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# Development of a Network System Combined with Ambulatory and Non-conscious Physiological Measurements for Supporting Challenged Kids -A New Proposal of a Gait Monitoring System for Use in Rehabilitation-*

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*Abstract*—**Various physiological measurement techniques have been developed to support healthcare and daily living of adult including elderly. However, in light of the rapid growth of the declining birth rate, promotion in care and life support for children are not enough. Especially in rehabilitation for disabled children, i.e., challenged kids, it is important for therapist to evaluate the efficacy of rehabilitation and the health condition. Share of these information with educational, welfare, and government institutions are also needed for accurate life support. Therefore, the quantitative data of the activities and daily health status are helpful. From these viewpoints, we are developing a new network system for monitoring the activities and the health status of children using ambulatory and non-conscious physiological measurements as well as data browse at anytime and anywhere. Firstly, we propose a wearable gait monitoring system to support evaluation for the efficacy of rehabilitation. In this study, the present system can successfully detect the characteristics of postural changes in children with disorder of movement, demonstrating its usefulness and availability to the evaluation for the effect of the brace attached to the subject's lower limb.**

## I. Introduction

In the super-aging society, promotion in daily physiological monitoring is needed for prevention of lifestyle-related diseases, acute life support or therapies for inpatients and/or outpatients having chronic disorder, and home medical care. From these viewpoints, various less-burdensome physiological measurement techniques and network systems were designed [1]-[10]. Also, we developed an ambulatory system measuring the detailed postural changes together with walking speed [11] and non-conscious measurement systems without the need either to attach any biological sensors to the subject's body and any troublesome operations of measurement devices during normal daily life [12]. These showed their high measurement precision by comparison with simultaneous recordings of conventional methods and their usefulness for the medical care and the rehabilitation field [13], [14].

On the other hand, in light of the rapid growth of the declining birth rate, further support for children and their family is also necessary. The importance of care, therapy, and life support for children with disabilities, i.e., "challenged kids" is well recognized in the field of rehabilitation. In order to carry out the efficient therapies, it is needed for therapist to evaluate the activities, the efficacy of rehabilitation, and the health condition. Furthermore, share of these information with the educational, welfare, and government institutions are also needed to support their daily life.

Therefore, to support the challenged kids accurately, the quantitative data of the activities and the daily health status are helpful for guiding the rehabilitation and care process. For example, the evaluations of the activities using video camera recordings or 3D motion capture system are impracticable, because the range over which such recording is possible is limited and its operation is troublesome. Moreover, the healthcare monitoring using commercially available devices are very burdensome for the children in terms of attachment of biological sensors and operations of the devices. Moreover, in the earlier study, new physiological measurement techniques and network systems have been applied for only adult including elderly and thus its availability to the rehabilitation of disabled child was not evaluated.

To solve these problems, we are developing a new network system for monitoring the activities and the health status of the disabled children using the ambulatory and non-conscious physiological measurements as well as data browse at anytime and anywhere. We are naming this system "Challenged-Kid's Information Delivery Service Note, *c*-KIDS Note". Especially in this study, using the wearable gait monitoring system [11], [13], newly combined with network, we have firstly investigated its capability to evaluation for the efficacy of the brace attached to the lower limb during rehabilitation program in five children with disabilities.

## II. Materials and Methods

Figure 1 shows the new concept of the network system combined with the ambulatory and the non-conscious physiological measurements for supporting disabled child. Using the ambulatory system, the postural changes and activities during rehabilitation program and daily living are obtained in order to evaluate the efficacy of the therapies.

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Also, using the system located in the toilet and the bed, the health information such as the body and excretion weight, the pulse, the respiration, and the body motion. These data are networked and shared using a tablet PC or a smart phone.

