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Design and Operation of Humanoid Robots with Incipient Fall Detection

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Проектирование и эксплуатация гуманоидных роботов с функцией обнаружения падения

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Falling is one of the main reasons of failure and damage of humanoid robots when they perform human-like tasks. Fall detection can be used not only to prevent damage to the humanoid robot when falling but also to adjust its actions so that the operation can run continuously. The paper discusses design issues, analyses the fall detection function and diagnostics sensors, and proposes rational design solutions for the required motion planning.

Keywords: humanoid robots, incipient falling, intelligent protections, motion planning

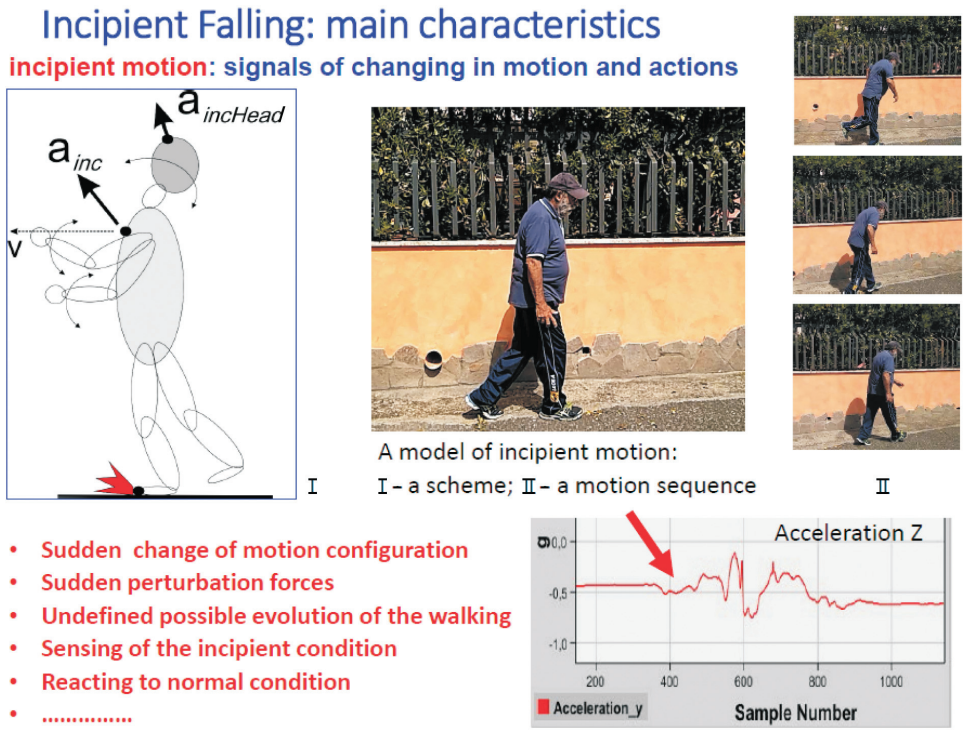
Падение гуманоидного робота является одной из основных причин его сбоев и повреждений во время выполнения человеческих функций. Обнаружение возможного падения гуманоидного робота предлагается использовать не только для исключения его повреждений при падении, но и для регулирования гуманоидного действия, предотвращающего прерывание операции, совершаемой роботом. Рассмотрены вопросы проектирования, проанализированы функция обнаружения падения и диагностические датчики. Предложены рациональные конструктивные решения, обеспечивающие необходимое планирование движения.

Ключевые слова: гуманоидные роботы, начинающееся падение, интеллектуальная защита, планирование движения

