Method to Integrate Human Simulation into Gazebo for Human-robot Collaboration

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Abstract. The human-robot collaboration (HRC) takes the advantages of both the flexibility of human workers and the accuracy of robots. Simulation is an effective and economical method to verify the safety and reliability of the HRC system. This paper presents an approach to integrate the simulation of human workers into a robot simulation environment. A digital human model is built in the robot simulator Gazebo and can be controlled by data from proprietary software for human workflow planning. As a result, a holistic HRC scenario is established in Gazebo, which provides the potential for workspace monitoring and robot collision-free trajectory planning based on the Robot Operating System (ROS).

1. Introduction
Individual customization and small-batch production have become a new trend in the manufacturing industry. Shorter production cycles and complex product variants require higher flexibility of the production. Human-robot collaboration (HRC) provides an economical solution for flexible and small-batch production. The core idea of HRC is that human beings are responsible for the processes that require high flexibility and touch sensitivity, while robots take on their fast, accurate advantages to take on repetitive tasks. Such a hybrid system can meet the requirements of a higher diversity of products, fluctuating batches as well as shorter production cycles.

Different from traditional industrial robots in HRC, human operators and collaborative robots work simultaneously within a collaborative workspace. When the power to the robot's actuators is available, the physical contact between the operator and robot system can occur within a collaborative workspace [1]. Therefore, ensuring the safety of human operators in collaborative workspaces is very important for the HRC system. Due to economic and security considerations, testing and verifying the HRC system faces many difficulties in practice. Simulation can be a more efficient and economical solution for validating the HRC system before implementation. For these reasons, this paper proposes an approach to integrate human workflow planning into the robot simulation environment for a holistic HRC simulation.

The structure of the paper is as follows: Chapter 2 introduces the previous research on the HRC simulation system. Chapter 3 gives an overview of the method and describes separately the software and technology used in each part of the system. Chapter 4 introduces how to build a human model that can be simulated in Gazebo. Chapter 5 explains the implementation of the interface layer, which enables the transmission of human simulation data to the robot simulation environment. In Chapter 6
2. Related work

In previous research, there have been some simulation systems for HRC. One of them is an application for a robot-based assistance system for welding tasks [2,3], which integrates a digital human model into a manufacturer-independent offline programming system FAMOS, and can make an ergonomic evaluation of welding tasks according to the OWAS analysis [4]. However, this research is only applied to HRC operation in an assistance system for welding scenarios but not for the universal HRC operation. Siemens' product lifecycle management system Tecnomatix also supports digital human modelling and simulation function, allowing human simulation for production process planning and ergonomic evaluation to optimize production processes and improve safety [5]. The robot simulation software RobotStudio from company ABB has a model library of ABB's collaborative robots, which enables to plan the path and the workflow for their collaborative robots. However, the simulation of human work is still a challenge in research and there has not yet been an integrated simulation system for the universal scenario of human-robot collaboration.

3. Architecture of the integrated HRC simulation system

As shown in figure 1, the integrated HRC simulation system [6,7] consists of three main parts: the human simulation, the interface layer, and the robot simulation environment. The main work in this paper is to build a digital human model in Gazebo and develop an interface between Gazebo and EMA. The HRC simulation will eventually be performed in Gazebo.

![Figure 1. Structure of the integrated HRC simulation system](image)

3.1. Human simulation

A human simulation system must be able to build the environment of most production scenarios and plan the workflows for operators in the environment [8]. In this paper, the Editor for Manual Work Activities (EMA) of the company imk is used to plan the human workflow. EMA is a simulation tool for human based-manual activities. It enables the holistic planning, evaluation and 3D simulation of human work in the context of a digital factory [9].

EMA also provides a digital model library of common robot systems, which can visualize the motion of the robot system. However, only limited simulation functions for robot components have been integrated [6]. In this paper, the operator motions planned in the EMA will be recorded by motion capture, and then exported in a format of Biovision Hierarchy (BVH) for the control of the human model in Gazebo.

