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MODEL-BASED MOTION ANALYSIS OF FACTORY WORKERS USING MULTI-PERSPECTIVE VIDEO CAMERAS

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Abstract: Motion simulation of factory workers is one of the core technologies to achieve optimum Human-Machine Co-existing Environment in modern factory design. For the purpose of posture and motion detection evaluation, we introduced Model based Motion Capture with a limited number of markers and Bone-Based Human-body Mockup (BBHM) which can represent bones, skin, muscles, etc. Also it is required that in any environment the motion capturing method can extract the feature points with sufficient accuracy in any environment. Then, we solved by performing a strict calibration using a simple calibration board and Light Emitting Diode (LED).

Key words: Load analysis, precise human mock-up, Calibration, Motion capture, Info-Ergonomics

1. INTRODUCTION

In order to achieve optimum Human-Machine Co-existing Environment in modern factory design, motion simulation of factory workers is one of the core technologies. We have proposed "Info-Ergonomics" as an integration of simulation/evaluation technologies of human workers' motion, in conjunction with database technologies which provides storing/retrieving functions [1]. We think that human centered factors are often overlooked or underestimated although human labor has an important role in the manufacturing process design. It is usually examined from the viewpoint of

Industrial Engineering, Ergonomics, etc. and results are used in production planning, working analysis, and work environment design. Info-Ergonomics is a promising solution to provide total environment of work simulation and evaluation[2]. It consists of a number of component technologies like Human body modeling, Customizing human body model to specific workers, Motion description, Capturing motions from video images, Simulation, Storing time-dependent data into databases, and Spatio-temporal retrieval on databases.

This paper first outlines the Info-Ergonomics concept, next we will be focusing on motion detection and precise human modeling for Info-Ergonomics simulation. Especially we will also discuss requirements of precision of motion detection and propose the motion detection method by multi-perspective video cameras.

2. MOTION ANALYSIS USING HUMAN BODY MOCKUP

2.1 Info-Ergonomics

Info-Ergonomics is a framework of information integration aiming for conceptual and total design of Manufacturing Systems. Recently modeling the machines in the factory, creating virtual machines by using CG, simulating their work and evaluating it are coming into use gradually [3]. But modeling human beings and creating "virtual employee" as a 3D object on computers still has very limited use, because of the human body's high complexity and the limits imposed by the computer techniques. We focus on human body modeling and cooperative work with machines, especially from the viewpoint of comfortability, safety and efficiency.

In Info-Ergonomics approach, we construct a precise human body mock-up which can represent the differences between individuals in body-part sizes, flexibility and other properties. Giving a movement to the human mock-up model, one can estimate physical load and comfortability on each part of that body.

However, due to the complexity of human body, physical-model based evaluation/estimation is applicable only in highly-restricted cases even on "precise" human body mock-up. For example, we cannot solve force balances on musculoskeletal models because infinite solutions exist depending on muscle tension assignment in each part.

On the other hand, in the traditional Ergonomics field, evaluation/estimation of fatigue on a specific part of human body has been done based on questionnaire studies. Also, in Medical Science field, many such discussions have been done from a variety of viewpoints depending on deep knowledge provided by medical experts.

Following the above discussions, we decided the optimal solution should be "hybrid" evaluating systems standing on the three different methodologies. This idea is shown in Fig. 1.

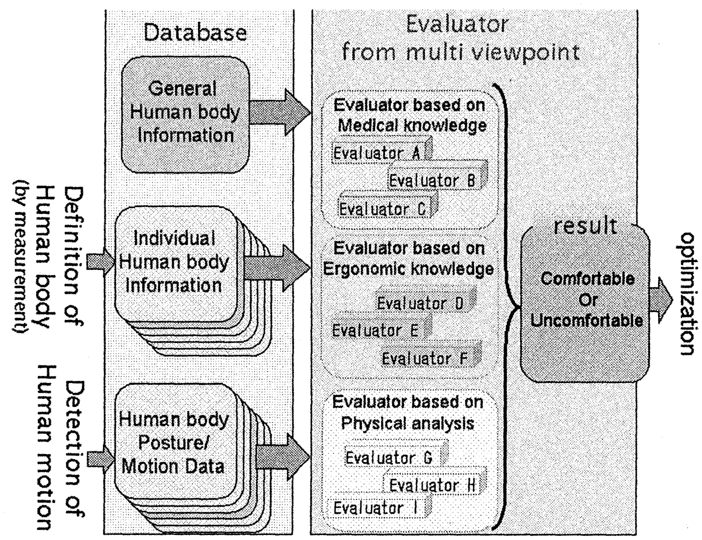

Figure 1. Concept of Info-Ergonomics

2.2 Conceptual Architecture of Info-Ergonomics Simulation System

In order to achieve precise simulation/evaluation, we must detect the postures and motions automatically from specific individuals. We are developing a prototype system on which whole functions are realized in a uniform way. The conceptual architecture and data flow of this system is shown in Fig. 2.

