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Analysis and Synthesis of Facial Color for Virtual Face Image in Force Display

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Abstract

In this paper, we develop a 4-DOF force display system for the analysis by synthesis of facial color for the interaction with anthropomorphic agent. By using the system, we analyze the changes in facial skin temperature and facial color associated with circulation dynamics in response to forced actions. On the basis of the analysis, we propose a synthetic method for the affect display of virtual face with facial color and expression in force display, and the effectiveness of the method is confirmed. Finally, we develop a prototype of virtual arm wrestling system with anthropomorphic agent using synthesized dynamic three-dimensional facial color and expression.

Keywords : Force Display, Facial Skin Temperature, Facial Color, Color Image Processing, Virtual Face

1. Introduction

Human facial color can be applied to the affect display of virtual facial image, emotional evaluation, and remote health care for friendly human interface. We analyzed the effects of facial color on virtual facial image synthesis with dynamic facial color and expression under the emotional change of laughing[1][2].

In the present paper, we propose a method for the analysis by synthesis of facial color for virtual face image in force display and develop a prototype of virtual arm wrestling system. By using a newly developed force display system and a simultaneous measurement system with a digital video (DV) and a thermography, we first analyze dynamical fluctuations in facial skin temperature and facial color when circulation is forcibly caused to fluctuate[3]. Next, based on the analysis, a three-dimensional facial expression and color enhanced model is developed, and the effectiveness is demonstrated by sensory examination. Finally, the synthesized three-dimensional facial expression model is incorporated in a virtual human, and the force display is used to develop a system for arm wrestling with the virtual human for the affect display of facial color and expression.

2. Force Display System

An outline of a force display system is shown in Figure 1. The specifications for the ranges of motion of each of the joints and the maximum torque (maximum pressure supplied from the air compressor:6.5 kgf/cm^2) of the force display are shown in Table 1. Four air cylinders (SMC) are used as the drive source that controls the joints of the force display;

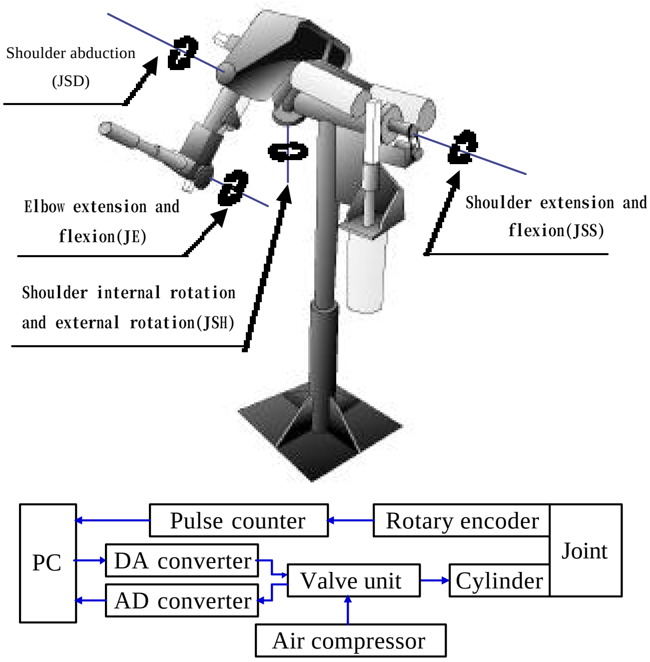


Fig.1: Outline of force display system.

Table.1: Maximum torque and movable range of each joint of force display.