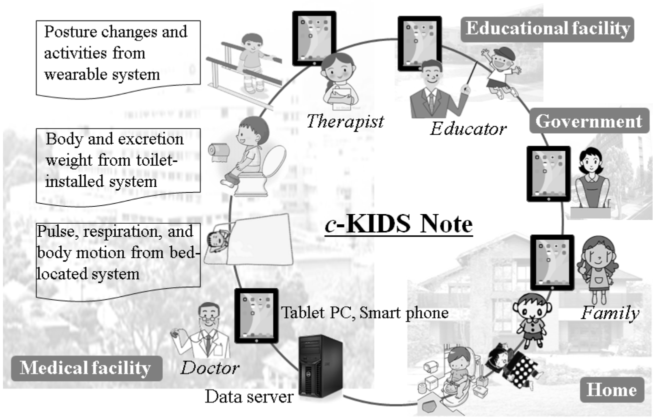


Figure 1. New concept of network system combined with ambulatory and non-conscious physiological measurements for supporting disabled child, naming Challenged-Kid's Information Delivery Service Note, *c*-KIDS Note.

To achieve the concept mentioned above, we firstly attempted the gait monitoring of the challenged kids in a rehabilitation room using the wearable system as shown in Figure 2. In this study, the sensor units are smaller than those of previous system [11] and in addition the data accumulated in the sensor units can be taken out using a smartphone and a tablet PC by the Bluetooth and be transferred to the data server. By these improvements, the therapist could measure the gait of the children and browse the data without cumbersome operation. The system details are shown below.

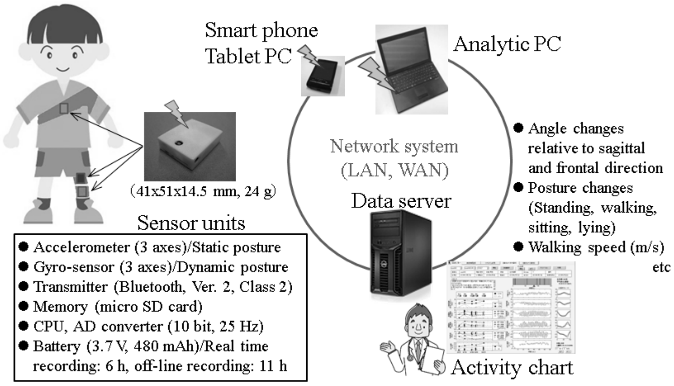


Figure 2. Outline of ambulatory gait monitoring system for quantitative assessment of posture changes and activities in challenged kids.

The sensor unit consists of three axes accelerometer (LSM303DLH, STMicroelectronics) and gyro-sensor (ITG-3200, InvenSense), transmitter (Bluetooth, Ver. 2.0, Class 2), micro SD card, CPU, and battery. Each sensor signal can be recorded with sampling frequency of 25 Hz to obtain accurate angle change, based on the preliminary experiment.

The data are automatically analyzed to obtain the angle changes of each part relative to the sagittal and the frontal plane and the knee angle using the accelerometer signal of DC~0.5 Hz during static posture and the gyro-sensor signal during dynamic posture of gait [13]. To obtain the accurate angle change during walking, the cut-off frequency of the digital band-pass filter for the gyro-sensor signal can be automatically selected based on the gait cycle of respective subjects.

The analyzed data are also led to the server and can be browsed in web page, no matter when or where the therapists, doctor, and the other care staff need these data. The data are securely transferred using the virtual private network and the input of ID and password are also required to view the data.

To evaluate the effectiveness of the brace attached to the lower limb of the children, we carried out the gait monitoring in five children with disabilities by cerebral palsy, chromosomal abnormality, and injure, as shown in Table 1. Before the measurement, we obtained permission from the Ethical Review Board of the hospital and written informed consent was obtained from each of the subjects and their parent. The experimental protocol is shown below.

