A HYBRID MARKERLESS APPROACH FOR 2D GAIT ANALYSIS: APPLICATION TO GAIT OF CHILDREN WITH CEREBRAL PALSY

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SUMMARY

In this study, a 2D hybrid markerless technique is proposed to estimate the lower limb joint kinematics in children with cerebral palsy (CP). The markerless methodology presented is defined as hybrid since it uses garments as “segmental markers”, specifically high-cut underwear which contributes in defining the pelvis segment and ankle socks for the definition of the foot segment. This method was validated by using a stereophotogrammetric marker-based system. Differences in the joint kinematics estimates obtained with the two techniques were within the intra-subject variability. This makes the proposed hybrid technique to be a possible economical alternative for estimating the lower limb joint kinematics of children with CP.

INTRODUCTION

Marker-based movement analysis is commonly used for determining the lower limb joint kinematics in children with CP [1]. However, skin markers may cause uneasiness to the children and hinder with their natural walking. Besides, the skin marker placement is time consuming. To overcome these setbacks, markerless techniques can represent a promising alternative. In this study, we present a 2D hybrid approach (HA) based on markerless methodologies [2] and which uses underwear and socks worn by subjects as “segmental markers”. The results provided by the proposed HA were compared with those obtained using a marker-based approach.

METHODS

Six CP children (four females, ages = 10 ± 2 yrs) walked at self paced speeds and five trials were recorded for each subject. During the acquisitions, subjects wore white high-cut underwear and white ankle socks. Marker positions data were acquired using a six-camera stereophotogrammetric system (BTS® SMART-D, 640x480 pixels, frame rate: 60Hz). One of the cameras was positioned laterally to obtain a sagittal view of the subject’s gait, its infrared filter was removed and shutter speed and strobe time were set to obtain a gray scale (GS) image of the scene including the subject’s lower limbs. Lower limb kinematics was estimated according to BTS Davis protocol. An AMTI force platform was used to detect heel strikes and toe offs.

In the HA, high-cut underwear and ankle socks were used to isolate the pelvis and the foot from the lower limbs. The following anthropometric measurements were recorded: M1, distance between the high-cut of the underwear to the femoral condyle; M2, distance between the femoral condyle and the edge of the ankle sock; (Figure 1a).

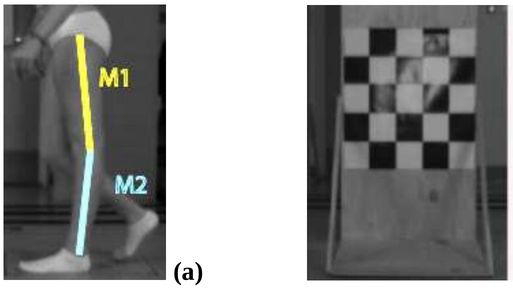


Figure 1 – (a) The measurements M1 and M2. **(b)** Checkerboard.

A checkerboard of known geometry and size (Figure 1b) was used for calibrating the GS camera. All cameras, including the GS camera, acquired the walking trials synchronously. A sample frame from the acquisitions is shown in Figure 2a.

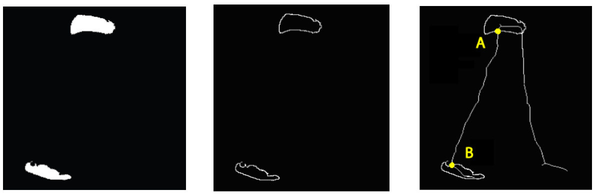
Mixture of Gaussians (MoG) segmentation method [3] was applied to the images acquired by the GS camera to extract the background from the moving foreground (Figure 2b). MoG is a statistical method which uses a finite number of Gaussian distributions to characterize the complex backgrounds.

Segmented outputs were “skeletonized” to determine the inner axis of the lower limbs. Medial Axes Transform (MAT) [4], a shape model that characterizes an object by the set of maximal circles that are completely contained in the object, was used. The medial axis passing through the centers of the circles represented the “skeleton” of the image. The skeleton of the segmented image is shown in Figure 2c.

(a) (b) (c)

Figure 2 – (a) Sample frame. **(b)** Segmented frame. **(c)** Skeletonized frame.

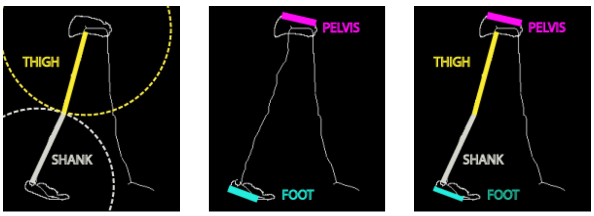
After the skeletonization, thresholding was applied to the original image frames to isolate the high-cut underwear and ankle socks from the image by using their intensity values (Figure 3a). The extracted garments were automatically grouped and labelled as distinctive objects. Edge detection was applied to the labelled garments to extract the edges of the garments (Figure 3b) and their edged outputs were overlapped with the skeletonized images so that the intersection points A and B could be determined (Figure 3c).



