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Airborne and landing phases of a simplified back somersault movement[☆]

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ABSTRACT

The issues of coordination, timing and control are addressed for a back somersault sagittal movement. The three-dimensional physical model is comprised of three segments for feet, torso, and hands. In the airborne phase, it is assumed that the head and the torso are held as one rigid body such that the angular velocities and accelerations, measured and estimated for the head, are the same as those of the torso. These physical states provide acceleration feedback to reduce rotational velocities before the landing phase. Successful stable airborne and landing phases are shown in a computer simulation.

1. Introduction

An ordinary backflip somersault maneuver [1,2] is a very interesting point-to-point movement. It embodies parallel and sequential coordination, as well as different dynamics over the four phases of takeoff, airborne movement, an impactive landing, and a stable and harmonious return to vertical stance. The main motivation for this work is to eventually understand the complex learning strategy of the central nervous system (CNS) activities involved in somersault.

A three-dimensional, three-segment body is considered: a leg, a torso and a hand. The model is formulated with three degrees of freedom for translation and nine degrees of rotational freedom (three Bryant angles for every segment) for a total of 12 degrees of freedom. The system is equipped with an elementary neuromusculoskeletal system that performs the coordination, control, and the more difficult landing phase [3].

A point-to-point movement may be carried out at a variety of speeds from very slow to a very fast ballistic type movement [4]. The speed (or, equivalently, the duration of movement) is consciously or unconsciously selected and the movement is scaled in time. The issues of timing, coordination, and control are addressed here for the three-segment model. Because of the lack of a physically meaningful foot that would propel the system in the air, the takeoff phase is approximated by the 24 initial positions and velocities, induced in the three-link system by an on-the-ground maneuver before takeoff.

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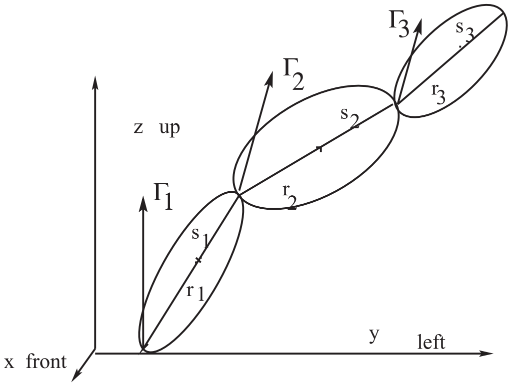

Fig. 1. The three-link system and the ICS coordinate system.

The airborne phase of the somersault is characterized by an under-actuated system that is not amenable to standard control mechanisms of feedback and stability [5]. Moving the segments of the body relative to each other is an important part of controlling the overall movement. Briefly, the control of the airborne phase is primarily dependent on the initial state of positions and velocities that not only dictate the airborne trajectories, but also the desired set of final states at the time of contact with the ground (from which the system can implement a successful stabilizing maneuver to a vertical stand.) During the pre-takeoff and landing phases, the system is fully controllable (one actuator for every degree of freedom) so that standard control methods apply.

The implementation of timing takes place in association with and parallel to the CNS motor system. A four-phase event is envisioned for the scaling that involves a sequential assignment of four time intervals to a liftoff phase, a coasting phase, an acceleration feedback phase, and a deceleration phase that involves impact with the ground, absorption of the kinetic energy by bending the knees and the hip, and slow rise to a stable vertical stance.

The airborne, acceleration feedback phase and the landing phase can be addressed with system theory, computer simulation, or as discrete time events [6]. The more challenging issues are how the required planning, processing, and signaling are implemented in the CNS.

Timing is an important part of the process. A timed event corresponds to a desired motion of a limb by a sequence of gains that implement a reflex signal or an efferent neural signal that induces a desirable motion. Specifically, fixed-action patterns are physical examples of centrally programmed actions. An example is the three timed events of tapping, stepping, and rocking that, with appropriate timing, produce a longer dance maneuver [7]. A timed event may also be part of a pattern generator or an oscillator.

The dynamic system can be divided into musculoskeletal and neural components. The neural portion may be described by an artificial neural network (ANN), a differential equation, or a set of programmable (settable) gains that control the behavior of the system.

A single trajectory of force or motion can be stored in a tapped delay line (compatible with the structure of short term memory.) When the clocking or processing of the delay line is speeded, the movement duration is shorter. With a slower clock rate, the signal is expanded in time, i.e., it is slowed down. Alternatively, Fourier transform can show that an expansion in the time domain corresponds to a frequency domain compression. Therefore, when a signal is generated in a simulation diagram, systematic increases in the gains of the simulation diagram correspond to a compression in time and compression of the gains amounts to an expansion in time.

A different kind of timing occurs when the CNS has to relate internal decisions to external events. Timing is also involved in complex sequential movements as in dancing, catching a ball, etc. The latter could involve associative learning. Simultaneous patterns may have to be recalled from storage or from pattern generators for this purpose.

The underlying philosophy of control presented here is to centrally command the system to execute the somersault maneuver and for the model to fit in larger skeletal systems that would be composed of a larger number of three-segment modules. The modeling and control merits further anatomical, physiological, and experimental testing for viability. A three-segment model is used here to test the feasibility and effectiveness of the model in executing the movement using different a-priory selected speeds, heights, and rotations. The performance of the control strategy is tested by computer simulation.

The structure of the paper is as follows. The three-link system's dynamics are reviewed in Section 2. Timing issues are considered in Section 3 . Design of the airborne trajectories are presented in Section 4, Computer simulations are presented in Section 5, followed by discussion and conclusions in Section 6.

2. Dynamics of the Three-link system

The three-link system, as shown in Fig. 1, consists of one rigid body representing the two lower extremities, one rigid body representing the torso and one rigid body representing the two upper extremities. We will not formulate the dynamics