Instrumental movement analysis offers valuable insights into human movement for screening, treatment planning, and predicting neurological disorders. Traditional marker-based (MB) systems, though precise, are costly and require extensive setup. Advances in computer vision have led to more accessible, portable, and user-friendly markerless (MS) systems. Recently, RGB-D technology has been emerging, integrating RGB with infrared depth sensors to enable the generation of depth images with a single camera. Human motion estimation algorithms from a single camera can be categorized into deterministic and AI approaches. Deterministic approaches use specific rules for defining joint centers, requiring a predefined model, or using human anatomical proportions. AI-based methods rely on data-driven motion characteristics enhanced by deep learning and may include human models to refine estimates. However, many single-camera methods lack validation against clinical standards in pathological populations, or, if validated, only a single joint was tested, or their clinical applicability is limited by uniform backgrounds and color filters.

The first part of this thesis focuses on gait analysis which is a useful tool for follow-up and screening purposes. In this context, the aim is twofold: (*1*) to propose and validate, against a MB system, deterministic MS protocols based on a single RGB-D camera in patients with cerebral palsy (CP) and foot deformities and (*2*) to explore the clinical validity of AI-based algorithms on healthy subjects. Regarding deterministic approaches, a 2D model-based protocol was proposed and validated on 18 patients with CP (*1a*). This method requires the calibration of a 2D model in static, loading, and swing phases to partially compensate for movements outside the sagittal plane including the manual identification of specific anatomical landmarks on the three images. To overcome these limitations, a 3D version was developed (*1b*), exploiting a 3D statistical lower-limb model, and validated on 10 patients with CP and foot deformities. The innovative aspect of this work lies in the reconstruction of a 3D subject-specific model from three static recordings using a single camera, unlike traditional methods based on multiple cameras. The 3D method demonstrated comparable performance to the 2D MS protocol in terms of mean absolute error against MB system for gait features related to the hip (4.2 deg vs. 3.7 deg), knee (4.0 deg vs. 4.3 deg) and ankle (3.8 deg vs. 3.5 deg). Moreover, this 3D protocol demonstrated good reliability (ICC>0.75) for gait features derived from sagittal joint angles comparable to MB protocol. The proposed 3D protocol is fully automatic and effectively compensates for movements outside the sagittal plane without requiring multiple 2D models and manual intervention during models' calibration. In addition, this thesis proposed an innovative 3D MS protocol for studying sagittal foot kinematics using a single camera (*1c*) as an alternative to MS methods modeling the foot as a single segment. A two-segment foot model composed by mid-rear and forefoot foot connected by metatarsophalangeal joint was developed, showing average root mean square errors of 5 deg for the metatarsophalangeal joint and 4.8 deg for the ankle in 10 children with foot deformities. The second aim (*2*) focused on the investigation of the clinical applicability of the Azure Kinect body tracking software development kit (SDK) evaluated against the MB system on five healthy subjects. Results indicated Azure Kinect body tracking SDK can introduce errors of about 8 deg for the hip, 2 deg for the knee, and 33 deg for the ankle, demonstrating that its main limitation is in ankle angle computation, which was estimated using the inclination of the segment from the ankle joint to the toe, not representative of actual foot inclination. Additionally, when legs overlap during the gait cycle, Azure Kinect body tracking SDK suffers from an unpredictable left-right confusion, making this method unsuitable for clinical gait analysis.

The second part of the thesis regards upper-limb movement analysis for early detection of movement disorders in preterm infants. General Movement Assessment, proposed by Heinz Prechtl, is the gold standard but requires extensive training and time, being based on visual assessment. 3D MB analysis could be accurate but interferes with infants' natural movements. Thus, many studies focusing on 2D MS video analysis have been proposed. However, 3D analysis using a single RGB-D camera could offer more accurate insights due to the 3D nature of movement. For this reason, a MS protocol was proposed to extract general movement metrics in preterm infants at home using a deep-learning algorithm, DeepLabCut, and a custom algorithm to reconstruct 3D trajectories of upper limb points of interest, using depth images, considering body occlusions and camera movements. This method was tested on 8 infants aged 3 to 5 months and on a pair of twins with divergent health profiles. The results showed that general movement metrics could be effectively extracted and may serve as valuable tools for the early detection of movement disorders, although with some limitations due to environmental factors in uncontrolled scenarios. In conclusion, this thesis demonstrates the increasing viability of MS approaches in clinical movement analysis due to advancements in technology and computer vision algorithms. The clinical applicability of the proposed protocols is being evaluated in Sweden, USA, and Italy aiming to integrate MS analysis into clinical practice.