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Keywords: Modelling, Robotics simulation, Virtual reality.

Abstract: This paper presents a free Java software platform which enables users to easily create advanced robotic applications together with image processing. This novel tool is composed of two layers: 1) Easy Java Simulations (EJS), an open-source tool which provides support for creating applications with a full 2D/3D interactive graphical interface, and 2) EjsRL, a high-level Java library specifically designed for EJS which provides a complete functional framework for modeling of arbitrary serial-link manipulators and computer vision algorithms. The combination of both components sets up a software architecture which contains a high number of functionalities in the same platform to develop complex simulations in robotics and computer vision fields.

1 INTRODUCTION

Robotics and Computer Vision (R&CV) systems have highly complex behaviours. For this reason, throughout the last two decades there has been a strong development of simulation tools devoted to R&CV systems. Some of these tools have been designed for professional applications, while others for educational and research purposes. In the field of industrial Robotics, several graphical software environments as for example Easy-ROB3D (Easy-ROB3D, 2004), have been created in the form of stand-alone business packages for well defined problems. These are powerful tools, but some of them lack of resources in some aspects for higher education. Otherwise, numerous open-source tools such as GraspIt (Pelossoft et. al, 2004), RoboMosp (Jaramillo et al., 2006) and Microsoft Robotics Studio (Jackson, 2007), overcome these deficiencies. Other open-source tools are in the form of toolboxes such as SimMechanics (SMC) (Babuska, 2005), RobotiCad (RBC) (Falconi and Melchiorri, 2008) and Robotics Toolbox for Matlab (Corke, 1996). With regard to Computer Vision tools, several libraries have been developed for education and research, such as the Open Computer Vision Library (OpenCV, 2001) and VXL (VXL, 2001), developed in C++ language, and Java Advanced Imaging (JAI, 2004), written in Java.

However, the majority of the above commented tools are independent software platforms which have been developed in a separated way. This feature represents a drawback when time comes to develop complex models which combine R&CV systems. Perhaps, only Robotics/Vision Matlab toolboxes provide a set of functions suitable for synthesis and simulation which can be programmed under the same environment. Nevertheless, both toolboxes do not provide a user-friendly graphical interface support for both creating a personalized application and building 3D virtual environments. Thus, educators and researches have to spend time and effort searching the suitable libraries and they must have programming skills to develop the application.

The approach presented in this paper is a new tool called EJS+EjsRL, which provides a complete functional framework for modeling and simulation of R&CV systems, all embedded in the same toolbox. In addition, this software platform gives full 2D and 3D graphical support both for creating user interfaces and complex robotic environments with computer vision algorithms in an easy and simplified way. The main novel feature of this approach is that its software architecture contains a higher number of functionalities in the same platform than the existing software applications for that purpose (see table 1). Most of these functionalities are included as high-level tools, with the advantage of allowing users to easily create R&CV applications with a minimum of programming. The tool presented contains several
features for Robotics such as kinematics, programming, dynamics, world modeling, importation of 3D model files, etc. and a higher number of Computer Vision algorithms than the JAI.

Table 1: Feature comparison with other toolboxes.

<table>
<thead>
<tr>
<th>Feature</th>
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<th>RBC</th>
<th>Matlab toolbox</th>
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Another meaningful problem is the platform dependency. Some C++ tools are not portable for all the operating systems. EJS+EjsRL is based on Java, a well-known programming language which is platform independent.

The remainder of this paper is organized as follows: section 2 describes the overall software architecture of the platform. Section 3 shows a complete application design. Section 4 shows other advanced features of the system. Section 5 shows the simulation capabilities of EJS+EjsRL by means of several test cases. Finally, some conclusions are discussed in section 6.

2 SYSTEM DESCRIPTION

2.1 Components

There are two main blocks that represent the functional core of this software platform: an object-oriented Java library (EjsRL) which allows users to model both arbitrary serial-link robots and computer vision algorithms, and Easy Java Simulations (EJS), powerful software for developing simulations. The combination of both tools (EJS+EjsRL) permits to easily and quickly create R&CV simulations.

