The Mechatonic Design of a Human-like Robot Head

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Abstract. In this paper the design concept as well as the constructed human-like robot head is introduced. Main goal of the head design is the support of an adequate human machine interaction. Therefore, our robots head should be able to support non-verbally communication based on facial expressions but should also have the skills to observe the intention of a human operator. Based on experience done with a graphical simulation system, the artificial skin movement is examined to express specific facial expressions. These results lead to the basic for the mechanical head design. In the paper also the neck design and the new eye construction is presented. At the end of the paper the sensor system and the control architecture of the head is introduced.

1 Introduction

Worldwide, several research projects focus on the development of humanoid robots. Especially for the head design there is an ongoing discussion if it should look like a human head or if a more technical optimized head construction (Breazeal, 2003, Esau et al. 2003, Takanobu et al., 2002) should be developed. The advantage of a technical head is, that there is no restriction according to the design parameters like head size or shape. This fact reduces the effort for mechanical construction. On the other hand, if realistic facial expressions should be used to support communication between a robot and a person, human likeness could increase the performance of the system. The aim of the humanoid head project of the University of Kaiserslautern is to develop both a very complex robot head able to simulate the facial expressions of humans while perceiving its environment by a sensor system (stereo-camera system, artificial nose, several microphones, ..) similar to the senses of a human. On the other hand, the robot head should look like a human head to examine, if its performance due to non-verbally communication will be higher compared to technical heads.

The starting point of our research was the human-like mask, which was designed by the company Clostermann Design Ettlingen, Germany (see figure 1). In the following first our head design is introduced. The first task for the head is the facial expression of emotions. Therefore, based on Ekmans Facial Action Coding System (Ekman, 1978) adequate action units are selected for the emotions that shall be expressible by the head. This is examined with the help of our graphical simulation system, which will be introduced. The results obtained from this are used as guidelines for the head and the eye construction. The neck pose supports also the expressions of emotions. On the other hand the neck similar that a human head is necessary for the detection of a human operator and its environment. Therefore, a neck was constructed based on design parameters of a human neck, which will be described. In parallel to the mechanical design the computer architecture and the sensor system are developed. In section 4 a short introduction to our sensor system and the implemented control architecture is given.

2 The graphical simulation system for the support of the design process

In (Ekman, 1978) a set of action units is introduced which are mainly used for the expression of emotions by means of facial expression. Each of these units consists of one or several muscles which are connected to specific parts of the skin. Ekman has shown that an activation of the muscles of a specific set of action units lead to an expression of the basic emotions like joy, fear, sadness, surprise or disgust. For example, the emotion ’disgust’ is expressed if the action units ’brow lowerer’, ’lip corner depressor’ and ’chin raiser’ are activated at the same time. Also action units exist for the neck and the eye movement to support the expression of specific emotions. If for the skin movements each of the action units is implemented by one motor and only the minimum number of units is selected for the expression of emotions, at least 30 motors must be installed in a robot head. For the design of a robot head able to express emotion like humans, it is first necessary to determine an adequate skin movement.

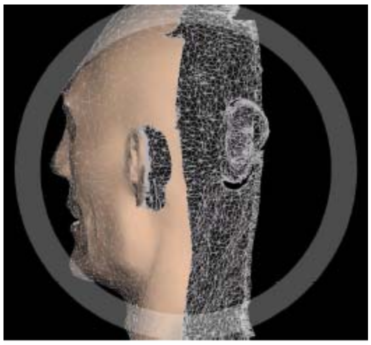



Figure 1: The human-like mask, which was the starting point for our head construction (left). Simulation of the head with the artificial skin (right)

To find a solution for this problem a simulation of the artificial skin was implemented together with the Computer Graphics Group (Prof. Hagen) of the University of Kaiserslautern. Starting with a 3D laser scan (using the Minolta-Digitizer Vi900) of the artificial head covered with a silicon skin, a triangular mesh with about 1,6 Mio triangles was generated and reduced by standard mesh simplification algorithms to about 100000 triangles. Then, the resulting mesh (see Figure 1, right) was modelled as a spring/damper system, which describes the behavior of the silicon skin when external forces are applied. Based on this simulation of the artificial skin, several tests were performed to find out where and how the artificial skin can be moved in order to simulate an action unit. After the realisation of Ekman´s action units in the simulation system, tests with about 60 students are performed to optimise the position and the direction of the motion of the action units. With these results an optimal placement for the action units are performed which yield to the final mechanical design concept.

3 The mechanical construction

The mechanics of the head consists of three parts the basic unit (cranial bone) including the lower jam, the neck, and the artificial eye construction. Beside the eye construction, which is built at the moment in our mechanical workshop, all mechanical components are installed in our head. In the following a short introduction of the basic unit and the eye construction is given. The main focus of the section is the design aspect and the implementation of the neck.