The left-side part of Fig. 2 shows database and data capturing functions. A Video Capture and Motion Analysis System captures several image sequences by multi-perspective video cameras and detects posture sequence of a specific human body (factory worker) by 3D image analysis method. The technical issues on this method will be discussed later.

On the other hand, to realize a precise simulation, the human body itself must be modeled precisely. For this purpose Human Body Measurement

System detect individual body data. All data described above must be stored in a uniform way into databases.

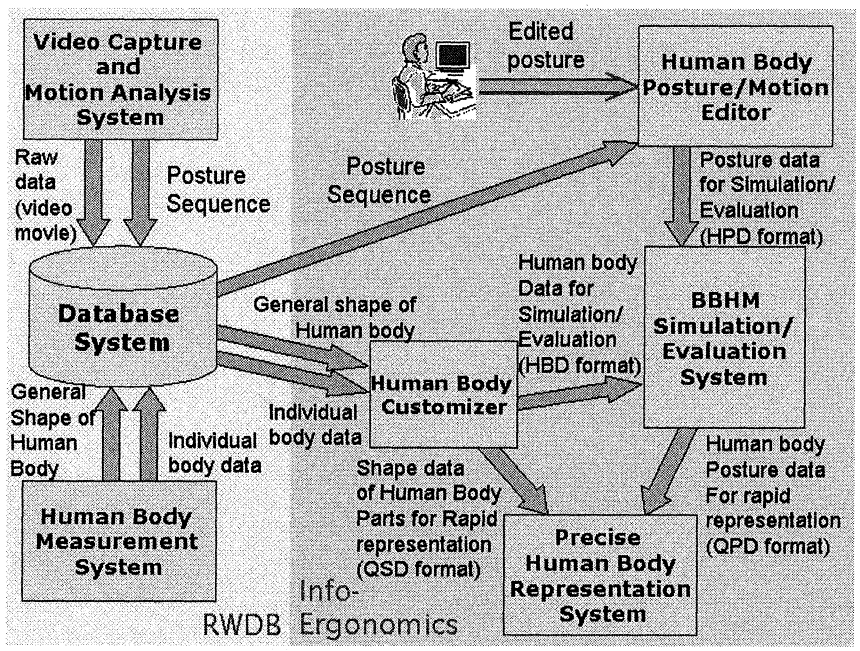

Figure 2. Conceptual Architecture of Info-Ergonomics Simulation System

The right-side part of Fig. 2 shows simulator/evaluator and result viewer. "Human Body Customizer" constructs precise human model from individual body data stored in the database. For the purpose of simulation/evaluation, the module constructs precise human model which reflects the "real" human body size, flexibility, physical strength, and other parameters. The module also constructs human body surface and bones' shape for the purpose of visualizing simulation results. On the other hand, "Human Body Posture/Motion Editor" retrieves a posture sequence in databases, and converts to posture sequence on the precise human model. From those data, "BBHM Simulation/Evaluation System" does hybrid evaluation mentioned above. "Precise Human Body Representation System" displays simulation/evaluation results graphically.

3. MOTION ANALYSIS BASED ON A FEW MARKERS AND HUMAN MOCKUP

3.1 Method of motion analysis

As discussed in previous sections, one of the most important issues is the method of motion analysis.

Especially in motion analysis of factory workers, reduction of testee's load and flexibility of motion capturing environment are quite essential. However, existing systems do not pay attention to such restrictions because most of them force the users to prepare specific environments.

In our approach we have proposed a new method for motion capturing. First of all, we considered again the role of "markers." In the existing systems, the testee must wear 40 or more markers on his/her body. Each camera of the system can detect only markers positions by hardware algorithm. By calculating spatial positions and connecting markers to each other, you can re-construct the posture on the simplified stick model of the human body.

Our first target is to reduce the number of markers, preserving precision. For instance, if we can reduce the markers to less than 6, testee's load will be remarkably decreased, and time for analysis will be also decreased. To solve this problem, we introduced "model based analysis" for posture detection. The outline of Model Based Motion Capturing is shown in Fig.3 and the brief algorithm in Fig. 4.

