

# Soft landing in jumping robot using compliant motor capability

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**Abstract**— We are using a similar approach of human robot interaction, where force sensors are used to implement better control of interaction force. This research has been conducted with the aim of developing a control strategy to produce soft impact in the landing phase of a jump process for a simple robot. An algorithm is proposed using motors with compliant capabilities and force sensors; a control strategy is applied to reduce the impact force in the landing phase of the jump process. A simple one-legged robot is implemented to test the proposed strategy. Reduction of the impact force was observed in the landing phase and a more robust control strategy is proposed as future work.

## I. INTRODUCTION

Human robot interaction is one of the most relevant present research fields and it is based on the idea of performing movements similar to human beings that allow the perfect interaction between man and machine. Force sensors are commonly used to detect contact and improve the performance of force control systems. In the same way, force sensors and force control systems can be used to reduce impact force in landing phase and perform soft contact on the ground

In order to do so, human natural movements such as walk, run, and jump must be studied. Then, better robotic control strategies must be developed to better mimic them.

There are several research studies addressed to perform jumping processes on biped robots and most of them are focused on increasing the height jump and reduce Ground Impact Force in landing phase. Some of them have studied the human jumping phases and the biomechanics characteristics in order to determine how to increase the jumper performance [1]. Raibert et al. [2] developed a theoretical and experimental study of a 3D control scheme for a spring leg that can jump and run. Sakka and Yokoi [3] proposed a human jumping dynamics model using real GRF (Ground Reaction Force) data as reference. Nunez and Nadjar [4] compared two mechanical models, one based on the assumption of a compliant contact and another one that relaxed that constraint. Both models were compared with Open HRP (Simulation software).

## II. HUMAN JUMP PROCESS

The human process is divided in four principal phases, which are explained next.

- **The preparatory phase** involves flexion of the hip and knee joints and dorsiflexion of the ankle joint. It precedes the take-off phase [5].
- **The take off phase** begins with the extension of the hip joint, followed sequentially by the knee and ankle joints. It ends when the feet loose contact with the floor.
- **The flight phase** begins when the feet loose contact with the ground and ends when it makes contact again.
- **The landing phase** is the last stage and it starts when the feet make contact with the land. In this moment the muscles try to damp the impact by gradually decelerating the body.

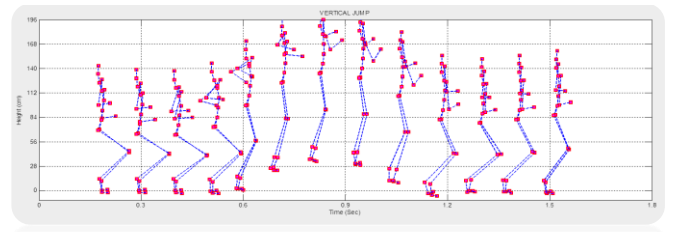


Fig. 1. Jumping process phases

## III. SINGLE LEG ROBOT

A single leg robot was implemented with the aim to perform experiments related to the jumping process. This robot has three joints (ankle, knee, and hip) and four links as shown in fig 2.

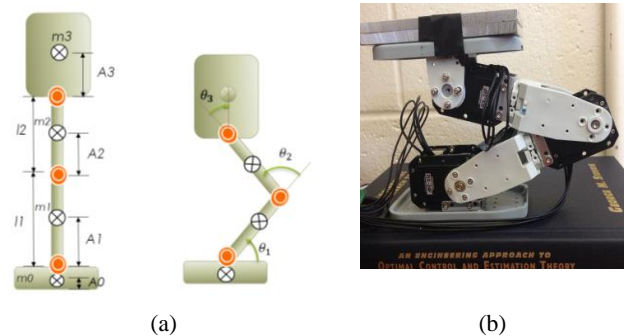


Fig. 2. Robot model and implemented robot

Fig 2 shows the model and implemented robot, where  $m_i$  is the mass of each link,  $A_i$  is the position of center of mass,  $L_i$  is

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length of every link and  $\theta_i$  is the angular position of each joint. The robot was implemented using Dynamixel DC motors (RX-24F). These motors have compliant capabilities and it is possible to control different levels of compliance while moving.

A kinematic model was implemented to estimate the position of each joint and Center of Mass (CoM) by joint and whole robot.

A dynamic model of three Degrees of Freedom (DoF) using Lagrangian formulation was performed to estimate torque applied to each joint.

$$D(\theta)\ddot{\theta} + H(\theta, \dot{\theta})\dot{\theta} + G(\theta) = T_{\theta} \quad (1)$$

#### IV. PROPOSED ALGORITHM

The aim of the proposed algorithm is to decrease the impact force during the landing phase of the jump process through compliance level manipulation.

