subjects 3 and 4 had more varying symmetry ratios, closest to 1 is the wearable system trial of subject 4. We speculate that with the flexibility of the system, users would be able to habituate to it in rather a short while, and achieve more symmetrical gait patterns. We will focus on this issue in future studies to observe the changes in gait patterns with assisted motion over time.

Figure 10 shows the joint trajectories and the ground contact pattern of the gait trial on ground with start and stop support. The trajectories shown from up down are the unaffected leg's hip and knee joints, the robot's hip and knee joints, the cane's tilting angle, the right foot sensors ground contact measurements, and the left foot sensors ground contact measurements. Underneath the trajectories are illustrations of the moments of transition, showing the successful transition from start to walk to stop motions. This experiment represents an aspect of basic locomotion assist such that for a hemiplegic person to start, walk, and stop with support from the exoskeleton robot. We consider that this scenario could also be implemented in robot assisted neuronal rehabilitation for a hemiplegic person. From the experiments we confirmed the feasibility of the developed wearable system for control of an exoskeleton robot with healthy subjects. All subjects used the system successfully and were able to use the wearable system to control the exoskeleton robot by using the instrumented cane as an interface with the robot for continuously and voluntarily guided support. However, we still need to run a pilot test with a hemiplegic person to verify the feasibility with a locomotion affected person. In the near future we look forward to having a pilot test with a hemiplegic person, and getting feedback on needed adjustments to the system. Then we may proceed to patient trials for assist and/or rehabilitation of hemiplegic people.

6. Conclusions

In this work we developed a wearable gait measurement system with an instrumented cane for control of an exoskeleton robot. The system utilizes the upper-lower limb coordination, which produces an assisted motion in harmony with unassisted limbs, and the body motion as a whole. We verified the function of the developed wearable system through trials of walking on treadmill, and comparison with similar trials by using motion capture system. The wearable system holds the advantages of being affordable and versatile for practical use.

By equipping the cane with motion and force sensors we were able to use it to capture the arm's motion, and to use it as an interface with the exoskeleton robot. We consider the instrumented cane also as a tool for gait measurement. It enables capture of the arm motion, and therefore the user intention. Measuring the arm motion directly could be prone to more cycle-to-cycle variation due to absence of the resetting effect of ground contact. The cane on the other hand extends the arm to the ground, which makes it more incorporated in gait, and also enables the benefits of light touch on balance and postural control.

Finding an intuitive and feasible interface between human and robot is essential for practical use of assistive technology. The wearable gait measurement system and robot control system suggested in this work represent a feasible approach for assistance and rehabilitation of locomotion affected people with an exoskeleton robot and an instrumented cane. With the proposed system it is possible to provide assistance in everyday life, and it is also possible to design new rehabilitation programs with consideration of upper-lower limbs coordination for physically challenged people.

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Conflicts of Interest

The authors declare no conflicts of interest.

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