

## GENERALIZED APPROACH TO THREE-DIMENSIONAL MARKER-BASED MOTION ANALYSIS OF BIOMECHANICAL MULTI-SEGMENT SYSTEM

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### INTRODUCTION

Three-dimensional motion analysis using photogrammetric techniques has been increasingly used in human movement studies recently. Although most 3D applications only focus on specific parts of the body with relatively simple structures (e.g. the lower limbs), real biomechanical systems are more complex as human and animal skeletons are composed of interconnected articulated links with hundreds of degree of freedom (DOF) and complicated topologies; moreover the environmental constraints are various.

This paper presents a methodology for 3D kinematic and kinetic analysis of general multi-body systems using marker-based photogrammetric devices, which can be used for a large range of biomechanical systems, whether human or animal. The proposed methodology is being implemented in a software package, SMAS (Salford Motion Analysis System).

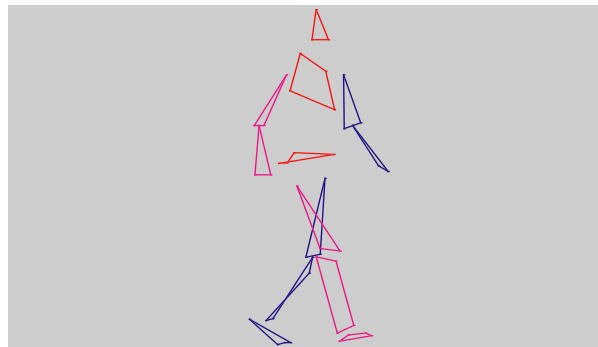
### METHODS

The biomechanical system is modelled as a set of rigid segments, connected by generic joints with up to six independent DOF. Three templates are employed to define the biomechanical system: the body template, marker template and force template. All definitions are generic, so that any biomechanical multi-body system can be described.

The body template represents the topology of the multi-body system, which includes the definitions of body segments, their adjacent segments, and interconnecting joints. The marker template defines two marker sets: technical markers and anatomical landmarks. Technical markers are attached to body segments to record their changing positions and orientations, and are associated with technical frames. Anatomical (or bony) landmarks are used to define bone-embedded local frames for each body segment. The force template describes the properties of the external force systems acting on the biomechanical system. These external forces can be set as known (e.g. measured by force plates) or as unknown.

For kinematic analysis, a least square method [2] is used to estimate the position and orientation of body segments from the technical marker coordinates. The CAST protocol [1] is employed, based on a set of calibration procedures, to establish the mapping between the technical and anatomical frames. The calibration procedure allows for the use of different landmark identification techniques (e.g. markers and/or wands). The joint centers can be identified using functional methods or directly from anatomical landmarks. The anatomical landmarks (derived or real) are then used to define anatomical frames and the orientations of body segments. Thereafter the joint kinematics can be described based on the topology defined in the body template.

For kinetic analysis, the inverse dynamics method is employed. However, this differs from the conventional approach where the calculations proceed sequentially, from distal to proximal segments. In SMAS, the calculation sequence depends on the system topology and the environmental constraints defined in the body and force templates. The algorithm starts from all solvable segments, calculates the forces and moments at their adjacent joints, and then runs iteratively until no solvable segment remains. Different approaches are used to derive joint forces and moments according to the determinacy of the system. In the under-determined case, inverse dynamics is used to derive all the solvable joint forces and moments, whereas, in the determinate case, all joint forces and moments can be calculated. If redundancy exists, a least squares method [3] is employed to improve the accuracy of the calculated joint kinetics.



**Figure 1:** A SMAS 3D model of whole-body walking. The polygons represent the body segments with anatomical landmarks at their vertices.

### RESULTS AND DISCUSSION

The methodology is being implemented as a MATLAB based software package, SMAS, which is now almost complete. Figure 1 shows a 3D whole-body SMAS model. The SMAS methodology applies to general biomechanical multi-segment systems, and makes best use of the available kinematic information. Moreover, unknown external forces and moments can be derived, as well as the internal joint forces and moments.

### REFERENCES

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