Joint		Range of movement: Human	Range of movement: System	Maximum torqu
JSH	Internal rotation	80 °	90 °	41.8 Nm
	External rotation	60 °	10 °	40.9 Nm
JSS	Flexion	180 °	90 °	83.6 Nm
	Extension	50 °	45 °	82.8 Nm
JSD	Abduction	180 °	90 °	88.0 Nm
JE	Flexion	145 °	120 °	25.5 Nm
	Extension	5 °	0 °	22.4 Nm

the shoulder and elbow joints have four degrees of freedom. Two pressure proportional valves (ITV3051-312BL, SMC) are used to obtain the rotation drive for one degree of freedom. In addition, a rotary encoder is attached to each joint; control of the position of the joint angle is also possible. The input / output signal from the personal computer is converted to a DC voltage by a 12-bit DA converter; the air pressure is controlled by adjustment of the pressure proportional valve by this voltage. The air pressure in the pressure proportional valve can be checked by input to the PC through a 12-bit AD converter. As a result of measuring JSH shaft torque characteristics with respect to five female students aged 15 to 18, the torque was found to be 30 [Nm].

3. Analysis of Facial Skin Temperature and Facial Color in Force Display

3.1 Experimental Apparatus

3.1.1 Apparatus for Measuring Changes in Facial Color

Facial color was measured in a constant state by maintaining the light source in a dark room where there was no effect of external light. Four daylight type photoreflector lamps (color temperature 5500 ° K) were used as the light source. An outline of the facial color measurement apparatus, including the force display system, is shown in Figure 2. The recording section uses a DV camera (DSR-PD100, SONY) capable of processing color images in one-frame unit. The distance between the DV camera and the subject's face is 130 cm. A fixing jig using urethane foam is employed to fix the subject's head in place. The lamp height is adjusted to the height of the seated subject's face. The effect of color temperature is minimized by performing white balancing using a JIS standard lamp (N9.0, white).

3.1.2 Apparatus for Simultaneously Measuring Facial Skin Temperature and Facial Color

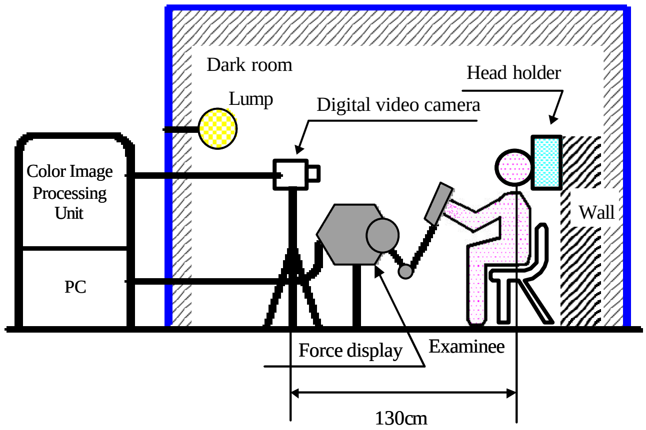


Fig.2: Setup of the measurement of facial color in force display.

An outline of a system for simultaneous measurements of facial skin temperature and facial color, including the force display system, is shown in Figure 3. Since facial skin temperature and skin color are measured simultaneously over a long period of time, the heat given by the photo reflector lamp inside the dark room may affect the measurement. Therefore, measurements were conducted in a room with a north facing window at a time when external light hardly varied. Recording was performed simultaneously by a DV camera and a thermography (TVS-8000, Nippon Avionics) that can record 512 frames.

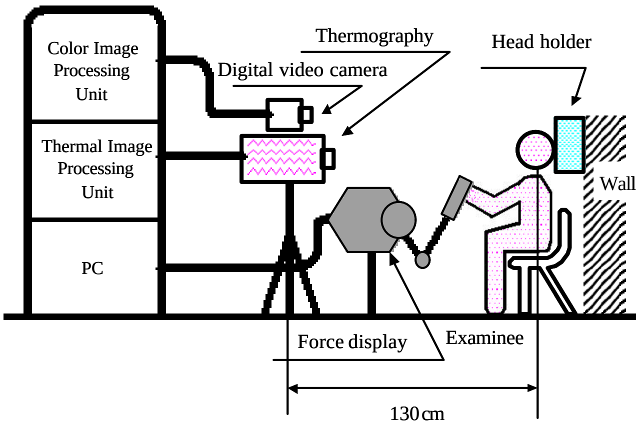


Fig.3: Setup of the measurement of facial color and facial skin temperature in force display.