3.2. Robot simulation

The robot simulation is based on the open-source software framework Robot Operating System (ROS) and the robot simulator Gazebo. As open-source software, ROS enables a cost-efficient and manufacturer-independent approach that makes the software future-proof and reusable by the use of
A variety of applications for the simulation of robots and sensors are integrated in ROS and a wide range of drivers for controlling sensors, actuators and entire robot systems are provided [9]. These advantages make ROS extremely suitable for the development of HRC simulation systems.

Gazebo is one of the opensource 3D robot simulators based on ROS, completed with dynamic and kinematic physics and a pluggable physics engine. As an effective and manufacturer-independent software, Gazebo offers a rich environment for rapid development and testing of complex robot system. However, Gazebo does not yet support the function of human simulation. In this paper, a human model will be built in Gazebo and an interface is developed to control the model with data from EMA.

4. Human body modelling in Gazebo

This chapter explains how to build a human body model for Gazebo. A skin file in COLLADA format is first built and then connected to an underlying skeleton that moves it. Through the “actor” function provided by Gazebo, the human model can be loaded into simulation environment.

4.1. Actor

By modelling a human in Gazebo, the "actor" is used. The actor is a kind of model of Gazebo, which allows adding animations to a common model. There are two main components in an actor: Skin and animation. The skin defines the visual of the actor and the underlying skeleton which moves it. The skin file is a COLLADA file (.dae). The animation element is an animation for the actor. The skeleton of the animation must be compatible with the skin skeleton. There can be one or more plugins in the actor, which provides access to and use of almost all aspects of the actor to control or customize the behavior of the actor.

4.2. Human body modelling by blender

In this method, the 3D computer graphics software Blender is used to create a skin file in COLLADA format. For the visual of the skin, a male model with a 95% Europe size is selected [11]. To ensure that the human model in Gazebo can be accurately controlled by the motion data from EMA, an underlying skeleton with the same number of joints and hierarchy as the skeleton in EMA must be established (see figure 2). Through the skinning function in Blender the skin is associated with the skeleton, so that the body of the human model can be controlled by the underlying skeleton.

![Figure 2](image-url)

**Figure 2.** Left: Definition of the human underlying skeleton in EMA; Right: Human model built in Blender

5. Implementation of interface layer

As shown in figure 1, the motion data is processed at the interface layer. An interface plug-in is developed based on the Gazebo function library, which has the following functions: Parse the motion data in BVH, calculate the world posture of each joint and add the posture data into the actor as a
skeleton animation.

5.1. Parse the BVH file
BVH is a widely used data format for motion capture. It defines the hierarchy of the skeleton and records the motion data for each joint at each moment [12]. A BVH file has two parts: a header section which describes the hierarchy and initial pose of the skeleton, and a data section which contains the motion data.

First, the hierarchical information in BVH is parsed and stored. Here, a nested if function is applied because the skeleton hierarchy in BVH is recursively defined. The hierarchical information is stored in the “skeleton” class (see figure 3). It consists of a sequence of nodes, each of which stores the original transformation information (i.e. offset) for the joint. The relationship between two nodes is described by “Parent” and “Child” pointers, thereby constructing a hierarchical relationship of the skeleton.

Figure 3. The standard class “Skeleton” that is used to describe the human model in Gazebo.

The motion data is then read line by line and the transformation of each joint is stored in a matrix. For example, the information of a joint is recorded by three channels, which are the rotation angles around the X, Y, and Z axes:

\[
\begin{array}{c}
\text{CHANNEL 3} \\
\text{Zrotation Yrotation Xrotation}
\end{array}
\]

The rotation matrix \( R \) of the bone is calculated as in equation 1.

\[
R = R_z R_y R_x \tag{1}
\]

Using a homogenous matrix to represent the transformation of the bone is illustrated in equation 2. The rotational components take up the top left 3x3 cells and the translation components are the first 3 cells of the 4th column.

