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ROBOT ROMAN FOR INVESTIGATIONS OF HUMAN-ROBOT INTERACTION

Abstract – For a long time people have been interested in the similarity between living organisms and the engineering devices built by them. Recent developments in the area of service robotics show an increasing interest in personal robots. Those personal robots can help to handle daily work and to entertain people. Future service robots will more and more be able to communicate with humans in a natural way. The communication between humans is not only based on speech in fact movements and emotions are very important. The expression of those emotions is a combination of neck, eyes and skin movements. Therefore this paper presents the construction of the humanoid robot head ROMAN with artificial eyes and neck. The head includes actuators, sensors and mechanical parts which are all integrated into the head. The currents design enable the robot to include a complex sensors system and a complete emotional system.

ROBOT ROMAN DO BADANIA INTERAKCJI CZŁOWIEK-ROBOT

Streszczenie – Od bardzo dawna ludzie są zainteresowani w podobieństwie budowanych przez siebie urządzeń technicznych i organizmów żywych. Aktualnie rozwój robotów usługowych pokazuje znaczny wzrost zainteresowania robotami osobistymi. Roboty osobiste mogą ułatwić i umilić codzienne życie. W przyszłości roboty usługowe będą mogły porozumiewać się z ludźmi w bardziej naturalny sposób. Komunikacja między ludźmi opiera się nie tylko na komunikacji werbalnej (słownej) lecz również w znacznej mierze na mimice ciała (wymowie ruchów) i emocjach wyrażanych przez mimikę twarzy. Emocje te są kombinacją ruchów szyi, oczu, i mięśni/skóry twarzy. W niniejszym artykule zaprezentowano rozwiązania konstrukcyjne robota humanoidalnego ROMAN, w szczególności głowy ze sztucznymi oczami i szyi. Głowa zawiera siłowniki, czujniki i układy mechaniczne zintegrowane w złożoną konstrukcję mechatroniczną naśladującą kształty i wybrane funkcje głowy człowieka. Aktualny stan projektu pozwala na włączenie skomplikowanego układu sensorycznego i wykonawczego do wyrażania emocji w sposób bardzo podobny jak to robią ludzie.

1. INTRODUCTION

For a long time people have been interested in the similarity between living organisms and the engineering devices built by them. Already Aristotle said: “both the whole organism and its parts exist for a specific purpose, which is the function performed”. It should be notice, that classifications according to functions of the organism are more compatible with the cybernetic approach than anatomical classifications [11]. Different properties of limbs of vertebrates are using in building of the constructions of robot-manipulators. One of a most interesting idea was observed by Wiener: both in engineering and biology there exist elements operating by the principle of minimum energy consumption, such as mechanical manipulators with springs for relief and human limbs with initial muscle tonus for the static equilibrium. Present and future engineering needs the concept of machine-systems, in which machines are conjoined to the environment not only by energy flow but also by signal exchange. The elements receiving outside signals are the counterparts of animal sense organs – the receptors, whereas the final executive elements are the effectors. Certain basic problems connected with reproduction of function of lively organisms in design and construction of robots undertakes biomechanics and cybernetics. It should be noted, that biomechanics is a study of movement and mechanisms of motion with special emphasis of human beings. By exploiting very simple biocybernetic models, it is possible to create mechanical devices similar to human, not only from geometrical point of view, but some functional characteristics too. Such a models can imitate behaviour and living functions of a human body, arms, legs, head, and by applying artificial receptors, can extract information from the environment for executing advisable exercices similarly to the human. Recent developments in the area of service robotics show an increasing interest in personal robots. Those personal robots can help to handle daily work and to entertain people. Both tasks require a robot that is able to communicate with people in a natural way. The communication between humans is not only based on spoken and written words. Several aspects like gestures, mimic and movements play an important role. Current robots lack the ability to communicate with humans in a natural way. An important part of non-verbal interaction are the movements of neck, eyes and the upper part of the body.

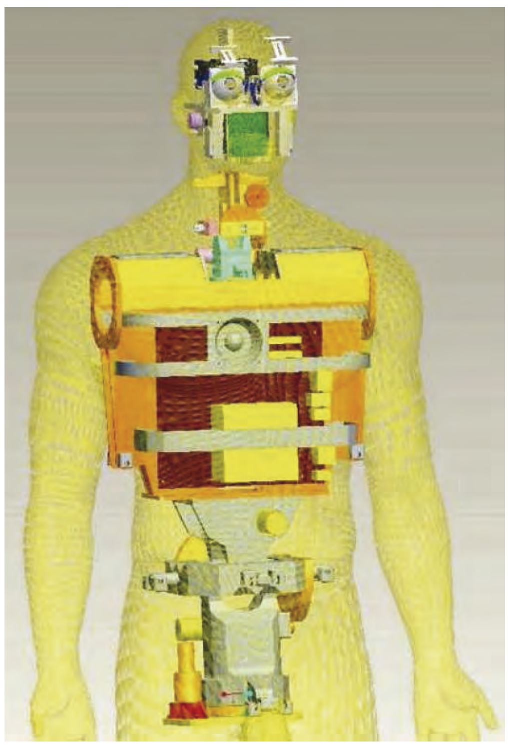

Fig. 1. Zygote's 3D realistic human model with engineering drawings of the upper body, the neck and the head construction