3.2 Measurement Method

3.2.1 Subject and Measurement Area

Subjects were 12 female students aged 15 to 18 who did not use makeup in a daily life and whose faces easily showed changes. The facial skin temperatures were measured on the nose and cheeks, where temperature changes caused by emotional fluctuations appear prominently. Facial color measurements were conducted at the center of the forehead and cheeks, where the facial color changes are relatively large.

3.2.2 Dynamic Changes of Facial Skin Temperature and Facial color

Force produced by the muscles can be roughly classified into two categories: static force and dynamic force. Static force makes the muscles tense for lifting or supporting a heavy object. Dynamic force is generated by the relatively large muscles of the body in a rhythmical manner. In the present paper, a force display is used to provide static and dynamic loads that match human muscle characteristics, and changes of facial skin temperature and facial color in force display were analyzed.

(1) Static load

The upper arm was held in a static position with the elbow joint at a right angle. The force display was controlled so that the inward turning (JSH axis) muscular force of the subject's shoulder was evenly matched. The subject and the force display were effectively engaged in arm wrestling. This evenly matched state was taken to be the subject's maximum allowable load, and the changes in facial skin temperature and facial color were analyzed under the force display of the maximum allowable load. The load was released when the subject signed that the limit of fatigue had been reached.

(2) Dynamic motion load

After the start of the experiment, the subject lifted the shoulder of the force display in a turning motion (JSH axis) from 0 to 90 degrees for 2 minutes (for a total of 24 times) in accord with an electronic sound presented every 5 seconds, and the subject's facial skin temperature and facial color were measured simultaneously. The displayed force was taken to be 50% of the subject's allowable load, and spring characteristics as shown in Figure 4 (max: 22 [Nm], 14.5 [Nm]) were obtained by analyzing the displacement action using a rotary encoder, and calculating sin θ of the displacement angle θ .

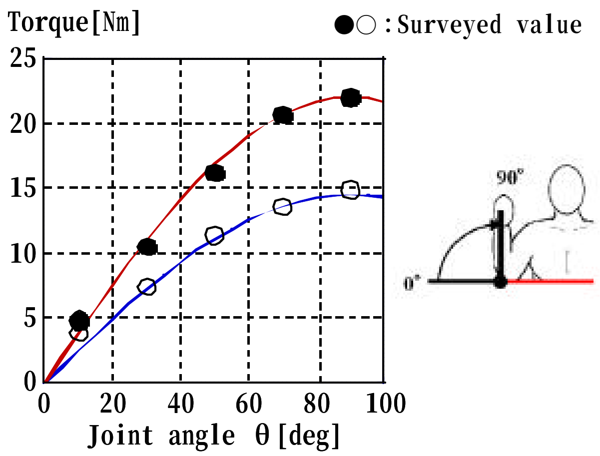


Fig.4: Surveyed value of torque to joint angle θ .

4. Measurement Results

4.1 Changes in Facial Color

Changes in hue and saturation from the initial resting state are designated by ⊿H and ⊿S, respectively. The average values of ⊿H and ⊿S under static load are shown in Table 2.

Table.2: Average of ⊿H and ⊿S.

	⊿H	⊿S
Forehead	-4.47	0.86
Cheek	-4.92	3.06

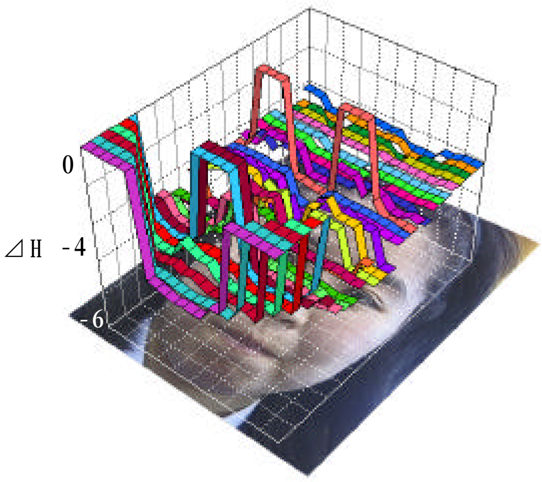
The average increments of hue and saturation (⊿H and ⊿S) in the central area of the face, with and without force display, are shown in Figure 5. Facial color obtained from images captured by DV camera was measured by dividing the area between the eyes and the area between the center point of the eyes and the mouth into 10 equal parts each. These partitions were then used to determine the size of the reference mesh. The mesh was then extended over the full image, with 31 grid intervals each in the horizontal and vertical directions. Then the averages of hue and saturation were determined for each mesh of forehead and cheek.

