1. Introduction

The human locomotion is one of the most important motions in daily life. The disease of gait has much influence on the patient's life in society and generally requires a long period of rehabilitation, during which it would be useful to have a periodic evaluation of the patient's recovery. Therefore, one of the main problems in the patients with disabilities is the evaluation of the initial functional loss and of the functional recovery which can be obtained by prostheses, braces, surgical operations or other rehabilitation procedures. The quantitative evaluation is particularly important because the recovery requires long period, sometimes, months or years.

It is general that the measurement data used for the gait analysis consists of three categories as follows:

1) Ground reaction force which reflects on the motions during the stance phase.
2) Kinematic coordinates which are angular and linear displacements at each joint.
3) Electromyographic (EMG) data from the various muscles associated with locomotion.

These data are utilized for the assessment of the therapeutic or training effectiveness, the comparison between gaits before and after operation, or the judgement of fitness of artificial legs etc. Then, the medical doctor or physical therapist has to read the biomechanical, kinematic and physiological meanings which the data patterns imply. However, since the human gait is complex movements where the body and limbs are tangled together, it is very difficult for them to identify the functional gait capability from the data in connection with the patient's disorders.

In a sense, it might seem to be similar to ECG analysis. However, the primary purpose of ECG analysis is to examine whether there is any disease. In contrast with that, the gait analysis need not to examine it, because it has been confirmed by the doctor's examination. It is the primary purpose of the gait analysis to identify the relation between the measurement data and the patient's disorders.

From this point of view, it is reasonable that the process of gait analysis is divided into the four stages as follows:

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1) **Identification of the gait**, which means to extract the essence of gait disabilities and functional deficits, called gait parameters, from the measured data.

2) **Estimation of causal relations**, which means to estimate various relations between the gait parameters and patient's motor disabilities.

3) **Gait evaluation**, which is to grade the degrees of gait disabilities and evaluate the effects of rehabilitation or surgical operation.

4) **Gait prediction**, which means to predict the gait after treatment and training.

In the last decade, new techniques have been developed in the field of artificial intelligence (AI) that have enabled clinically oriented diagnostic programs to be created. Such programs are most commonly referred to as {consultation system} or {expert system} and are characterized by large amounts of domain specific knowledge and methods that embody the clinician's problem solving strategy. Many AI-based medical diagnosis systems have had notable success in recent years, i.e., MYCIN, PUFF, INTERNIST etc².

The present paper proposes a new knowledge-based gait analysis consultation system which supports the doctor's or therapist's understanding of the patient's gait, particularly concerning its biomechanical aspects. The system enables them to extract different biomechanical and kinematic features of the patient's gait from the measured data. It must provide a useful tool for doctors and therapists.

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**Fig.1 Framework of Gait Analysis Consultation System**
2. Framework of Gait Analysis Consultation System

The gait analysis consultation system consists of five subsystems as follows (see Fig. 1):

1) Measurement data processing subsystem
2) Biomechanical analysis subsystem
3) Knowledge database
4) Inference/Analysis subsystem
5) User Interface subsystem

The system is implemented on a multi-windows system in a SONY NEWS (main memory: 4 MB, 156 MB hard disk, OS: Unix, Language: "C").

3. Measurement Data Processing Subsystem

3.1 Gait Parameters

A gait cycle is divided into seven phases based on floor reaction recordings as follows (see Fig. 2).

**phase 1**: the first double stance phase from the foot contact of the right (left) leg to the foot off of the left (right) leg.

**phase 2**: the first half of single stance phase from the foot off of the left leg to the sign inversion of fore and aft component (Fy) of floor reaction force of the right leg.

![Fig. 2 Phase divisions Based on Floor Reaction Recording](image-url)
Table 1  Gait Parameters (Floor Reaction Force)

<table>
<thead>
<tr>
<th>Temporal/Distance Factors</th>
<th>step length, gait velocity, gait cycle, stance phase, swing phase, double stance phase,</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Component (Fz)</td>
<td>contact force, rising time, number of peaks, first and second peak values</td>
</tr>
<tr>
<td>Fore and Aft Component (Fy)</td>
<td>contact force, max. of acceleration and deceleration forces, integrated values of acceleration and deceleration forces, time ratio, first derivative of acceleration force</td>
</tr>
<tr>
<td>Lateral Component (Fx)</td>
<td>force directions of foot contact, mid-stance and toe off, oscillation component</td>
</tr>
</tbody>
</table>

phase 3 : the latter half of single stance phase from the sign inversion to the foot contact of the left leg.
phase 4 : the second double stance phase from the foot contact of the left leg to the foot off of the right leg.
phase 5 : the first half of swing phase of the right leg corresponding to phase 2 of the other leg.
phase 6 : the latter half of swing phase of the right leg corresponding to phase 3 of the other leg.
phase 7 : the third double stance phase from the foot contact of the left leg to the foot off of the right leg.