3.1 Basic unit and eye design

In the basic unit 10 metal plates, which can be moved via wires, are glued on the silicon skin. The plate areas as well as its fixing positions on the skin and the direction of its movement are optimized in a simulation system mentioned above (see Figure 2, left). As actuators, 10 servomotors are used to pull and push the wires. Additionally, a servo-motor is used to raise and lower the lower jaw.

The requirements for the eye construction are strongly related to the human eyes. The eye has 3 DOF one degree for moving up and down (+-40°), one for left and right (+-45°), and an additional one for the eyelashes (30°). The eye design was done in a way that 2 dragonfly cameras could be included. The total weight of the eye design including the camera is less than 200g. The max. angular velocity of the eye axis are 200°/s. The angular velocity of the eyelashes is about 120°/s.

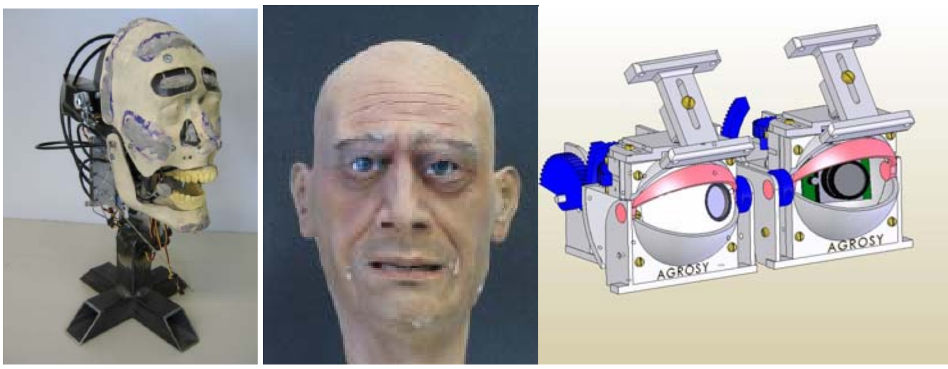


Figure 2. Mechanical construction of the humanoid robot head including 11 servo motors for the skin and mouth movements (left), the artificial skin glued on the basic unit (middle), and the new construction of the artificial eyes for stereo image processing (right)

3.2 The neck design

Analysis

Biological neck contains bones, joints, tendons, ligaments, muscles and nerves. Bones and muscles of the neck region of human body are shown in Figure 3. It is one of the most flexible regions of the spine, which consists of vertebrae, seven shock-absorbing discs, muscles, and vertebral ligaments to hold them in place. The uppermost cervical disc connects the top of the spinal column to the base of the skull (for further information see (Berme, 1990, Morecki, 1980).

The basic control task of the neck in nature is to keep its pose in a "neutral" position whenever possible. The neck region of the spine treated as a bio-mechanism consists of the links and joints is shown in Figure 4. Two upper joints of this fragment have one degree of freedom (DOF) each, so they can be treated as kinematic pairs of fifth class. The next six pairs have three DOF's each, and so they can be treated as kinemtic pairs of third class. Of course the angular range of motion of each pair is rather small, but because of long serial chain (see Figure 4) the global number of passive degrees of freedom is high, while the ranges of resulted motion are high. In Figure 5 and Figure 6 the ranges of resulted motions of the neck region of the man are shown. Due to the view in Figure 5, the ranges of inclination motion from the side could be estimated as +/- 45˚. Form Figure 6 the ranges of in the frontal plane can be estimated as +/- 50˚.

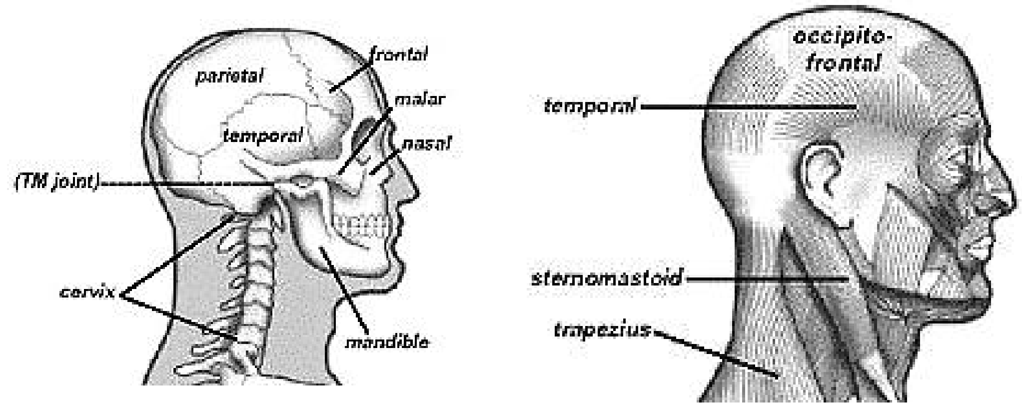


Figure 3. Bones (left) and muscles (right) of the human neck.