EJS is a freeware, open-source tool developed in Java, specifically created for the creation of interactive dynamic simulations with higher graphical support (Esquembre, 2004). EJS has been designed for people who do not need complex programming skills. In order to develop a simulation, the user only provides the most relevant core of the algorithm and EJS automatically generates all the Java code needed to create a complete interactive application. There are a lot of applications which have been developed with EJS for research and teaching activities (Jara et al., 2008; Jara et al., 2009).

EjsRL is a Java library specifically designed for EJS which provides a complete functional framework that enables it to model and design advanced R&CV applications. All the components belonging to this software layer have been structured and organized in an object-oriented form. Figure 1 shows a simplified class diagram of EjsRL, specifying the most important packages and classes. For a complete description of all the classes, readers can visit the web page: http://www.aurova.ua.es/rcv.

2.2 Software Architecture

The software design is based on a hierarchical coordination between EJS and EjsRL. Each of them is divided into systems which must interchange data in order to develop R&CV simulations (figure 2).

A specific simulation within the EJS’ environment must include the definition of the model and the definition of the view or graphical interface (figure 2). In order to describe the model, users must write the differential equations that establish how these variables change in time. For this last step, EJS offers two options. The first is a built-in editor of Ordinary Differential Equations (ODEs) in which users write the system equations in a similar way to how they would write on a blackboard. Users can choose different standard algorithms to numerically solve them (Euler, Runge-Kutta, etc.). The second facility is a connection with Matlab/Simulink that lets users to model systems with the help of these tools (Sanchez et al., 2005) (see section 5). In relation to the view, EJS provides a set of standard Java Swing, Java 2D and Java 3D components to build the interface in a simple drag-and-drop way. In addition, VRML and OBJ external graphic files can be imported to the view. These
3 DESIGN OF A ROBOTICS APPLICATION

3.1 Creating the Robot Arm and its Workspace

The first step in order to create a robotic simulation is to execute EJS and to insert the library EjsRL as external resource (figure 3). In this way, all the methods and classes of EjsRL can be used within EJS’ environment. Secondly, it is necessary to create a specific robot in the model part. This action implicates to define the variables and to program a robot of 6 rotational DOF.

For creating an arbitrary robot arm object, users only have to know its Denavit-Hartenberg parameters, its physical features and the type of joints. With these data, a Java object variable defined in the EJS’ environment has to be initialized using the robot’s constructor of the Robotics module of EjsRL. Figure 4 shows the Java code which must be inserted in the model of EJS’ environment and the necessary variables to program a robot of 6 rotational DOF.

After programming the robot object, the next step is to develop the interface or view for the final user. As stated, EJS provides a set of components to build the interface in a simple drag-and-drop way. In the case of a robotic simulation, the interface can be composed by the 3D solid links of the robot and its workspace, and other standard components to control the application (panels, buttons, sliders, plots, etc.). Figure 5 shows the construction of the interface for the example proposed. The component drawingPanel3D is the 3D environment where the robot and its workspace will be displayed. Here, it is defined each one of the 3D links of the robot by means of the VRML component, which allows to import models from existent VRML files. As mentioned, all the interface components of EJS have certain properties which are used for the simulation. Figure 5 shows the properties of the VRML component (Position and Size, Visibility and Interaction and Graphical Aspect). The position and transform fields will be used to move the robot since they will be connected with the model variables which define the robot. Figure 5 also shows a dialog.
where some sliders controls \((q_1\ldots q_6)\) have been added from the view components. These sliders are connected with the \(q\) variable of the robot model (see figure 4).

\[\text{Move Joints}\]

\(\text{VRML Components}\)

3D Solid

VRML File

Figure 5: Interface construction of a Robotics application.

