierarchical structure of the manipulator. In this stage, the pieces remain free, with absence of a physical link between them.

In this stage, the visualization corresponds to the necessary steps to translate the 3D geometric information, which is stored on the data structure of the ASIMOV, into lines of CRT monitor, which form the image of the mechanical manipulator. The Figure 4 presents the pipeline of viewing at modeling stage, i. e., all the steps in the sequence of execution.

6.2 Viewing at Simulation Stage

The viewing module allows the user to select a manipulator already defined from the database and to simulate its functioning. Therefore, it is necessary to have a data structure representing the hierarchy of manipulators. So, the viewing process at simulation stage is different from the process at modeling stage.

The differences between viewing at simulation stage and viewing at modeling stage are the inclusion of some new steps and the division of the viewing process into two blocks at simulation stage. These blocks are:

- Steps executed before the start of the simulation;
- Steps executed at each loop of simulation.

The steps executed before the start of the simulation generate the structures to represent the existing hierarchy among the pieces of the manipulator.

The steps executed at each loop of simulation analyze this hierarchy and extract the necessary geometrical information. After, the viewing process at simulation stage is similar to the viewing process at modeling stage.

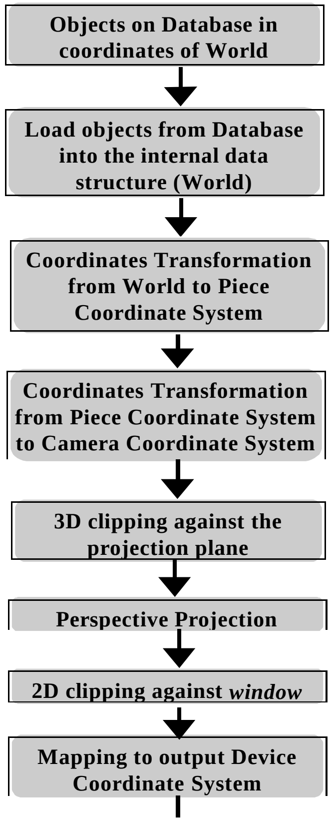

Figure 4

The Figure 5 presents the sequence of the steps in the viewing at simulation stage.

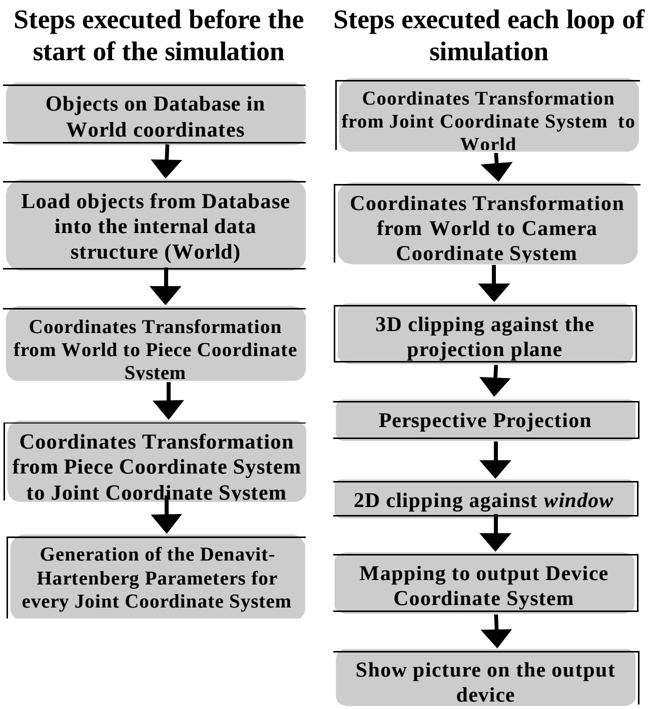

Figure 5

7. SIMULATION MODULE

The actions that should be made by the manipulator are defined by a program.

The simulation of a program begins by the program definition. The ASIMOV environment presents a syntax oriented program editor integrated in the system. The language used in the ASIMOV system to manipulators programming is VAL II [10].

After the program edition, it is submitted to an analysis process to verify the correction and a program more appropriated to simulation is generated.

From the program generated by the analysis process, a set of target points and respective Cartesian coordinates is generated. After, the conversion of these points to joint coordinates is made through the use of inverse kinematics algorithms. The inverse kinematics uses homogeneous transformations to generate a system of equations in which the result is a function of the Cartesian coordinates of the target point, and of the other positions of the joints [11]. To obtain the solution of these equations an interactive algorithm in needed. However, considering that the programming of tasks of robot relatively simple generates a great amount of position points, the use of these algorithms demands a great computational effort. In face of this difficulty, closed form solutions have been adopted. In the ASIMOV system, closed form solutions were developed to most industrial mechanical manipulators available.

The figure 6 shows the ASIMOV during the simulation of a program. It can be seen the teach pendant panel, the sensors panel and the manipulator being simulated.