The algorithm is based on the manipulation of the CoM and the compliance level. Each phase of jump process has different setup of CoM and Compliant as shown in fig. 3.

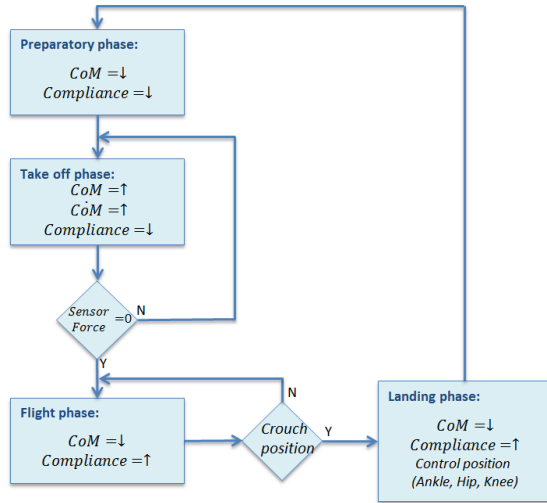


Fig. 3. Soft landing Algorithm

According with fig.3 the compliance level is reduced for preparatory and take off phases giving more stiffness to the robot. The compliance is then increased for flight and landing phases reducing stiffness and, thus, reducing the impact force. The CoM is accelerated upwards during take off phase to increase the body's inertia and goes down during the flight and landing phases. During take-off, the velocity and acceleration of the CoM is increased with the aim to improve the jump height.

#### V. RESULTS

The algorithm was applied to the main control loop of the leg robot. Fig. 4 shows the jumping process using the real robotic leg.

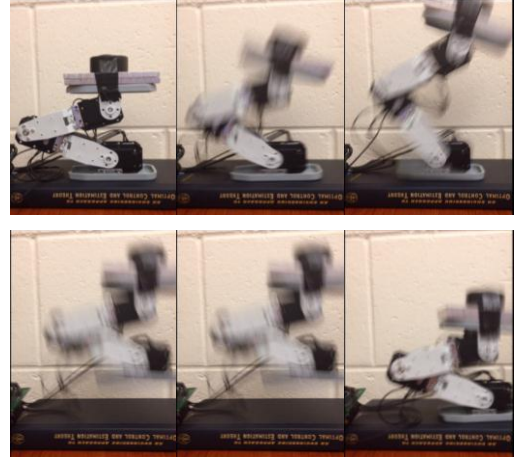


Fig. 4. Jump Process performed

The implemented algorithm is producing a soft landing according with the compliance level manipulation. In turn, this improves the balance of the robot in landing phase by avoiding bounce motions after the first impact. Last but not least, overheating on the knee motor is decreased due to the lower current required by the compliant strategy. In this way it is possible to perform the jumping process for longer periods of time.

#### VI. CONCLUSION

A framework of human robot interaction was used to execute a soft landing jumping process using a single legged robot. A heuristic algorithm was designed and implemented with the aim to improve the performance of the process. The proposed algorithm manipulates the CoM position of the whole robot and the compliance capability of each motor. A three DoF robot was built to perform experiments. It shows a successful soft landing, while keeping its balance and allowing repetitive jumps. Future work involves the implementation of impedance control. It will consider a tradeoff between position and force control during the landing phase and the use of more information coming from force sensors.

#### REFERENCES

- [1] G Jan Babic and Jadran Lenarcic. Vertical Jump: Biomechanical Analysis and Simulation Study, Humanoid Robots: New Developments, 2007, Armando Carlos de Pina Filho (Ed.), InTech.
- [2] Raibert, M.H., Brown, J.H.B., Chepponis, M.: Experiments in balance with a 3d one-legged hopping machine. Int. J. Robot. Res. 3(2), 75–92 (1984)
- [3] Sakka, S., Yokoi, K.: Humanoid vertical jumping based on force feedback and inertial forces optimization. In: Proc. of the IEEE Int. Conf. on Robotics and Automation, Barcelona, 2005, pp. 3752–3757 (2005)
- [4] Víctor Núñez, Nelly Nadjar-Gauthier: Humanoid Vertical Jump with Compliant Contact. CLAWAR 2005, pp. 457-464 (2005).
- [5] Umberger BR. Mechanics of the vertical jump and two joint muscles: implications for training. Strength Condition 1998;20(5):70–4.