The subjects walk in straight of 16 m. To evaluate the effectiveness of the brace for the walking, the posture changes in attaching the brace and bare feet were monitored. The categories of the brace attached to the respective subjects were selected based on the therapist's evaluation for gait using the directly observation as shown in Table 1. In this study, the insole to arrange the foot angle or the ankle foot orthosis to support the motion of lower limb is attached to the respective subjects. The lower limb sensors were attached on more severe side of disabilities. To clarify the motion characteristics of the children, the analytical program detect the positive and the negative peaks of the angle changes every gait cycle and their mean and standard deviation, S.D. values. The angles in heel contact and off are also obtained. Using these data and subject's leg length, the walking speed can be calculated every gait cycle [13]. After the measurements, the effectiveness of the brace was evaluated using the analytical result obtained from the present system.

TABLE I. SABJECT DETAILS

| Subject | Gender | Age | Diagnosis | Brace |
|---|---|---|---|---|
| Child 1 | Female | 8 | Cerebral palsy | Insole (Both legs) |
| Child 2 | Female | 8 | Cerebral palsy | Ankle foot orthosis (Left leg) |
| Child 3 | Female | 5 | Cerebral palsy | Ankle foot orthosis (Both legs) |
| Child 4 | Male | 4 | Chromosomal abnormality | Insole (Both legs) |
| Child 5 | Male | 6 | Drop foot by Injury | Ankle foot orthosis (Left leg) |

## III. RESULTS

Firstly, the representative data are shown in two subjects. Figure 3 shows the angle changes in sagittal plane and walking speeds in child 1. The posture changes in non-brace (left part) and attaching the brace (right part) are shown in this figure. In non-brace, the thigh was seen to move only forwards and the knee joint moved with too wide range, in addition fluctuations in the trunk angle were observed. However, by attaching the brace, the thigh was seen to move backwards and the shank moved more forwards. The range of knee angle and the fluctuation of the trunk angle also decreased. Moreover, the walking speed increased, showing that the gait motion was improved by the brace. But, the repeatability for the peak values of the knee angle changes decreased, showing the need of the further training.

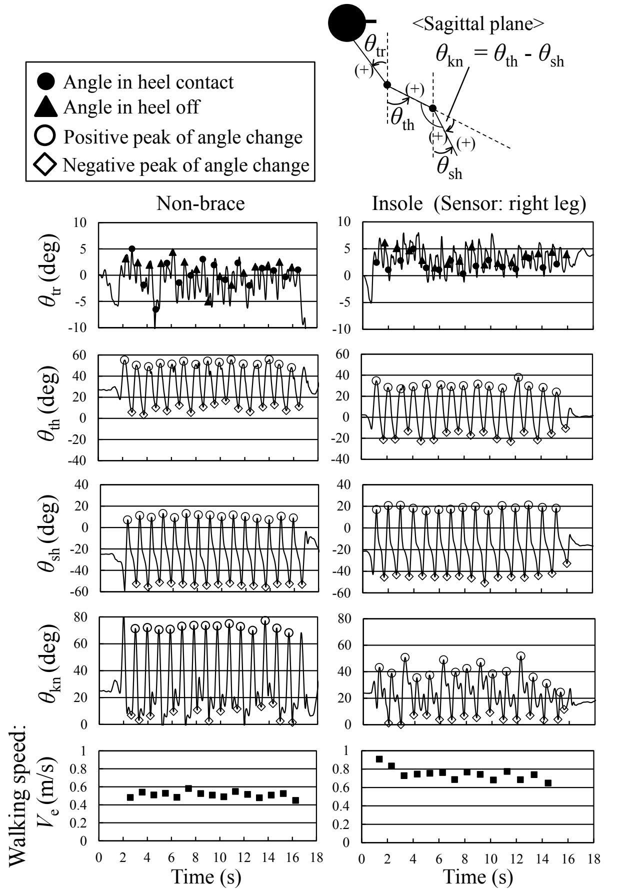


Figure 3. Recordings of gait monitoring in child 1. The trunk, thigh, and shank angles relative to the sagittal plane and knee angle are shown. The walking speeds from heel contact to off are also plotted every gait cycle. Definitions of angles are also shown in the top of the figure.