Figure 4. Links and joints of the human neck (left)and its kinematic structure (right)

Figure 5. Ranges of angular motion of the neck shown from the side

Figure 6. Ranges of angular motion of the neck shown from the front.

Mechanical neck design

As one requirement of the neck construction it was assumed, that the global motion of the neck will be realize by the kinematic chain with only three degrees of motion. It should be stressed, that the possible poses of the artificial neck should be appropriate to support the human machine interaction. For the design of the neck basic characteristics of the geometry, kinematics and dynamics of a human neck is considered.

From the analysis of the neck (Figure 5 and Figure 6) with 3 DOF of motion a ball joint could be an adequate solution. Unfortunately, it is very hard to design appropriate driving system for such a solution. So, it has been decided, that for kinematic functions of the natural neck serial chain similar to Cardan joint solution will be applied (see Figure 7). The first degree of freedom is the rotation over vertical axis. The range of this rotation for artificial neck was assumed as +/- 90˚. The second degree of freedom is the inclination of the neck over horizontal axis in the side plane. The range of this motion was assumed as +/- 30˚. The third degree of freedom is the inclination of the neck in frontal plane. It is rotating around the axis which is moving accordingly to the second degree of freedom. The range of this motion was assumed as +/- 30˚. The design of the neck was done with the CAD program ProEngineer (see Figure 7).

The rule of the design structure was simply similar to the nature one: keep the artificial neck in a "neutral" position whenever possible. This problem was solved in a way, that spring elements (not shown in Figure 7) has been applied for balancing the gravity forces and moments. The springs are stretched between special bridges mounted on the ring outside the central Cardan joint and previous/second links. For the driving system Faulhaber electric rotational motors with gears are selected. As result a mechatronic construction was designed, which is very compact and which simulated in its dimension and the degree of motion the “natural” neck in an appropriate way. For the compensation of external gravitational torque of the neck, the system of spring has been applied. It is shown in Figure 8a. The characteristic of gravitational external torque, additional torque produced by springs and the sum of them is shown in Figure 8b). One can see, that the resultant torque not exceed 0.2Nm in the range of angle –30°÷30°.

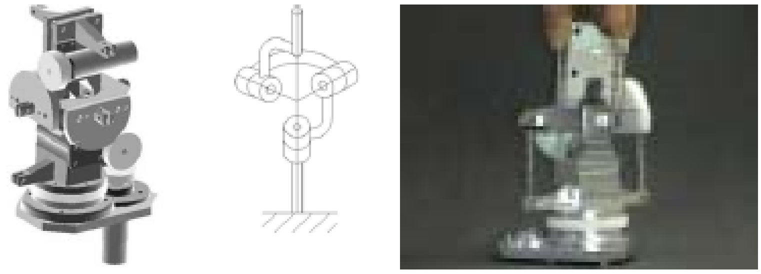
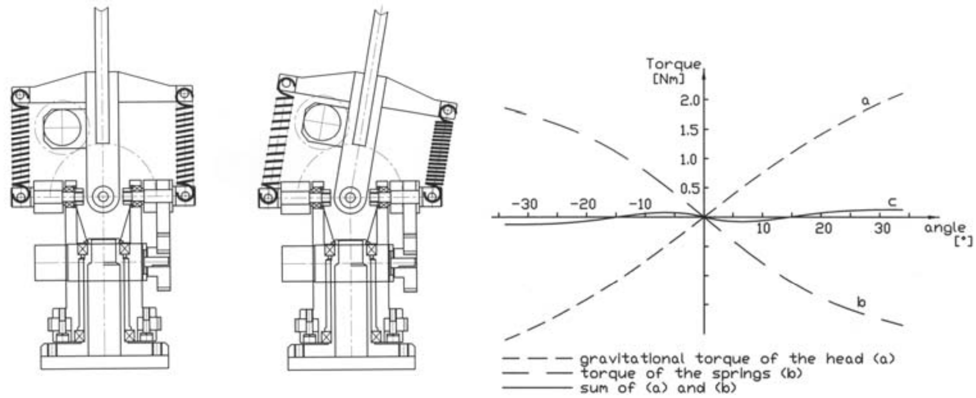