Transition of hue and saturation in the HS plane for all subjects is shown in Figure 6. This diagram clarifies that facial color becomes more reddish and the saturation increases under a static load.

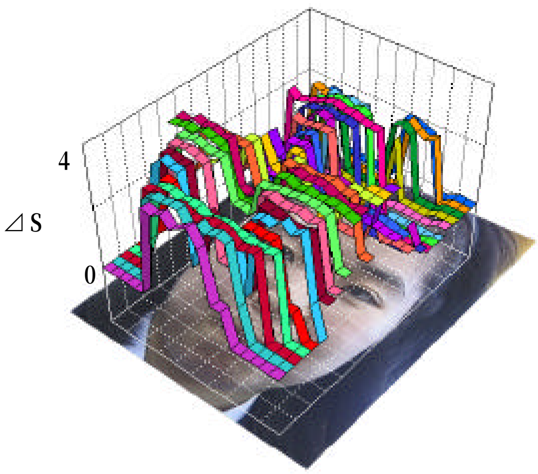
4.2 Dynamic Changes of Facial Skin Temperature and Facial Color

An example of the changes of facial skin temperature and facial color under a static load is shown in Figure 7. As a static load was applied, the cheek skin temperature increased rapidly while hue decreased. The dynamic changes of cheek skin temperature and cheek color were coupled. The skin temperature on the nose showed a tendency to decrease sharply as the load was removed.

An example of the changes in facial skin temperature and skin color under a dynamic load is shown in Figure 8. Rapid decrease in skin temperature was observed at the nose both immediately after the dynamic load was removed and again 1 minute later. After 2 minutes, the skin temperature returned to the level before the dynamic load was applied. On the cheek, a rapid decrease in skin temperature was



(a) Change of hue.



(b) Change of saturation.

Fig.5: Change of facial color dividing areas on the facial image in force display.

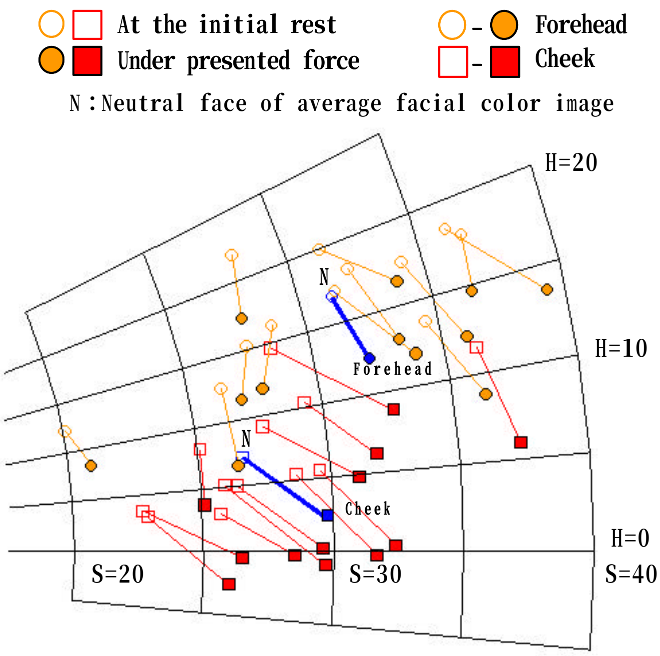


Fig.6: Transition of facial color on HS-plane.