\[
M = \begin{bmatrix}
R & R & R & T_x \\
R & R & R & T_y \\
R & R & R & T_z \\
0 & 0 & 0 & 1
\end{bmatrix} \tag{2}
\]

5.2. Calculate the world posture
The transformation of the bone in the BVH file represents the rotation and translation components of the bone relative to its parent’s coordinate. However, the control of joints in Gazebo requires the pose of the joints relative to the world coordinate system. To obtain a global matrix transformation for a given bone, the local transformation needs to be pre-multiplied by its parent’s global transformation, which itself is multiplying its local transformation with its parent’s global transformation and so on [13]. Equation 3 shows the calculation process, where \( n \) is the current bone whose parent bone is \( n - 1 \) and \( n = 0 \) is the bone at the root of the hierarchy.

\[
M_{global}^n = \prod_{i=0}^{n} M_{local}^i \tag{3}
\]

For example, the global transformation of bone “Left Leg” can be calculated by Equation 4. Where
M is the local transformation of each bone. After the above calculations, the global transformation of each bone can be obtained.

\[ M'_{\text{LeftFoot}} = M_{\text{Hip}} M_{\text{LeftThigh}} M_{\text{LeftLeg}} M_{\text{LeftFoot}} \] (4)

5.3. Add the posture data into the actor

To drive the human model in Gazebo, the calculated transformation of each joint at each moment must be sequentially added to the object “skeleton animation” of skeleton class through an AddKeyframe Function (see figure 4). If the “Skeleton Nodes” is compatible with the skin skeleton, the object “Skeleton Animation” will be added into the actor as the animation component, so that the human model can correctly display the animation in Gazebo.

![Figure 4. Process of importing posture data into actor](image)

6. HRC simulation scenario

In this section, a sample HRC scenario is built in Gazebo. At first, a sample workflow with walking, picking up, and screwing is planned in EMA (see figure 5). The workflow planning in EMA bases on a task library. The tasks library in EMA is a collection of basic operations or human behaviours in common production. Each task can be customized through the setting of different parameters. By combining and ordering multiple tasks a complex workflow can be comprehensively defined. Then, the human work is simulated and the human motion is recorded by motion capture.

![Figure 5. Human workflow planning in EMA for the HRC scenario simulation](image)

As shown in figure 6, the previously created human body model is loaded into the Gazebo world. Through the interface ros_gazebo pkg between Gazebo and ROS, a robot model can be spawned in the Gazebo world and be controlled by MoveIt!. The human motion data from EMA is transmitted into Gazebo through the interface layer. With the update function in the plug-in, the posture of the human model is continuously updated according to the data from EMA.

![Figure 6. Method to integrate both robot and operator in a Gazebo .world file](image)
As a result, the human model in Gazebo accurately repeats the workflow planned in EMA, both in terms of time and position (see figure 7). Through this method, human motion planned in EMA is simulated in the Gazebo environment, so that it can combine with the robot simulation functions in Gazebo and realize an HRC simulation.

![Figure 7. Comparison between the workflow simulated in EMA (above) and Gazebo (below)](image)

7. Conclusion and future work

In this paper, a method is developed to build a digital human model in the robot simulator Gazebo. This model can be controlled by the data from the human simulation software EMA, which provides human simulation and workflow planning for HRC. This method integrates human simulation into a robot simulation environment and provides the potential for testing and verification of the HRC system. This paper introduces the way to build a human model for Gazebo, explains the concept of workflow planning in EMA, and describes the implementation of this integration method. As a result, human motion planned in EMA can be successfully simulated in Gazebo.

Concerning future work, with the rich sensor library in Gazebo, human workspace can be monitored. A collision-free trajectory planning on the collaborative robot based on workspace data can be performed through MoveIt! or other applications based on ROS. Besides, using real human motion data collected by cameras or other sensors to control the model in Gazebo, which will provide the potential for a more complex scenario of HRC and real-time HRC simulation, is another direction of research in the future.

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