Falls Control using Posture Reshaping and Active Compliance

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Abstract by Lucie MATHÉ

Index Terms—humanoid robots, fall control, fall singularities, impact absorption, posture reshaping, compliance control.

1 Introduction

When a human is learning how to walk, he does many tries and falls. As grown-up, we still fall sometimes, being pushed or missing a step. The same issue exists for humanoid robots. When we fall, we try as much as possible not to be hurt, we use our reflexes to reduce the impact. Robots do not have this intuition to protect themselves when falling. The goal of this article [1] is to propose a motion control policy to limit the damages of the robot during a fall.

The authors accumulated significant experience on humanoid robot, especially for rescue [2] or home service companion [3]. In both case, robots can be surrounded by humans or different objects. When a fall occurs, the robot has to follow a priority order : first, protecting human nearby, then avoiding objects in his environment (potentially protecting objects he carries) and finally reducing the damages on himself. Here, the work is only focused on the last part : protecting the integrity of the robot. The positioning of the article assumes that the robot is alone in his environment - there is no human or objects close to the robot. Some researches has been carried on how to avoid falling [4]. Here, this article assumes that it is impossible to recover, the robot will fall, the only concern is so reducing damages.

In this case, the authors developed a two behaviors solution. First, the robot will try to reshape his posture in order to absorb the impact. The reshaping algorithm is in a closed loop because it is using feedback from the motors to adjust the orders given to motor taking care of the difference between the command and the measure. The error is calculated by a PD controller using proportional and derivative parameters. Then, the shock is reduced thanks to an active compliance. ”Compliant control can be defined as the allowance of deviations from its own equilibrium position, depending on the applied external force ” [5]. When the compliance is active, the parameters of the controller (PD gains) are changed using the feedback in order to increase the compliance.

I am working with the RoboCup humanoid soccer team of Bordeaux, Rhoban. Soccer player robots walk on artificial grass and often fall during a match. This article is dealing with a robot alone in his environment falling on a flat ground. It matches perfectly with some of our issues. Indeed, in RoboCup humanoid soccer started in 2005 and falls became immediately a research topic [6]. Nowadays, in Kid-Size competition (robots smaller than 1m), players need to be able to stand-up by themselves. During a match, we want to have the maximum number of robot on the pitch, when they falls, motors are damages, changing them takes time we do not want to lose during the game. Therefore, fall control is a problematic we need to solve.

This document summarizes the work presented in the article ”Falls Control using Posture Reshaping and Active Compliance” [1] and explain why it is related with some Rhoban research issues.

After positioning the fall experience, the authors present the different situations we can have when a robot is falling. Then, they exposed the control policy they use during the falls. Finally, they proved the validity of the method, proposing different experimentations they tried in both simulation and real robot.

2 Context

2.1 The positioning of the fall experience

Many articles deal with robot falling, there is a lot of different cases explained. It is important to react with the right strategy in order to have the best behavior possible. They explain the positioning of the fall experience through a graph showing us the different researches which had been made. In our case, we assume that there is no human near the robot and the robot cannot do any damages on the environment. In the experience, we assume the robot cannot recover and will fall on a flat floor.

On the field, the robot cannot interact with humans and the ground is flat. In actual version of rules, the robot does not have to avoid other robot when falling. Consequently, the article corresponds to a situation we can have during a game.

Another problem discussed in the paper is the fall detection. Different methods exists to detect the fall, all using the center of mass of the robot and its acceleration. Estimating accurately the center of mass and its acceleration is already an issue in robotic [7], fall detection is never obvious. Here, the detection of the fall is not the main issue of the article. Authors based their work on a simple loss of balance calculated by an Inertial Measurement Unit (IMU) but they explains it exists more sophisticated method to detect a fall.