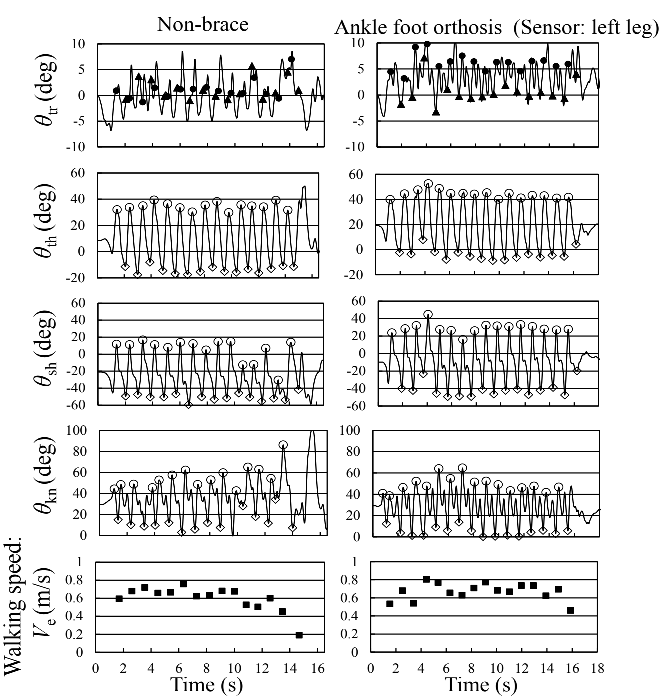


Figure 4. Results of gait monitoring in child 2. The angles relative to the sagittal plane, knee angle, walking speeds are shown. Definitions of angles and plots are same with figure 1.

Figure 4 shows the results of gait monitoring in child 2 with or without a brace (ankle foot orthosis). In these results, while the drastic differences of the walking speed between two conditions were not observed, the motion fluctuations of the positive peak in the lower limb decreased, showing the effectiveness of the brace. However, in the trunk, unsteady fluctuations were detected, showing the need of further support.

Figure 5 shows the averages and the S.D. values of walking speed, $V_e$, gait cycle, $T_e$, trunk angle in heel contact, $\theta_{tr,hc}$, and off, $\theta_{tr,ho}$, positive and negative peak values of thigh and shank angles, $\theta_{th,p}$, $\theta_{th,n}$, $\theta_{sh,p}$, $\theta_{sh,n}$, and range of knee angle change, $\theta_{kn}$, every gait cycle. From these results, $V_e$ of all subjects increased using the brace ($p < 0.05$) especially. However, increase of the S.D. values by attaching the brace were also observed in the data, showing the decrease of the repeatability of the motion.