Figure 7. Artificial neck. Left the Kinematic scheme of the neck and the ProEngineer design, right the mechanical construction



a) b)

Figure. 8. Spring compensations of gravitational torque of artificial neck:

a) general view of the neck with compensational springs,

b) external characteristic of the torque for control

4 Sensor system and control architecture

Sensor system

Beside encoders fixed on the DC motors the neck and the eye movements, an inertial system are integrated in the head which measures the angular velocity and the acceleration in all 3 DOFs. This gives an estimation of the pose of the head. Also two microphones (fixed in the ears) and a loudspeaker are included in the head. The main sensor system for the interaction with human is the stereo-vision system, which consist of two dragonfly cameras. Several experiments have been performed like the detection of a human head (see also (Braun et al., 2005). At the moment the integration of the stereo camera system in the eye design of the head is under development.

Control architecture

The control of the servo and DC motors as well as the determination of the pose from the inertial system is done with a DSP (Motorola 56F803) connected to a CPLD (Altera EPM 70 128). In total 5 of these computing units are installed in the head one for the inertial system, two for the DC motors for eye control, one for the 3 DC motors of the neck and one of the 11 servo motors which move the skin. These computing units are connected via CAN-bus to an embedded PC (see Figure 9). The two microphones and the loudspeaker are connected to the sound card of the embedded PC. The cameras, which are included in the eye construction, use the firewire IEEE 1394 input channel of the embedded PC. The calculation of movements of the different facial expressions is done on a Linux-PC. The behaviour based control is implemented with the help of the Modular Controller Architecture (MCA). MCA is a modular, network transparent and realtime capable C/C++ framework for controlling robots (see Scholl et al. 2000 for details). MCA is conceptually based on modules and edges between them. Modules may be organized in module groups, which allow the implementation of hierarchical structures.

5 Summary and outlook

In this paper a human-like robot head is introduced, which will be used to interact with humans. One focus of the present research is how the facial expressions of a human being can be transferred to a robot head. Based on a simulation of the silicon skin of the head and the implementation of Ekman´s action units facial expressions were simulated. The simulation was also used to reduce the number of actuators. Based on these results the head was constructed. The neck construction was also done based on the geometry and the degree of motion of a human head.

Present research is focusing on the implementation of behaviours for the control of the action units in the eye, artificial skin and the neck. In addition we have started to set up and emotional architecture and design a concept for the modelling of a human in the environment of the robot head.

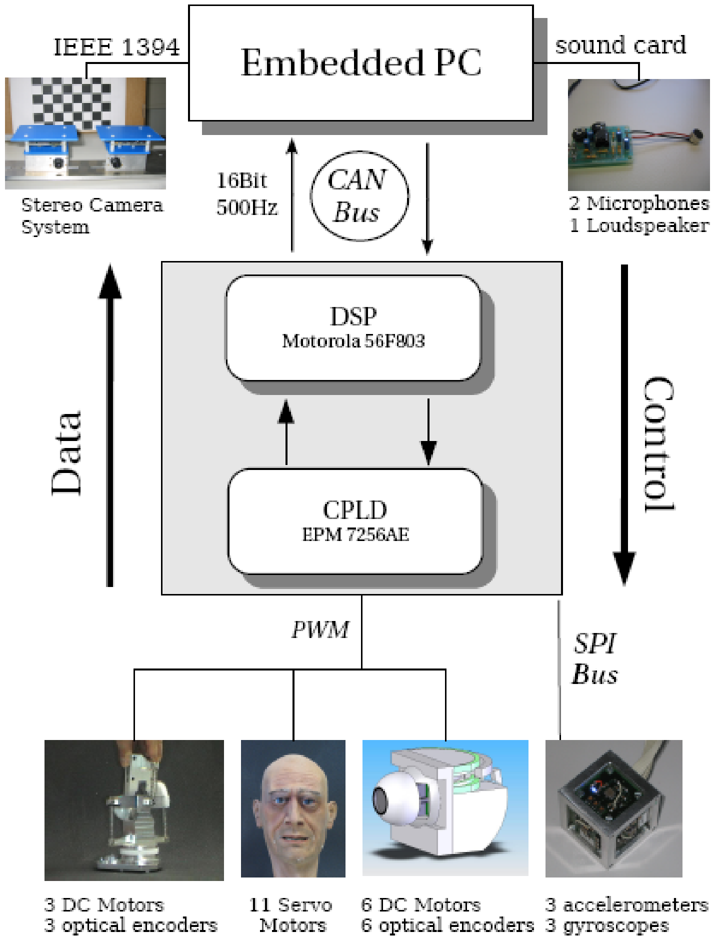


Figure 9. The control architecture applied to the humanoid robot head

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