2.2 Taxonomy of Fall Singularity

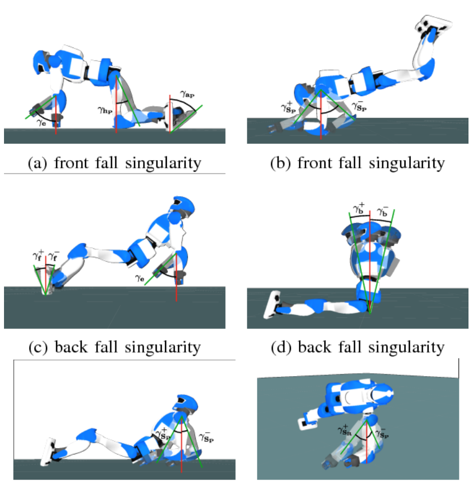
An object falls due to gravity, the kinetic energy accumulated throughout the fall depends of the mass of the object and his distance to the ground (gravitational potential energy). At the impact, the energy dissipation will injure the fallen object (and the ground).

When a human falls, he tries to touch the ground with the feet and the hands because in a situation where he falls on our knee or elbow, bones are in contact with the ground, it is harder to absorb shocks. Moreover, we never fall straight on our legs or arms, we use our articulation to protect ourselves.

In robotics, we also try to limit the impact on the robot. Here, the goal is adapt human falls method on a robot. In their reshaping part, the goal is to avoid positions of the joints which absorb badly the shock between the robot and the ground.

The authors defined few configurations of the robot we would like to avoid to reduce the damages. This situations are called *Fall singularities*. ”For all joints, a fall singularity is defined to be present if the line passing through the impact in body joint and its parent joint is aligned with the impact force direction”. This is a situation to avoid because in this case, there is no torque on the motor, it means the force apply on the joint will be directly reverberate in the motor, it will not cause a rotation on the motor to absorb energy.

During a fall, we would like to control several motors to obtain a virtual linear spring-dampers effect along the direction of the impact force in order to reduce the shock. If the impact generate no torque on the motor, it is impossible for the joints to comply. No energy will be absorbed by the joints so the shock will be stronger for the robot.



(a) front fall singularity

(b) front fall singularity

(c) back fall singularity

(d) back fall singularity

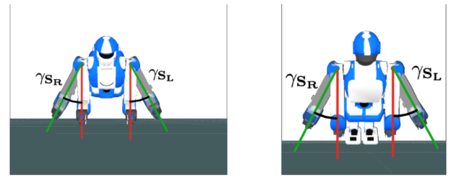
(e) back fall singularity

(f) side fall singularity

Fig. 1: Falls singularities in median plane (from [1])

There is two planes to see the fall singularities. In a median plane Figure 1, we have to be cautious with all joints: the elbow (a, b), the foot(a), the ankle(c), the hips(a), the shoulders(b,e,f), the butt(d). In the traverse plane Figure 2, in case of simultaneous fall of the two arms, we have to be careful about the elbow.

As there is an infinity of possible configuration for the falls, the goal here is to eliminate all the possible situations for the joints defined as fall singularities. Fall situations are divided in three categories : Front Fall (FF), Back Fall (BF) and Side Fall (SF). With all this fall singularities in mind, we can now understand the algorithm used in the article. It is basically the same for every case but the singularities are different.



(a) Front closed kinematic loop singularity

(b) Back closed kinematic loop singularity

Fig. 2: Falls singularities in horizontal plane (from [1])

3 Contribution

3.1 Singularities avoidance controller

3.1.1 Algorithm needs

The main goal of the algorithm is mainly to avoid the fall singularities explain earlier but also to help the robot falling in FF or BF not SF. The algorithm needs 3 elements :

- the distance between the robot’s links and the environment : to know when the impact will occurs;
- the robot configuration : the position of each joint in order to reshape the robot from the actual position;
- the robot’s orientation.

All these data are easy to collect, the joint’s position are given by the motors. The IMU (Inertial Measurement Unit) transmits information about orientation. The robot configuration and orientation are useful for the inverse kinematic which will make sure each joint of the robot is in a wanted position.

For each direction, the robot has several contact points between his body and the ground. We avoid Side Fall because we only land on one arm and one leg. Front Fall and Back Fall allow the robot to fall on both arms, elbows and legs. Additionally, in FF, the robot can help himself with the knees. Having more impact points allows the robot to absorb the shock by different part, consequently, the Front and Back Falls are preferable.

3.1.2 Algorithm bases

First, we need to define d_f the direction of the fall thanks to the IMU. The first step of the algorithm is to align the torso yaw joint with the fall direction. the goal here is to align the chest of the robot with the ground. In order to make sure we will fall in a good BF or FF position and not SF, the next step is to place one arm on each side of the projection of d_f in the gravity orthogonal plan.