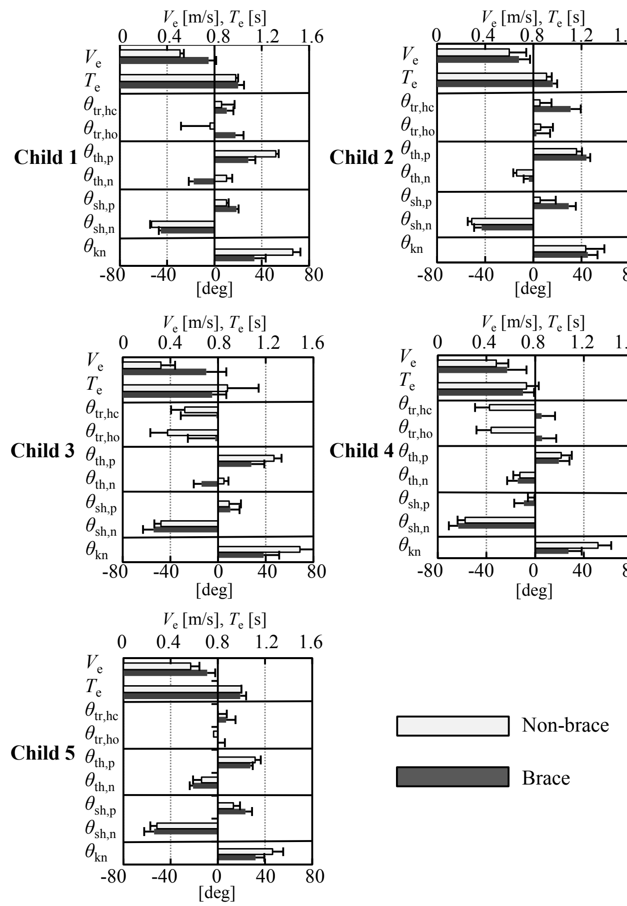


Figure 5. The averages and S.D. values of walking speed, $V_e$, gait cycle, $T_e$, trunk angle in heel contact, $\theta_{tr,hc}$, and off, $\theta_{tr,ho}$ (= actual value x5), positive and negative peak values of thigh and shank angles, $\theta_{th,p}$, $\theta_{th,n}$, $\theta_{sh,p}$, $\theta_{sh,n}$, and range of knee angle change, $\theta_{kn}$, every gait cycle.

## IV. Discussion

From these results, it is demonstrated that the present system can successfully monitor the gait motion of the challenged kids. Furthermore, not only the child's respective therapists but also the other staffs could share these information using network system and thus they can provide the more effective rehabilitation program and support the daily life of the children and their family as a team.

Using the angle changes and the walking speeds, therapists could assess the change of the motion characteristics by attaching the brace and the improvement of the walking performance. Moreover, the S. D. values of peak values could provide the motion repeatability quantitatively. The therapists cannot understand these characteristics by only direct observation, being useful for evaluating the effectiveness of the brace more accurately. For example, while a child could walk faster by attaching the brace, the decrease of motion repeatability was observed from the S. D. values. In this case, therapist would be able to accurately find out not only improvement of the gait performance but also the needs of further continuous training. Therefore, the therapist can develop the appropriate rehabilitation and life support program for respective children.

To investigate the availabilities mentioned above, more measurements and analyses with a longer time in many subjects would be needed. The changes in the motion characteristics and the keep or recovery processes of the activities in many symptoms should be analyzed. Based on these studies, we need to investigate the assessment method for clarifying the efficacy of the rehabilitation. Also, in these processes, development of the more suitable calculation method of the angles and the walking speeds would be also needed to obtain more accurate value in respective symptoms. Moreover, the posture analysis in 3D orientation would be needed to evaluate more detailed motion characteristics.

On the other hand, the frequency analysis for acceleration, angular rate, and angle changes might demonstrate the repeatability and stability of trunk, thigh, and shank motions. This method would be useful for easily checking not only the effectiveness of the brace but also the risk of falling. Moreover, these studies might decrease the number of the sensor units attached to the subject, if the frequency spectrum showing the effectiveness of the rehabilitation is clarified in specific body part. These investigations are carried out now and we will report these developments near the future.

Furthermore, to implement the network system combined with the non-conscious physiological measurements, the design of the sensing techniques in the challenged kids will be needed for pulse, respiration, and body motion in bed and body and excretion weight in toilet. Their fusion with the network system and the data visualization are also needed to clearly observe the efficacy of the care.

## V. Conclusion

In this study, we proposed a new network system combined with the ambulatory and non-conscious physiological measurements for supporting challenged kids. To achieve this purpose, we firstly investigated the capability of the ambulatory gait monitoring system. From the results, the motion characteristics during walking in five children are successfully obtained, demonstrating its usefulness to the evaluation for the effectiveness of the brace attached to the subject's lower limb. Further investigations will be needed, such as more measurements and design of the non-conscious physiological measurements in toilet and bed and their network system.


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