Constructions for eye movements like [1] cannot be positioned precisely as nylon cables are expandable. Direct connections via gears improve the precision of eye movements but they also increase the complexity of the construction. Small systems [2] includes only tiny cameras with low resolutions. Those sensor systems cannot be used for complex vision algorithms which are important for several aspects of natural communication. It is important to focus the sensor systems precisely on different points of interest which are detected by the sensor system [3]. Besides the construction of hard-ware, several projects concerning man-machine interaction can be found in literature. It can be seen that those projects either focus on the expression of emotions [4] or on the application of those robots [4,5]. Robots including a complex vision system and additional sensors often simplify the emotional feedback and vice versa. It is a complex task to integrate both vision and emotional systems into a single head. At present humanoid robot are not able to realize all human motions so important movements have to be selected. [6] numerates several action units which describe humans motions including body, neck, eye and skin movements. The combination of those action units results in the expression of emotions like fear or joy.

In this paper we describe the mechanical design and construction of upper body, eyes and a fourth neck joint for the humanoid robot ROMAN. The revised emotional system and the 3DOF neck is described in [7] and [8]. Based on the previously build neck and the arti┐ cial skin we also show how we integrate the vision system and several other sensors into the robot head. Additional sensors like a smell sensor and an inertial system will be integrated in future. Picture 1shows an engineering drawing of ROMAN including upper body, neck and eyes included in Zygote's human 3D model. The human model has natural dimensions and can be used to realize a design with realistic human proportions.

2. THE HUMANOID ROBOT ROMAN

The humanoid robot ROMAN (see Fig. 2) of the University of Kaiserslautern is designed to both simulate facial expressions of humans and perceive the environment with a complex sensor system including stereo-camera system, artficial nose and several microphones. In contrast to

Fig. 2. A previous version of the humanoid robot .ROMAN” (ROMAN = RObot huMan interAction machiNe) with human-like silicon skin

several other humanoid projects it will be analyzed if a humanlike robot head can increase the performance of non-verbal communication in comparison to technical heads. Therefore it is necessary to construct and realize a robot which integrates both emotional and sensor system which is a complex task due to the limited available space.

TABLE I

LIST OF ALL REALIZED ACTION UNITS CORRESPONDING TO EKMAN'S NUMBERING SYSTEM INCLUDING THE APPROXIMATED MAXIMUM RANGES OF MOTION

Head Positions	
1 Inner Brow Raise	1 cm
2 Outer Brow Raise	1 cm
9 Nose Wrinkle	1 cm
12 Lip Corner Puller	1 cm
15 Lip Corner Depressor	1 cm
20 Lip Stretch	1 cm
24 Lip Presser	1 cm
26 Yaw Drop	10°.
Head Positions	
51 Turn Left	60°.
52 Turn Right	60°.
53 Head Up	20°.
54 Head Down	20°.
55 Tilt Left	30°.
56 Tilt Right	30°.
57 Forward	2 cm
58 Back	2 cm
Eye Positions	
61 Eyes Left	30°.
62 Eyes Right	30°.
63 Eyes Up	40°.
64 Eyes Down	40°.
65 Walleye	see above
66 Crosseye	see above

The previous mechanical design of ROMAN consists of a 3DOF neck construction, an artificial skeleton and the emotional system based on eleven servo motors moving small metal plates which are glued to a silicon mask. The neck [8] realizes all 3DOF in a single point and clamps the two main aluminum plates. The artificial skeleton consists of the entire head and the lower jaw which are attached to the main plates together with the servo motors. The silicon skin is glued to the skeleton and can be moved with the help of 8 small metal plates which are connected to the servo motors with cables. Further information about the emotional system can be found in [7].

The first design of the robot head revealed several drawbacks which leads to an enhanced design. A major drawback of the previous design is that several emotional expressions
cannot be recognized due to missing movements of the robot. It is obvious that additional actuators and complex sensors must be included in the head to realize the presented goals. Therefore a complete redesign of the main plates is necessary to reduce the weight and create the necessary space to integrate the desired sensor system.