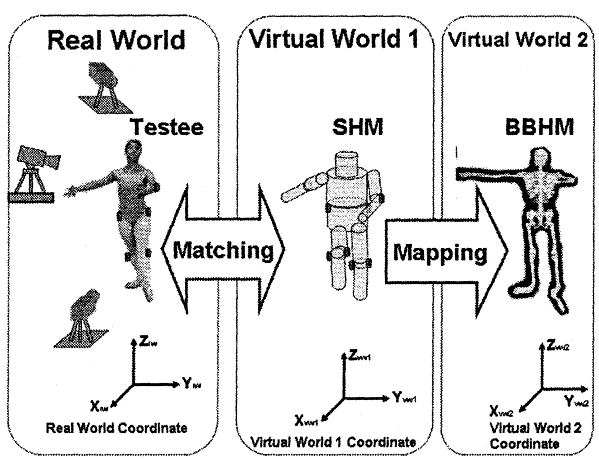

Figure 3. Outline of Model Based Motion Capturing

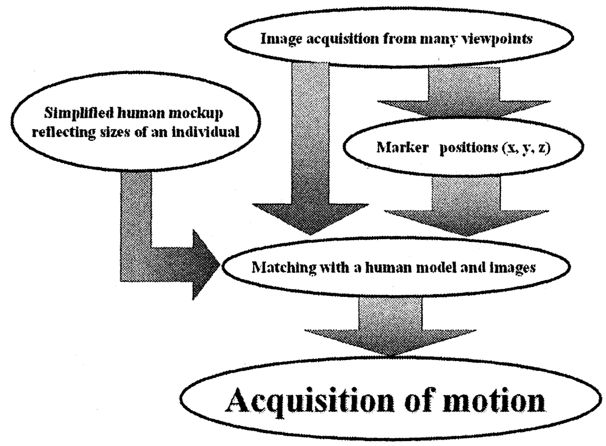

Figure 4. Procedure of Model Based Motion Capturing

In this procedure, after calculating spatial (x, y, z) positions of each marker, the system assigns a tentative posture to the SHM which represents the testee's body. Here we use inverse kinematics to decide the positions of several parts because markers are placed on the limited number of parts. Then using the multi-perspective camera images, we can adjust the posture precisely in a heuristic way.

3.2 Requirements for markers

In the method described in the previous sections, the most important technology is to detect precise positions of markers. Also, the small numbers of markers must always specify the correct posture of a SHM continuously. Generally those are very hard problems to solve. In our experimental system, we introduced three ideas to overcome these problems.

- Camera calibration method using a "standard" object
  To guarantee the accuracy of marker position, a simple standard object are taken from each video camera simultaneously. Then we can calibrate the required camera parameters beforehand.

- Adjusting the markers brightness on the environment
  The brightness of marker points always changes in the environment in which we actually take pictures. We use a light emitting diode (LED) as a marker and choose the brightness depending on the environment.

- Model based Analysis
  We proposed analyzing method which uses a human mockup depending on personal information. This contributes to reduce the number of markers.

In our on-going development, each technology has almost fully been established and contributed to significant results.

4. INVESTIGATION ON DETECTING MARKERS

As discussed in previous sections, markers play the most important role in the motion capturing system. This paper, from now on, will be focusing on marker-related issues. That is:

- Accuracy of the 3-D position detection of the markers
  We confirmed that 3-D positions can be detected with sufficient accuracy by using a standard object.
- Traceability of the marker points in various environments
  We checked that a marker can be pursued by using LED marker, even if brightness changes.

The following subsections describe the verification method concretely.

4.1 Verification of the accuracy of the 3-D position of marker points

In order to detect 3-D positions from images, we have to compute the camera position, camera posture (pan and tilt), and focal length strictly. That is, we have to calibrate the camera parameters.

Generally this problem is called PnP problem, and various discussions has been done. Tsai's algorithm [6] which considers distortion of a camera lens is quoted by many references.

The Tsai's algorithm inputs a set of points on the picture coordinate system and converts them to those of the world coordinate systems ones. Then, it computes a rotation procession and a parallel translation vector as an external parameter, and computes a focal length, lens distortion, a scale coefficient, and the picture starting point as an internal parameter.

We verified whether it can be extracted the marker points with sufficient accuracy by this calibration. As the technique, after calibrating the camera by Tsai's algorithm we take pictures of the pendulum which is attached the LED (light emitting diode) downward, and compute the position of this LED.

External appearance of experimental equipment is shown in Fig. 5.

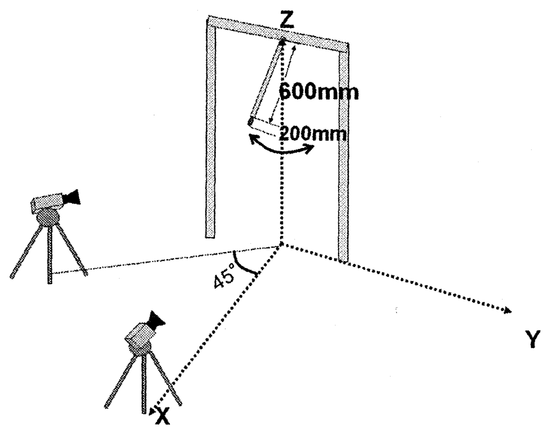

Figure 5. Experiment environment

We used 2 cameras. One is in front position and the other is left. Then, we took an image of the standard object for calibrations.