(a) (b) (c)

Figure 3 – (a). Thresholded garments. **(b)** Edged garments. (**c)** Intersection points.

The intersection points were used for the extraction of body segments. The thigh segment was identified as the segment connecting point A to the intersection of the circle, centered in A and having radius equal to M1, with the skeletonized line of the leg. The shank segment was identified as the segment connecting point B to the intersection of the circle, centered in B and having radius equal to M2, with the skeletonized line of the leg (Figure 4a). The pelvis reference axis was defined by fitting a line to the upper edge of the underwear. The foot reference axis was defined by fitting a line to the rear part of the lower edge of the sock (Figure 4b). The reference axes can be seen in Figure 4c.



(a) (b) (c)

Figure 4 – (a) Thigh and shank segments. **(b)** Pelvis and foot segments. **(c)** The four reference axes fitted on the skeleton.

During walking, swing of the arms caused occlusions hence the high-cut underwear was seen partially or as two blobs and the intersection point A was undefined. To overcome these problems, labeling and convex hull operations [5] were used.

RESULTS AND DISCUSSION

The kinematic curves obtained using the HA and the marker-based technique were compared by computing the Root Mean Square Deviation (RMSD) after removing the mean differences of the curves (Δ). A similar analysis was performed on the kinematics estimate provided by the marker-based technique to determine the intra-subject variability ($RMSD_v$). Table 1 shows the average values of RMSD relative to the lower limbs sagittal kinematics, average Δ values and average $RMSD_v$. Results showed that lower limb sagittal kinematics provided by the HA and the marker-based technique showed similar kinematics estimate throughout the gait cycle. Higher Δ values for the ankle plantar/dorsi-flexion angle were due to the marker-based system's computation: the marker on the heel was removed after acquiring an initial standing acquisition and that initial angle was used as an offset in the walking acquisitions. RMSD values were in general within the intra-subject variability.

CONCLUSIONS

This is, to authors' knowledge, the first attempt to apply a markerless technique for the gait analysis of CP children. The absence of markers represents a valuable advantage in terms of patient discomfort. The performance of the proposed hybrid markerless approach was quite promising for its future use. A major limitation was that only one side during gait could be recorded, however by adding an additional sagittal camera bilateral analysis can be performed. As a future work, the proposed technique can be improved so that CP children with assistive devices can also be analyzed. Finally, the reduction of the processing time (60 sec per image frame) is desired for clinical applications.

ACKNOWLEDGEMENTS

The authors thank BTS® Bioengineering for the instrumentation and technical support provided for this study.

REFERENCES

1. Gage JR, et al., *The Journal of Bone & Joint Surgery*. **77**:1607-1623, 1995.
2. Surer E, et al., *Gait & Posture*. doi:10.1016/j.gaitpost. 2011.01.003, 2011 (in press).
3. Stauffer C and Grimson WEL. *Proc. IEEE Conf. Coputer Vision and Pattern Recognition*. **2**:246-252, 1999.
4. Lam L, et al., *IEEE Transactions on Pattern Analysis and Machine Intelligence*. **27**:553-568, 1997.
5. Barber CB, et al. *ACM Transactions on Mathematical Software*. **22**:469-483, 1996.

Table 1: Average RMSD values and Δ of six subjects for the angles of ankle plantar/dorsi-flexion (α), knee flexion/extension (β) and hip flexion/extension (γ) and their average intra-subject variability.

	Subject#1			**Subject#2**			**Subject#3**			**Subject#4**			**Subject#5**			**Subject#6**		
[deg]	**α**	**β**	**γ**	**α**	**β**	**γ**	**α**	**β**	**γ**	**α**	**β**	**γ**	**α**	**β**	**γ**	**α**	**β**	**γ**
$\mathbf{RMSD_{avg}}$	3.1	3.9	4.7	4.5	4.7	4.1	3.8	8.5	7.6	6.0	6.0	7.1	2.8	5.2	3.9	3.0	4.6	5.4
$\mathbf{\Delta_{avg}}$	2.9	0.3	0.7	4.0	1.2	0.4	3.9	1.8	1.4	4.5	2.1	2.4	4.3	0.8	1.2	4.5	1.1	1.5
$\mathbf{RMSD_{v\_avg}}$	2.9	5.0	3.3	9.3	12.8	11.9	2.7	7.9	6.3	9.7	6.9	4.7	1.7	3.5	2.3	2.3	4.2	3.3