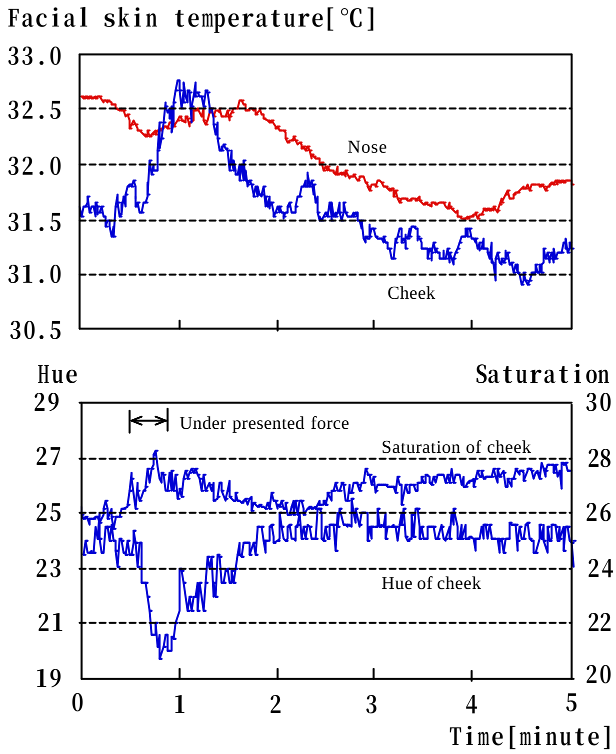


Fig.7: Example of transition of facial skin temperature and Facial Color（I）.

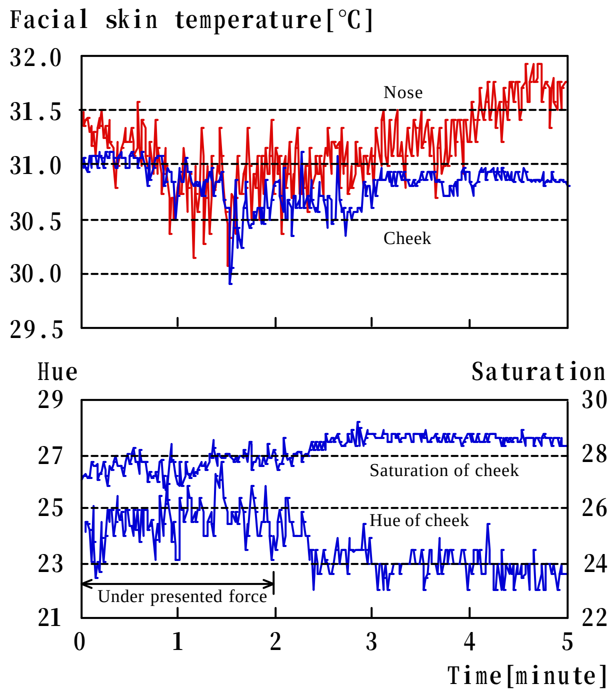


Fig.8: Example of transition of facial skin temperature and Facial Color（II）.

observed immediately after the dynamic load was removed. For facial color, immediately after the dynamic load was removed, the hue decreased while the saturation increased.

5. Analysis by Synthesis Using A Virtual Facial

Image

5.1 Synthesis of Expressions Using a Three-dimensional Shape Measurement System

A DV camera and a non-contact camera shape measurement unit (VIVID700, Minolta) were used simultaneously to measure the facial expressions of subjects viewed from the front and synthesize a facial image and three-dimensional face model.

In order to synthesize the virtual facial image, first an average facial color image was prepared from 10 facial images of female students (aged 18 and 19) [4]. The average facial image (source image) is shown in Figure 9. Since this is an average facial color image, the effect of individual differences is eliminated in sensory evaluation. Next, the average facial color image was mapped on a three-dimensional face shape model of the one student among the 10 subjects, which was most similar to the average facial color image in the distance between the eyes and the mouth by parallel projection. An animation creation tool called "3D Studio MAX4.0 (autodesk)" was used to edit the facial image. The average facial image mapped on the three-dimensional facial shape model is shown in Figure 10. In addition, to give the average facial color image an expression, the distance of movement of characteristic points was estimated as force was applied, and this information was then re-synthesized using the three-dimensional facial expression model. Specifically, information was obtained on the movements of four points, on the eyebrow, eye, cheek and mouth.