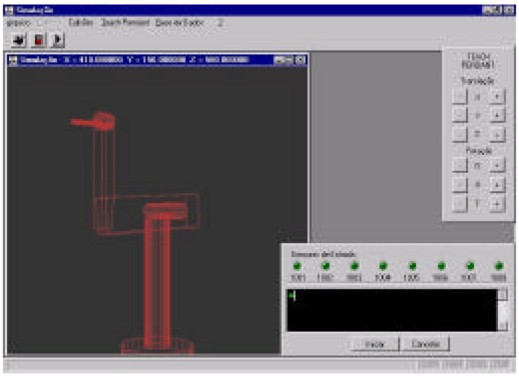

Figure 6

8. RENDERING

Some elements that did not belong to original ASIMOV project were added. These components are implementations of methods of rendering and collision detection. These elements were included to ASIMOV project by needs identified during the validation of the system. This validation was developed by specialized people in Mechanical and Electrical Engineering. These components were implemented as undergraduate course final works, developed by students of Computer Science, UCS.

The rendering methods approximate the images produced by computer to the reality. The rendering methods implemented are remotion of hidden elements and calculation of illumination and shading.

Among the various rendering methods found in literature, the selected method was the Gouraud shading, applied to a model of local illumination. The Gouraud shading interpolates the intensity inside the surface. In a model of local illumination, only the first reflection of light is considered. The Gouraud shading calculates the intensities of the illumination for each vertex of the polygons that form the primitive objects and uses a interpolation among the vertices. The Gouraud shading eliminates the effects of discontinuous intensities and gives an aspect of suavity at curve objects represented by a mesh of polygons.

This method is not the most realistic, however its implementation is simple and its execution is faster than other methods of realism. In the case of ASIMOV project, the main goal is a simulation of the movement. Then, the Gouraud shading is adequate, because:

?? It is the fastest method to generation of images;

?? It is adequate to the data structure used in the representation of mechanical manipulators of the ASIMOV ;

?? It supplies the degree of realism necessary so that the ASIMOV project reaches its goals.

9. COLLISION DETECTION

Other method added to the original ASIMOV project is the collision detection. In a real operational environment, a mechanical manipulator can hit other objects or people. So, it is important during a simulation of a mechanical manipulator to have conditions to verify if any collision occurs.

This verification can be done through the use of the perspective projections, obtained under different positions of the viewer in environment during the simulation. It can be made with the use of the synthetic camera.

This is an exhaustive alternative and errors can occur. To avoid it, an automatic procedure of collision detection is used. This procedure verifies if any object occupies the same space already occupied by other object. This test is made from the geometrical description of the objects and their positions and orientations in the World.

After a study of the existing algorithms in the literature about collision detection, it was concluded that the *four-step* algorithm, presented by Garcia-Alonso, has great advantages over the others. Among the criterions used to evaluate the more adequate method are included mainly the well fitness to the geometrical structure representation of the ASIMOV and the speed, which must give an answer that makes possible a simulation in real-time.

This method executes a sequence of four steps where each step is a filter of possibilities of collision and the last step needs to be executed rarely, when some possibility of collision could not be discovered with the anterior steps. Also, series of procedures are executed in the pre-processing stage. This pre-processing stage reduces the amount of processing necessary during the *loop* of simulation. The *minimax* envelope and *voxelization* are two methods used by the Garcia-Alonso algorithm with the goal of optimizing the collision detection process so that the collision detection can be executed in a standard PC (personal computer).

10. IMPLEMENTATION

The framework ASIMOV was developed using the language C++. The ASIMOV runs in Windows 95 and Windows NT operational systems. The compiler used was the Borland C++ 5.01 of Inprise Inc. The components database routines were also developed in C++ using an Oracle DBMS.

11. CONCLUSIONS

Usually, to evaluate the behavior of a mechanical manipulator, it is necessary to build a physical prototype to check if it fits the design goals. To build this prototype, normally a considerable amount of time is needed. If there are changes in the initial design, new prototypes have to be built. On the other hand, sometimes with a prototype it is not possible to get all information that is necessary to analyze the design. An environment to represent and manipulate physical objects is important because it eliminates, or at least reduces, the need to build a physical prototype, through the support to the development of virtual prototypes, which can be designed, analyzed and evaluated under different situations, using less time, effort and resources.

In this context, the ASIMOV project was developed. The ASIMOV framework is an integrated environment to aid the design and simulation of mechanical manipulators and the teaching of robotic foundations, in academic or technical level, or even in an industrial environment as a complement for the professional who develops or operates this equipment.

Nowadays, the ASIMOV is being used in the Mechanical Engineering and Automation courses, in the UCS and tutors for the teaching of electricity and pneumatics are being developed.

The next step in the development of the ASIMOV is its integration in a global environment simulating a production line and some work still has to be done to consider the dynamics in the simulation.

12. ACKNOWLEDGMENTS

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