After changing the orientation of the torso, we realign the frontal plane with the ground by changing the yaw joints in order to have the legs and the arms touching the ground at the same time.

Finally, the last reshaping helps to avoid the fall singularities configuration listed previously. Avoiding fall singularities is different for each fall direction.

3.1.3 Front Fall

When a robot falls in a front direction, the fall singularities we need to avoid are Figure 1a, Figure 1b and Figure 2a.

We have to make a compliant control, mostly on the arms. There is an angular offset between an incorrect position and the targeted one to make sure the robot do not fall in a singularity. This angle is called δ for the shoulder and δ_e for the elbow. For each joint they used hand-crafted reference value for the angle. Later, their perspective is to use a formal approach including the friction coefficient or allowing a better sliding between the wrist and the floor.

In transverse plane, a similar method is used to avoid fall singularity on the shoulder in Figure 2a (similarly for Back Fall and Figure 2b).

For the legs, motors are stronger and their position is lower, less energy is accumulated. Consequently, compliance will better absorb the shock. Here, we just have to make sure both feet and both knees impact at the same moment to have a better torque absorption.

3.1.4 Back Fall

In a back fall, additionally to avoid Figure 1c, Figure 1d and Figure 1e singularities, we have to make sure the arms impact before the butt. δ_e is wider than in Front Fall but still defined in a empiric way. The angle δ is defined thanks to an equation taking care of the position of the hand, δ_e, the position of the butt and the normal of the ground.

Vincent Samy detailed the result in his PhD thesis [8] saying " This equation results in two possible values. The solution is the one that is in the range of motion of the shoulder joint and with the highest force in the direction of n" (the normal of the ground).

3.1.5 Side Fall

The side fall is avoided as possible. The goal is first to avoid the fall singularity in Figure 1f and then to create a rotating movement in order to reach the FF or BF schemes.

3.2 Compliance

The most common solution for impact is to to shut down all motors when the robot touch the ground [9].

The solution in this article is to reduce PD gains before contact, it is an innovating approach. There is two stages in gain reduction. First, after fall detection we reduce but still allowing reshaping. Then, the PD gains are reduced again to have a spring-damper effect on the servo-motors.

3.3 Simulation and Experimentation

First they tested in simulation using a HRP-4 humanoid robot starting in a half sitting position. They tried BF, FF and SF (where the robot could not change the fall in BF or FF). An initial push force of 200N is applied on the robot for 0.2ms. In both simulation and experimentation, fall detection is 15 degrees of torso binding. Side Fall simulations show the arm being crushed by the trunk at the impact so the authors did not test SF in real experimentation.

To limit the damage during real experience, the robot falls on a mattress from a platform at the same level and is pushed frankly by someone. The experimentation has been successfully done twice for each side.

The experience is split in three phases : the push, the fall and the impact. The data collected during the experience is focused on the impact of the arms. We can notice different observations. First, at the impact the robot is parallel to the floor which represents a good front or back fall. If both arms or both legs did not impact at the same time, the robot can have a rolling effect at landing. Results shows rebound when the robot is landing. This is due to the mattress, in a solid floor, it should less move.

Focusing on the arms motors, we can observe the impact occurs right after the joints reached the desired state. Then, the difference between the targeted position and the actual position increases due to shock absorption and low PD gains (feedback from the motor position are less taken in account). We can also notice the two important motors are the one from the elbow and the shoulder pitch (used to avoid fall singularities of the median plane).

4 Discussion

4.1 The experimentation

Even if the experimentation on HRP-4 did not break the robot, I think there was few limits in this article.

First, the algorithm assumes some ad-hoc which are just set during simulation (δ_e in both BF and FF, δ in FF, all PD values) and we do not know which criteria are used. This parameters needs to be tuned for every robot, this implies we need to have recreate the parameters of our robot in a simulator. Thus, the experience is difficult to reproduce on another robot. The authors are concerned by this issue, they would like to find exactly the best position for each joint, taking into account the motor characteristics, the mass of each part of the robot and the velocity of the fall. The main goal is to create as much as possible the spring-dampers effect to absorb the impact.