Fig.9: Average facial color image.

5.2 Enhancement of Colors on The Average Facial Image

Enhancement of coloring for the purpose of showing expression on the average facial image was synthesized by adding increments of hue and saturation to each of the mesh squares into which the facial image was partitioned, as shown in Figure 5. The initial positions of the measured area on the average facial color image (symbol N) and the facial color synthesized after incorporation of the above increments denote the solid squares (cheek) and solid circles (forehead) on the HS plane as shown in Figure 6. The color in each pixel was enhanced by the equation (1),

$$\begin{cases} H = H_{org} + \Delta H \\ S = S_{org} + \Delta S \end{cases} \quad (1)$$

where H_{org} and S_{org} are the hue and saturation of the average facial color image respectively.

The increments are different in each of the meshes into which the image is partitioned. Because differences in hue and saturation arise among the meshes, images were smoothed by taking the moving averages of pixels around the boundary of the area.

The average facial color image with color enhancement and expression is shown in Figure 11. The color image

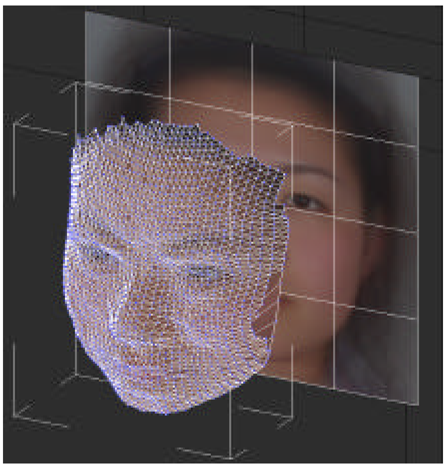


Fig.10: Three-dimensional facial expression model of average facial color image.

Fig.11: Average facial color image with color enhancement and expression.

with facial expression and the enhanced color facial image with expression were displayed simultaneously and in parallel on a color monitor (PVM-2059Q, SONY), and sensory evaluation by paired comparison was examined in 10 students. All answered that the color enhancement was effective.

6. Application to Virtual Arm Wrestling System

As an example of affect display using facial color, which can express excitement under presented force, we applied the system to arm wrestling with a virtual human. The configuration of the constructed virtual reality system is shown in Figure 12. The system consists of visual, audio and force subsystems. The visual subsystem consists of a computer graphics control PC, a stereo head mounted display (i-visor, Personal Display System), and a spatial position sensor (FASTRAK, Polhemus). Omega Space (SOLIDRAY) software was used to construct the virtual world. The subsystem displays a view synthesized from a real image and computer graphics by chroma key processing. The audio subsystem consists of a musical instrument digital interface (MIDI), a sampler, and RSS-10 (Roland) to generate a three-dimensional sound field. The force subsystem was explained above. The force display system is shown in Figure 13. An image of the virtual human actually displayed to the HMD is shown in Figure 14. A compound realistic feeling by means of chroma key processing is created. In order to synthesize the virtual human on the force display, the body size of the virtual human is adjusted, providing an image that makes it appear

Fig.13: External view of virtual arm wrestling system.

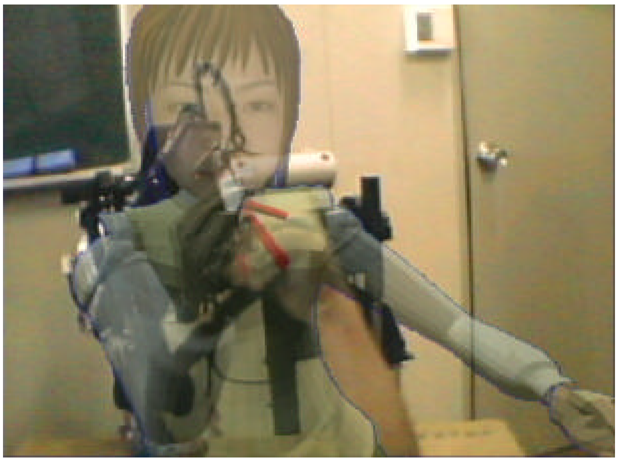


Fig.14: Virtual human.