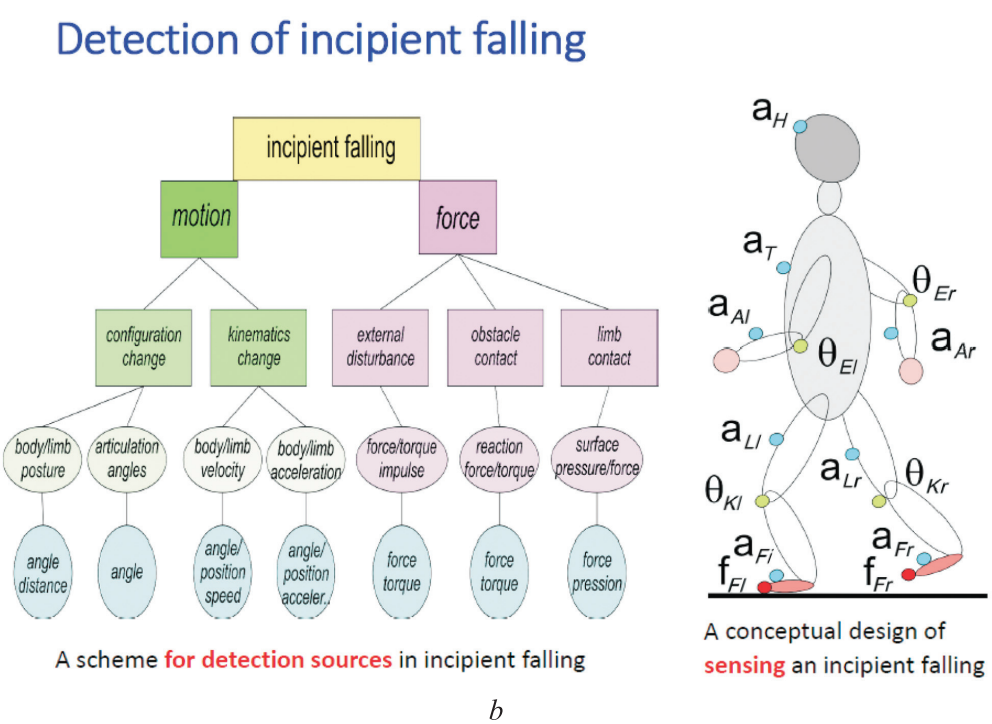
The incipient of falling is the initial phase of falling with the possibility to recover the normal posture behavior avoiding the falling as summarized in the presentation slide in Figure 1. The incipient of falling can be detected by using proper sensors in the main body or in the limb extremities and using those acquisitions in a proper motion control to let the humanoid body to react to the incipient falling [1–3].

Figure 1, *a* shows an example with using inertial measurement unit (IMU) on the human body to detect the torso acceleration $\mathbf{a}_{inc}$ whereas the first variation indicates the incipient of the falling motion, to which a proper reaction restored a normal walking. Design issues can be expressed as function of the falling detection with its incipient characters, as summarized in Figure 1, *b*, and the used sensors as well as the incipient motion can suggest convenient design solutions and proper motion planning.

The analysis of a human falling either forward or backward can be used conveniently not only to understand the fall characteristics but to design both structure protection to avoid damages and motion planning to avoid the falling, as summarized in Figure 1, *b*.



a



b

Figure 1. An analysis model of incipient motion:
a — modeling and example of human behavior; *b* — sensing for detection of faking sources

The main parameter that can be used from the incipient falling is acceleration and beside suitable protection in well-defined humanoid parts, it can be used in a motion planning reacting the body or part of it to the incipient falling similarly to the human reaction, as suggested from Figure 1 and 2.

In particular, Figure 2 shows the possible evolution following an incipient motion with reaction by a human being considering the feedbacks from the

muscles and joints with motion strategies and actions that can resolve towards the restoration of a regular situation. The reaction to the incipient of falling can evolve both in a resolution of the instability and in a failure and therefore in a falling which, in any case, one still tries to minimize with appropriate reactions in movement and actions of the body.

Therefore, both the modes of falling and incipient motion can be considered characterized by a combination of movements and actions tending to react to the anomalous situation towards the fall and/or to plan the fall with a minimization of the consequences. The strategy outlined in Figure 2 emphasizes that the process of rearrangement in a configuration of the forces in the human body proceeds with several attempts to resolve or minimize and the impact of the fall. The combination of movements and perhaps muscle can be considered fundamental for a controlled motion also in force actions.

In the case of human body this combination is achieved through the action of the muscles and the appropriate movement of the articulations not only of the legs. Therefore, the analysis of the incipient motion and the use of its knowledge require knowledge of both the movements of the articulations and the actions of the muscles, with the aim of predicting a suitable reaction and programming of both behaviors but considering the prominence of the kinematic aspects in combination with the inertial parameters to produce dynamic effects.

The analysis of the biomechanics of fall and incipient motion focused on humans is of interest both for applications on humans and for useful solutions in the design and functionality of humanoid robots. In the case of applications for humans, the study is useful for defining both motion rehabilitation strategies but also for defining tools and protections that can help and avoid excessively harmful consequences following both fall and its incipient motion.

In literature but also on the market, solutions for protections of parts of the human body as well as tools to assist in the prevention of falling are widely available. For example, there are protections that are also used in sports for the protection of articulations or parts of the body that may be affected by possible impacts such as in the case of sports like rugby or in many other types of sports.

Aids can be available to prevent falling as those structures that can help especially elderly people to avoid an instability of movement and to facilitate a stable configuration even while walking.