Secondly, in the experience, their robot is pushed on a mattress. This means the shock is less powerful than on a soccer field (this is artificial grass) or the normal floor in a house. The robot may be more hurt in real experimentation.

Finally, the authors add in the conclusion that the results are worst if the force exercised on the robot is not in a defined axes (Back or Front). A force applied on the shoulder will need more reshaping from the robot, this has not be detailed in the results.

In [10], this algorithm is criticized explaining the joints are too stiff and robot will have damages on the arms.

4.2 Link with Rhoban

After finishing understanding the article, I watched again our semi-final and final games in the RoboCup this year, looking for the falls of our robots. In the last 10 minutes of the final, our four robots accumulated 55 stand-up. We change our walk engine this year [11] (section 4.1) trying to stabilized our walk. The robot's main position is not very far from half-sitting position. However, we fall rarely in a front position (I just saw it once), but mainly in BF or SF.

During falls, we try to protect the arms and the head, we do not use them at all, we do not have an algorithm to reduce the impact. In back fall, the impact with the robot is on the butt (Figure 4a). This choice has been made due to our hardware, joints break if we use them during a fall and the control is less reliable than the HRP-4 robot. We use piano wire on the front and the back to absorb the shocks.

In another experience on humanoid soccer robot [12], we can see the difference between our actual fall and what we can imagine for a small soccer robot. Indeed, HRP-4 is a 1,5 meter robot for 39kg, our Sigmaban are only 64 cm (6,5 kg), the mass and the center of mass are lower, it is not obvious a fall reshaping algorithm will be efficient on our robot.

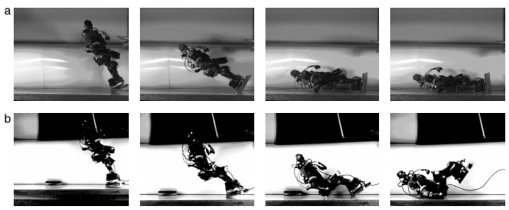
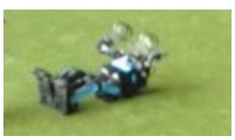


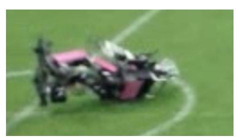
Fig. 3: Reducing fall damage on a soccer robot (from [12])

In this article, the experience shows clearly that the robot has lower velocity when he touches the floor in 3b. This is promising in the idea to create such an algorithm for soccer.

During the matches, most of the falls are due to a shock between two robots, our robot falls rarely in a perfect back fall situation. I think we should try making a similar algorithm in order to reshape the robot and avoid side falls as possible.



(a) Back Fall



(b) Side Fall

Fig. 4: Examples of Sigmaban Fall

In the example in Figure 4b, the robot is almost in a back fall, it should be possible to change the orientation

In soccer, the goalkeeper should dive to avoid opponent to score. This article gives us a possible strategy : rotate the robot to start a controlled front fall in order to stop the ball.

5 Related Work

The management of falls is an important issue in humanoid robotic, the robots are mostly very expensive (300 000 US dollar for HRP-4), falling without damaging the robot is important. As said in introduction, the integrity of the robot is rarely the goal in a fall. The authors enumerate lots of articles covering all falls which does not correspond to the actual context of this article but helps to clarify which situation they are targeting.

One of the problem I described in section 4.1, is the empiric way used to tune PD controller. A policy gradient reinforcement learning algorithm used to optimize the parameters is proposed the following year in [13].

Also working with policy optimization, [14] combines both discrete and continuous variables for his reinforcement learning. This method has been tested while the robot was walking. This is important because robots can be pushed by another one during the match while both are walking.

To focus in the context of a soccer game, I think we should split with a second type of fall to avoid any possible opponent which can be close to us. This has been tested with NAO robot (which are soccer robot too) in [15].

6 Conclusion

To conclude, I think this article is very interesting in humanoid robot fall control researches because the combination of the posture reshaping (to avoid fall singularities) and the active compliance at the impact had never been used before this article (according to the authors). The work on the spring-damper effect has been more developed by the author with a method that could be applied on arms or legs but it is efficient in post-impact compliance [16].

The algorithm detailed in this article can be adapted with our soccer footballer but it will need some changes on the robot. At least, the article gives us lots of ideas to reduce our hardware troubles.

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