3.2 Kinematics and Path Planning Simulation

The implementation of the forward kinematics can be easily programmed and simulated with EJS+EjsRL. Figure 6 shows the Java code to resolve the forward kinematics of the robot proposed. The joint values are got from the interface Move Joints for updating the \(\text{DHParams}\) array of the model. Afterwards, the homogeneous transformations of each link are computed using the method \(\text{FKinematics}\) of the Robotics module of EjsRL. Finally, these matrix objects \((A_{01}\ldots A_{06})\) are inserted in the property \(\text{Transform}\) (figure 5) of the VRML components in order to move them according this kinematics algorithm.

public void forwardKinematics () {
  //Update the current values of the joints
  \(\text{DHParams}[0] = q[0] + \pi/2;\)
  \(\text{DHParams}[1] = q[1]-\pi/2;\)
  \(\text{DHParams}[2] = q[2]+\pi;\)
  \(\text{DHParams}[3] = q[3];\)
  \(\text{DHParams}[4] = q[4];\)
  \(\text{DHParams}[5] = q[5];\)
  //Compute the forward kinematics
  \(A_{01} = \text{robot.FKinematics(}\text{DHParams}[0],1);\)
  \(A_{02} = \text{robot.FKinematics(}\text{DHParams}[1],2);\)
  \(A_{03} = \text{robot.FKinematics(}\text{DHParams}[2],3);\)
  \(A_{04} = \text{robot.FKinematics(}\text{DHParams}[3],4);\)
  \(A_{05} = \text{robot.FKinematics(}\text{DHParams}[4],5);\)
  \(A_{06} = \text{robot.FKinematics(}\text{DHParams}[5],6);\)
}

Figure 6: Java code for the forward kinematics of a 6 rotational DOF robot.

EjsRL contains some methods to solve the inverse kinematics problem. Figure 7 shows an example for solving this based on the Jacobian operator. The method \(\text{IKinematics}\) receives the position and orientation of the end effector (Matrix \(T\)) and the current joint values of the robot (array \(q_{\text{current}}\)) as input parameters. Finally, the robot is moved to the suitable position using the forward kinematics method described before.

public void inverseKinematics () {
  //Current values of vector q
  double[] \(q_{\text{current}} = [q[0],q[1],q[2],q[3],q[4],q[5]];\)
  //Position and orientation of the end effector (X, Y, Z, X°, Y°, Z°)
  Matrix \(T = \text{new Matrix}(4,4);\)
  \(T.set(0,3,X); T.set(1,3,Y); T.set(2,3,Z); T.set(3,3,1.0); //Position\)
  \(T.setMatrix(0,2,0,2,\text{Maths.transRPYtoR}(\text{Roll, Pitch, Yaw})); //Orientation\)
  //Call to the inverse kinematics algorithm
  Solution sol = robot.IKinematics(T,q_{\text{current}});
  if(sol!=null){
    q[0] = sol.getElemSolution(0); q[1] = sol.getElemSolution(1);
    q[2] = sol.getElemSolution(2); q[3] = sol.getElemSolution(3);
    q[4] = sol.getElemSolution(4); q[5] = sol.getElemSolution(5);
    //Move the robot with the updated q values
    forwardKinematics();
  }
}

Figure 7: Java code for the inverse kinematics problem.

With regard to trajectory planning, EJS+EjsRL allows users to easily perform the simulation of many path planning algorithms for n-axis robot arms. The ODEs editor implemented in EJS is employed to generate the position, velocity and acceleration values. The Robotics classes of EjsRL contain a path planning module which computes the acceleration parameters of several trajectories from their imposed constrains. Thus, two steps are only necessary to create a planning algorithm for a n-axis robot manipulator:

- To write the equations of the basic motion of a multi-body system. Figure 8 shows these equations in the ODEs editor of EJS. These equations compute the sequence values of the position \((q)\) and velocity \((V_{\text{Plan}})\) of all the robot joints from the acceleration of the trajectory \((A_{\text{Plan}})\);

- To compute the acceleration of the path planning algorithm proposed using one of the functions provided by the Robotics package. The trajectory planning module returns the acceleration parameters of several kinds of trajectories which can be used in the motion equations;

Figure 8: ODEs of basic robot motion.
There are a lot of methods implemented in the Robotics module: splines, cubic interpolators, synchronous, asynchronous and linear trajectories, and the 4-3-4 polynomial path planning algorithm. Figure 9 shows the Java code to program this last interpolator in order to determine the acceleration array for the differential equations.