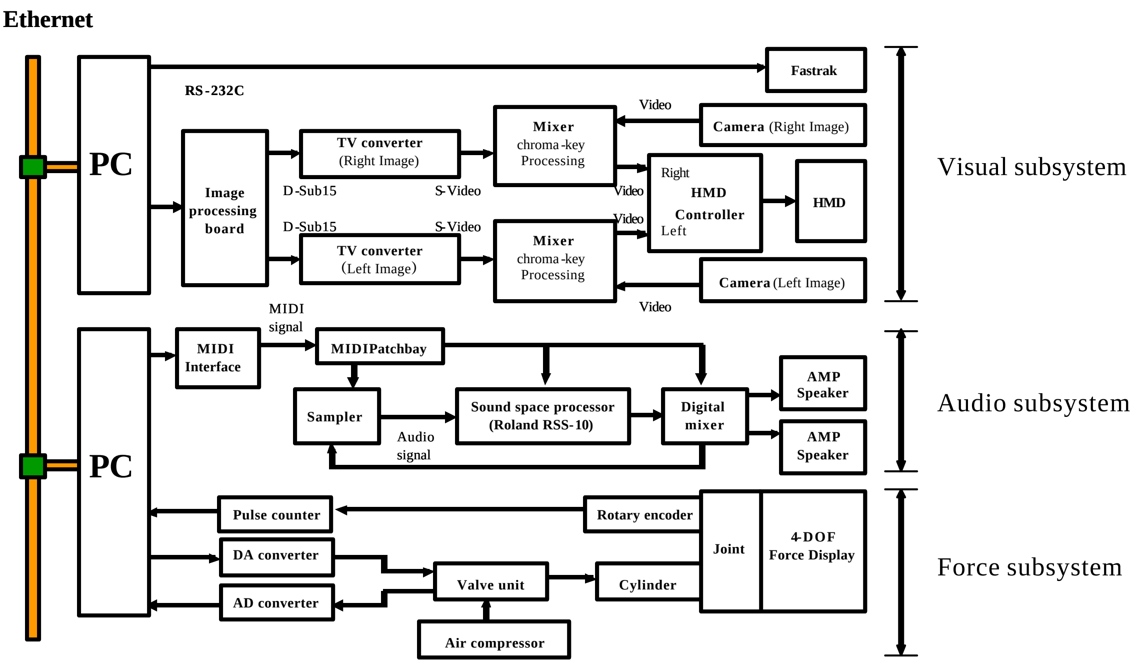


Fig.12: Construction of virtual arm wrestling system.

as though the subject is arm wrestling with a virtual human. As a result of applying a static load of 70% of the subject's maximum capacity and adding facial color to the virtual human, this system is effective in affect diplay.

7. Conclusion

On the basis of the analysis of the facial skin temperature and color associated with circulation dynamics in response to applied forces, virtual facial images were synthesized to present the dynamic facial color and expression variations that occur during exertion. The effects of adding a dynamic facial color to a synthesized facial expression were also confirmed In addition, synthesized facial images were incorporated into a virtual arm wrestling system as a virtual reality system for amusement.

The present system has no algorithm for arm wrestling with a virtual human, and the subject does not feel as though he is actually engaged in a real arm wrestling. There has been researches on attempting to find a tactical algorithm to give the feeling that one is actually engaged in arm wrestling with the virtual human by learning the strategy on a computer[5]-[7]. We intend to effectively represent the facial color of a virtual human to reflect such physiological states as exertion and fatigue in a force display.

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