In the case of humanoid robots there are several solutions that are inspired by the solutions for

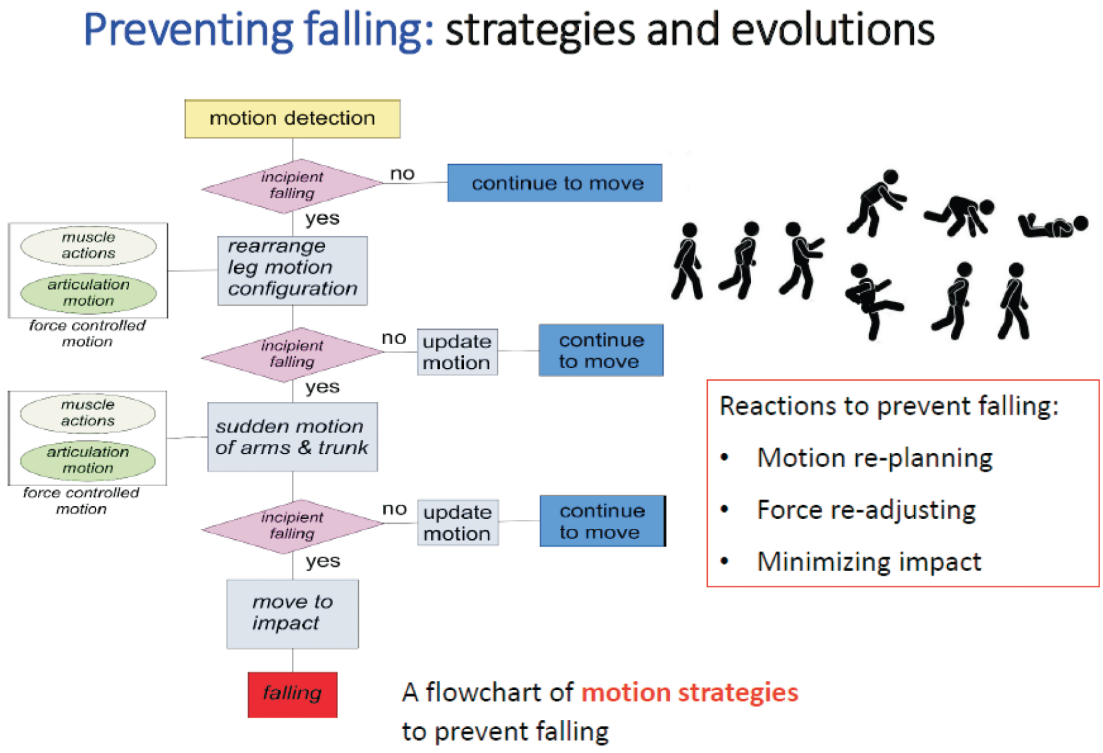


Figure 2. An analysis model of preventing falling

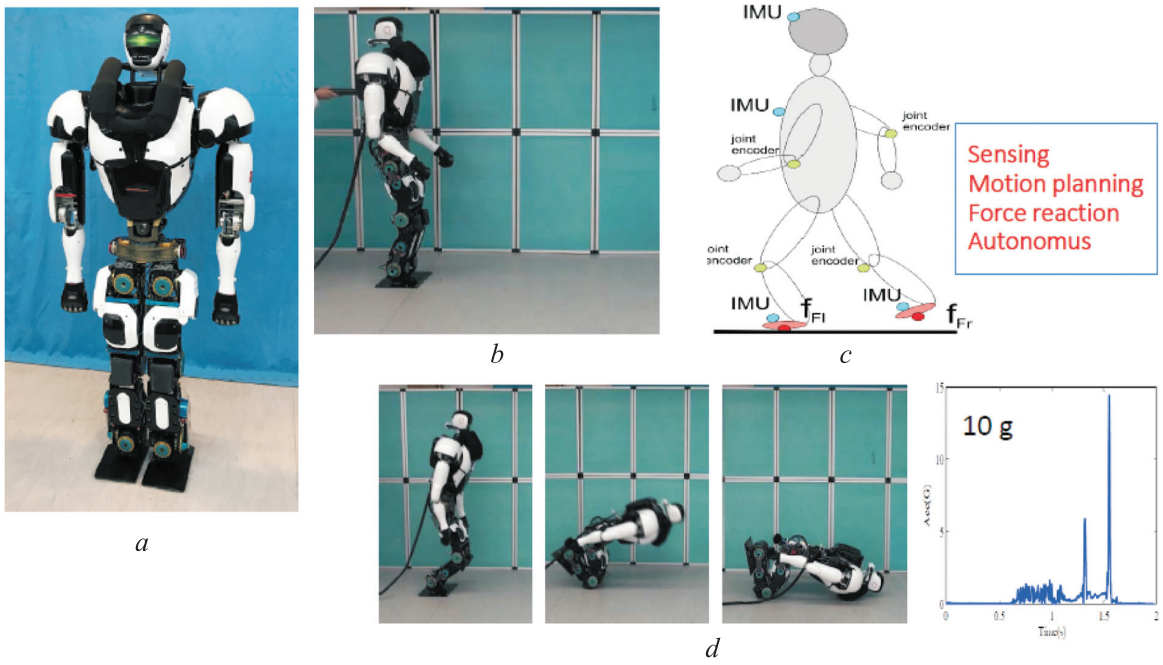


Figure 3. Examples with humanoid robot BHR:
a — BHR with protections; *b* — a snapshot of incipient falling in humanoid robot without falling; *c* — motion planning; *d* — a snapshots of incipient falling in humanoid robot with falling

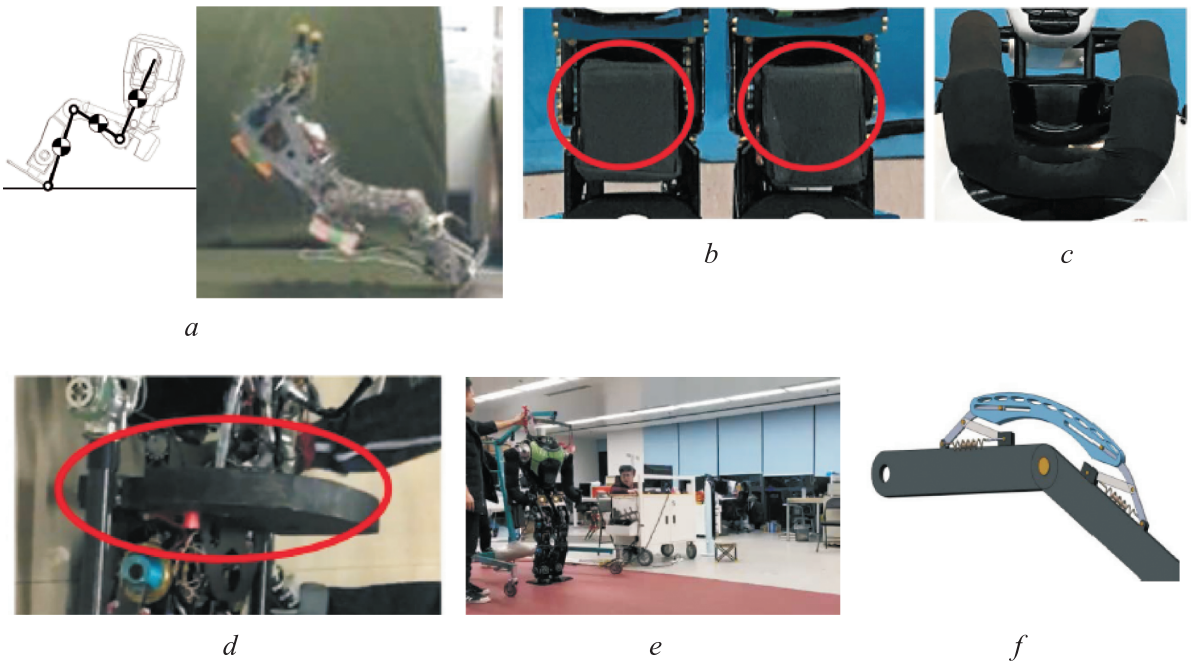


Figure 4. Examples of protections in BHR humanoid robot against falling damages:
a — rigid shell; *b*, *c*, *d* — knee, trunk, waist deformable covers; *e* — supporting device; *f* — smart protection (intelligent mechanism with energy storage and use)

human beings especially in terms of protections and tools but also specific solutions are studied considering the characteristics of humanoid robots with the differentiation of human biomechanics.

Examples of both mechanical protections and motion planning are discussed with experiences of the BHR humanoid in Beijing [4, 5], as in Figure 3 and 4 to illustrate the feasibility of the introduced concepts with experimental validations. In Figure 3 and 4 both solutions recall human cases and the specificity of solutions for humanoid robots can be noted in terms of protections

and movement strategies to avoid damage following the fall but also of an incipient motion.

It is notable that the protection solutions in line with the functional structure of a humanoid robot can also refer much more to active and intelligent protections that allow to recover energy in an impact or even in movement due to the movement strategy in incipient motion recovery.

Conclusion

It can be noted that an appropriate analysis of the incipient motion can help not only to prevent the fall but also to study suitable movement and control strategies for an efficient functionality of humanoid robots.

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