The generated joint values are automatically given to the kinematics model to simulate the robot movement (method _play). In addition, EJS plot controls can be used to visualize the trajectory variables (figure 9).

### 3.3 Dynamics Features

The Robotics module of EjsRL implements numerical methods to solve the forward and inverse dynamics problems (Newton-Euler and Walker-Orin, respectively). Figure 10 shows an example which obtains the inverse dynamics with an external force. Mass, inertias and friction properties must be known in order to solve this algorithm. The array variables $V_{Plan}$ and $A_{Plan}$ belong to the velocity and acceleration of the path planning previously computed.

The control action and the interaction matrix $\tau$ are returned as an array variable. These point features can be seen in the window “Virtual Image” of the figure 12.

### 3.4 Using Computer Vision Features

The Computer Vision classes of EjsRL provide a complete library for the development of image processing algorithms within EJS’ environment. There are approximately fifty different functions implemented in this module, ranging from basic operations (format conversion, image adjustment, histogram, etc.) to image feature extraction (point and edge features). As example, authors implement a computer vision algorithm in the virtual robotic environment previously created. The aim is to perform an Eye-In-Hand (EIH) vision based control using four corner features in the control loop.

First of all, it is necessary to obtain a view projection from the end effector of the robot. For that end, EJS has an option which allows users to create a virtual camera in the 3D robotic environment. Figure 12 shows the appearance of the interface developed where the window “Virtual Camera” shows the projection of the EIH virtual camera. Secondly, this projection must be processed in order to extract the corner features of the object. Figure 11 shows the Java code which computes corner detection in the virtual camera’s image (this code can also be used for real images). Initially, the image of the virtual camera control is obtained (variable $v_{camera}$) and the image objects are created. Afterwards, the processing algorithm is defined by means of the ImageFunction interface. Finally, the image is processed (processImg method), the point features are detected using one of the implemented algorithms, for example the SUSAN method (Smith and Brady, 1997), and these are returned as an array variable. These point features can be seen in the window “Virtual Image” of the figure 12.

```java
public ArrayList Corner_Detection(){
    ImageFunction f1 = new FColorToGray();
    ImageFunction f2 = new FSusan();
    ImageObject initialImage = new ImageObject(vcamera.getImage());
    ImageObject result_Image = new ImageObject();
    result_Image = f2.processImg(f1.processImg(initialImage));
    ArrayList pointsSusan = ((FSusan)f2).getPoints();
    return pointsSusan;
}
```

Figure 10: Programming the inverse dynamics with an external force.
classical 2D visual servoing task, according to the following expressions:

\[ v_c = -\lambda \hat{L}_v (s - s^*) \]  
\[ \dot{L}_v = \begin{bmatrix} -1/Z_i & 0 & x_i/Z_i & x_iy_i & -(1+x_i^2) & y_i \\ 0 & -1/Z_i & y_i/Z_i & 1+y_i^2 & -x_iy_i & -x_i \end{bmatrix} \]  
\[ \hat{L}_v = \begin{bmatrix} \dot{L}_{s1} & \dot{L}_{s2} & \dot{L}_{s3} & \dot{L}_{s4} \end{bmatrix} \]

where \( s \) are the current visual features, \( s^* \) are the desired visual features, and \( \lambda \) is the proportional controller; \((x_i, y_i)\) are the point coordinates of each feature; and \( Z_i \) is the current distance from the camera to the each feature. The evolution of both velocity module and point features are showed in figure 12, which validate the correct convergence of the visual servo task.