On every phase, data processing system computes various gait parameters in terms of floor reaction forces, three dimensional joint angles and torques and EMG. As an example, the gait parameters in terms of the floor reaction force are shown in Table 1.

3.2 Patient's database

The following parameters are used to describe the patient's clinical state.

1) date of examination
2) patient's name
3) name of disease
4) disabled legs
5) with a stick or not
6) with a brace or not
The human body can be considered to consist of a series of links connected together by joints. Assuming rigid body motion, the resulting equations of motion are a set of second-order coupled nonlinear differential equations. Such equations of motion are useful for the evaluation and computer simulation of the human motion. It may be required to compute the dynamic equations which unfortunately requires a fair amount of arithmetic operations. The present
The system has five kinds of typical models as shown in Fig.3. Link models other than them can be arbitrarily chosen by the user. Then, there are the following alternative problems as shown in Fig.4.

1) Inverse Dynamics Analysis

Given the joint angles and their first two time derivatives, the dynamic equations are used to compute the joint forces/torques. In the case of analyzing the closed link systems (e.g. double stance phase), constraint forces such as floor reaction forces are required.

2) Forward dynamics Analysis

Given the joint forces/torques, the dynamic equations are used to solve for the joint accelerations which are then integrated to obtain the joint angles and their velocities. The joint forces/torques might be derived from the control theory or be obtained by modifying the joint forces/torques which have been estimated from the inverse dynamics analysis.

5. Knowledge database

The knowledge base includes the following contents.
1) Normal data knowledge base
The normal values and their fluctuation ranges of the gait parameters are stored, each of which was determined from the references.

2) Gait parameter knowledge base
The kinematic and dynamic interpretations of the gait parameters are stored. In terms of fore-aft component Fy of floor reaction force, for example, it is described that the maximum value is a function of walking velocity and step length, closely depending on the center of mass of the body, and the angles and movable ranges of hip and knee joints.

3) Medical knowledge base in terms of gait diseases
The pathological gaits are globally classified into:

a) abnormality of neuro-muscular system,

b) gait with a pain,

c) disorders of foot or ankle joint,

d) disorders of knee joint,

e) disorders of hip joint.

Further, these five categories are classified into fifty subitems. The medical characteristics of each gait are stored in the database.

6. Inference/Analysis Subsystem

Causal sequences between the gait parameter and the patient’s disease are estimated based on the rules for analysis. The rule is given in "If-Then" form as follows:

If <attribute> of <object> is <value>,
Then <action> Else <action>.

At first, the gait parameters of each phase which have been computed from the measurement data are compared with the normal values. If they are abnormal, the biomechanical causes are estimated from the gait parameter knowledge database based on "If-Then" rules. Then the biomechanical causes which are contradict each other are eliminated. Comparing them with the medical knowledge database and the patient’s database leads to the final causal relations.

Fig. 5 shows an example of the patient with tonic hemiplegia. The right in the figure shows ground reaction forces and the part enclosed with a square denotes the current phase which is covered by the analysis system. The left shows the qualitative evaluation, the normal values and ranges of the gait parameters. The
estimated causes[2/5] denote that there are five estimated causes and the second among them is here shown. The related items list up the items in the patient’s database which seem to be related to the estimated causes.

7. Conclusion

The present system not only displays various graphs of the gate data but also estimates the relation between the doctor's examinations and the gait parameters representing the biomechanical and kinematic characteristics of the gait. The consultation system must be able to provide useful information in different forms for the doctor and physical therapist. In a word, it must be well used as "a tool of thinking". From this point of view, the system would be extended to include dynamic knowledge and qualitative or ambiguous representation.

[References]