We compute the 3-D position of a LED using the camera parameters and compare the Actual measurement values.

4.2 Traceability of the marker point in various environment

Since we were able to extract 3-D positions, next problem is how to extract them in the arbitrary photographical conditions. The background brightness is always changing violently in actual capturing environment. Therefore, a marker must be extracted independent from background color changes. Then, we used the LED as a marker which hardly changes hue, even if luminosity value changes.

As for verification method, we used the pendulum attached LED used in the previous section. Since the LED has shone itself, its hue should seldom change even if surrounding brightness changes. We took image sequences in which the pendulum is swaying by 2 cameras. Then, we performed calibration and pursued a light emitting diodes by image analysis.

Now we will explain the procedure of this LED tracing. First, we performed the following procedures in the 1st frame.

1. Edge-preserving smoothing
2. Extract the domain of the color which resembled the specified pixel position mostly.
3. Calculation of each maximum and minimum of HSV in the domain obtained by 2.
4. Calculation of the middle of the domain extracted by 2.

To the successive frames we trace LEDs by following procedure.

1. It leaves only the pixel which is contained in each maximum and minimum of HSV calculated with the 1st frame.
2. Dilation and erosion processing
3. Labeling processing
4. Extracting the domain near the position of the middle of the pixel in the 1st frame.
5. Extracting the position of the middle of the domain extracted by 4.

With the above procedure, we extracted and pursued the 3-D positions of an object from the pixel positions in each extracted picture.

5. AN EXPERIMENT RESULT AND EVALUATION

5.1 The accuracy experiment of the 3-D position of the feature point

We show a calibration result with 2 cameras in Table 1.

Table 1. Calibration result

	Left Image		Center Image	
	Measured value[mm]	Result value[mm]	Measured value [mm]	Result value[mm]
x	2300	2303.2	0	-38.7
y	1329	1351.6	2234	2379.8
z	1041	1041.1	1055	1056.5
x	90	94	90	89
y	-60	-59.4	0	1.2
z	-180	-175.1	180	179.4
f	30	30	25	25.8

Based on this calibration result, we show the result of the 3-D coordinates values of the center of the stationary LED of a pendulum in Table 2.

Table 2. Calibration result

	Measured value[mm]	Result value[mm]
X	0	-46.73
Y	0	-10.83
Z	945	946.65

5.2 The pursuit experiment of the feature point in various environment

We show the result of tracing without shining LED in Fig. 6, and show the result of tracing with shining LED in Fig. 7.

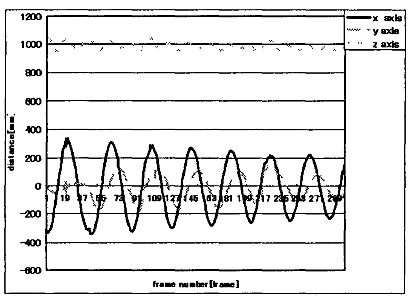

Figure 6. The result when turning off a LED

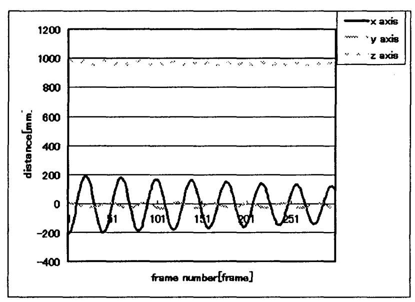

Figure 7. The result when turning on a LED

From these two tables, it can be said that the result with a LED turned on was better. Especially, in fig.6 there is a large difference of the value of y-axis.

6. CONCLUSION

In this paper we described Info-Ergonomics concept which makes it possible to simulate/evaluate human posture/motion with precise human model called BBHM. We also described the conceptual architecture of a simulation system.

Also, we proposed a motion capturing method based on a few markers and human mockup. Then we discussed the motion capturing method which can extract the feature points required for motion analysis with sufficient accuracy in arbitrary environment. The problems are performing calibration correctness and the extraction method of the feature point. We solved them by performing a connect calibration using a standard object, and using Light Emitting Diode as markers.

Many problems are left for the future. By modeling the other components of the human body such as tendon and muscle, it becomes possible to evaluate human motions more precisely and to obtain a lead to understand diseases and factors which restrict the range of motion of joints.

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