### 4 ADVANCED FEATURES

EJS has a connection with Matlab/Simulink which lets users specify and solve their models with the help of these tools (Sanchez et al., 2005). Next, authors show a decoupled control of a 3 rotational DOF robot where the electrical model is computed by a Simulink diagram and the 3D graphical interface is developed using EJS+EjsRL. Figure 13 shows the appearance of the application.

In the upper part of this figure, it can be seen the simulation of the robot with its respective plot controls, which show the input and the output values. Simulink diagram is set up by the PID control of each DOF, the power amplifier stage and the engine blocks with the model of a DC motor. The torque values are transferred to the forward dynamics method of EjsRL to compute the acceleration for the path planning algorithm. Feedback variables \( q \) and \( v \) are values obtained directly from the path planning and connected with the Simulink blocks.

### 5 EXPERIMENTAL EXAMPLES

#### 5.1 A Virtual and Remote Laboratory

Authors have developed with EJS+EjsRL a virtual and remote laboratory for training in Robotics. This
system, called RobUALab.ejs (Jara et al., 2008), allows users to simulate path planning algorithms in a virtual robotic environment, as well as execute remote commands in a real robotic plant.

Programming classes of EjsRL (figure 1, package “Programming”) enable users to develop Java routines in a robotic simulation. Figure 14 shows a programming experiment which consists of doing pick-and-place operations of virtual objects located in the conveyor belt using synchronous trajectories (parameter “Syn” in the method moveJ).

```java
void main () {
  double [] onBeltJ={27, 84.25, 20.30, -9.73, -61};
  double [] beltJ={27, 98 ,5.82, -9, -61};
  double [] onTableJ={80.10, 52.54, 31, 11.8, 90};
  double [] tableJ={80.11, 59.48, 42.3, -6.43, 90};
  double [] homeJ={0,0,0,0,90};
  double [] time1={3.0};
  double [] time2={1.0};
  int dataObject; double plus = 10.0;

  DECLARATION OF THE VARIABLES
  posJ onBelt = new posJ(onBeltJ);
  posJ belt = new posJ(beltJ);
  posJ onTable = new posJ(onTableJ);
  posJ table = new posJ(tableJ);
  posJ home = new posJ(homeJ);

  CREATION OF THE OBJECTS posJ
  for(int i=0; i<dataObject; i++) {
    belt();
    moveJ("Syn",onBelt,1,time1);
    open();
    moveJ("Syn",belt,0,time2);
    close();
    moveJ("Syn",onBelt,1,time2);
    moveJ("Syn",home,1,time1);
    moveJ("Syn",onTable,1,time1);
    table.setV alue(table.getV alue(0)+plus*i, 0);
    moveJ("Syn",table,1,time2);
    open();
    moveJ("Syn",onTable,0,time2);
    close();
  }
  moveJ("Syn",home,1,time1);
}
```

Figure 14: States of the virtual robot during the execution of the programming experiment.

5.2 A Multi-robot System

EjsRL allows users the instantiation of different robot objects. Thus, it is possible to developed multi-robot simulations in an easy way. As example, a multi-robotic system composed by a PA-10 robot of 7 rotational DOF and a 3 rotational DOF robot (RRR) is presented here. This last serial robot is attached to a link of the upper part of the PA-10 (figure 15). In addition, the robot RRR has a virtual camera at the end as an EIH configuration. Figure 15 shows the interface of the application developed: on the left, the 3D virtual environment of the workspace; on the right, the virtual projection of the EIH camera located at RRR.

6 CONCLUSIONS

In this paper, a free Java-based software platform for the creation of advanced R&CV applications has been presented. EJS+EJSRL is a suitable tool to develop research and educational simulations in R&CV systems. The paper has showed several high-level applications which illustrate a part of the possibilities of EJS+EJSRL. More information can be obtained from http://www.aurova.ua.es/rcv, where readers can also execute a lot of test examples.

ACKNOWLEDGEMENTS

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