Based on these drawbacks the most important aspects for the improved head construction are:

- Integration of an artificial upper body with 3DOF
- Integration of the artificial eyes including a stereo camera system
- Additional neck joint to realize a 4DOF neck
- Guidances and traverse paths for wires and metal plates for the motion of the artificial skin

The additional movements of body, neck and eyes are necessary to improve the non-verbal communication system. The movements of the human non-verbal communication system are described in [6]. Ekman categorizes human movements and builds so called action units which must be combined to generate an emotional expression. The availability of these units is a major criteria for the quality of non-verbal communication.

As it is not possible to realize all human movements we decided to realize the most important action units listed in I. These include all human head and eye movements as well as the most important movements of the skin.

3. DESIGN AND CONSTRUCTION

Based on the insights of the previous chapter we present a new design for the mechanical system of the humanoid robot. The following chapters will present upper body, eyes, neck and the new interior frame in detail. All following parts since not mentioned otherwise are made of Polyoxymethylen (POM) which is a thermoplastic with a density of 1:41 g/cm^3 and a high stiffness.

3.1. Upper body

The movements of the human spine will be aproximated with three degrees of freedom in relation to the base in an open kinematic chain. The kinematic scheme of the lumbar spine is similar to the one used in the design of the neck, while ranges of motion should be appropriate to the functions of the spine. The ranges of motion include rotation over vertical axis), inclination forward/backward in relation to horizontal axis (±30° and ±40°) and inclination left/right in frontal plane (±30°). Figure 3 shows the engineering drawing of the upper body including all necessary electronic devices. It was assumed that two mainboards will be located on the chest in the front and in the back side. For the synthesis and recognition of speech a four channel sound card and a loud-speaker in the front of the body will be applied. For the protection of the equipment, the chest has to be adequately stabil and safe, so the basic design of the chest has the form of a stiff box with artificial ribs for protection. The chest as a mechanical part should be adequately resistant to transfer gravitational and external moments/forces acting to the head and to upper limbs (arms, hands), and should be relatively lightweight. It was decided to use the typical shell-shaped design for the box with planar walls made as a bent of tick plates and welded duraluminium.

The mechanism consists of the base, rotational fork 1 driven by electric motor with gear, special cross yoke beared by ball bearing in the fork 1 for inclination forward-backward and fork 2 for inclination left-right side beared by ball bearing in the cross yoke. Driving forces (torques) are generated by electric motors with gears choosen in such a way, that typical compact solution of the motor with planetary gear is mounted to the fork (1, 2) and each one propels by small toothed wheel the big one mounted to the cross yoke. The only problem is with the gravitational forces (generated external torques) from the main part of the construction. The total mass of the body is estimated up to 50 kg. To compensate (partially) the external torque over horizontal axes produced by gravitational forces, in theproposed solution it has been applied special additional bridges attached outside the cross yoke on each inclination axis with elastic elements for compensating changes of potential energy, i.e. external springs which can be seen in Fig. 3 and 4.

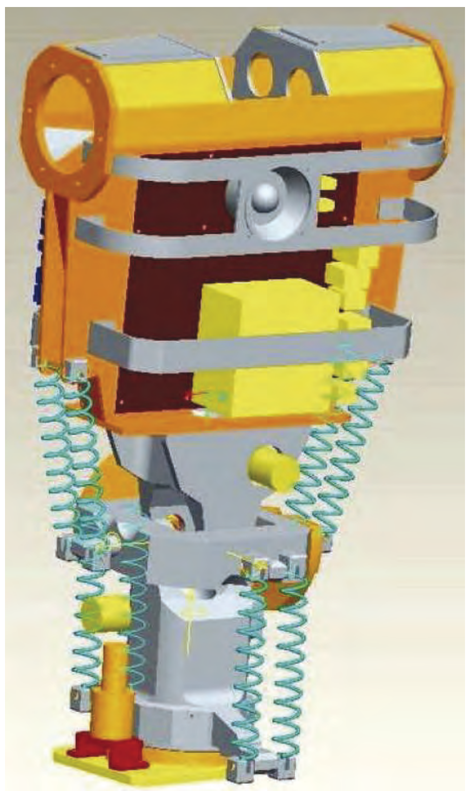

Fig. 3. Engineering drawing of the upper body of the humanoid robot with inegrated mainboards, loudspeaker and the 3DOF hip with supporting springs

Dynamic (quasi-static) characteristics of the driving systems of the neck and of the spine are shown in Fig. 6. As it is shown the driving torque does not exceed 10 % of the maximum value of gravitational torque of the head. Unfortunately there is not to much place and there are no appropriate springs to very accurate compensating of gravitational torque of the body. The total mass was estimated up to 50 kg, the estimated mass of the model of corpus of the body with the spine shown in Fig. 3 is nearly 15 kg, while the real mass will be known when the prototype of all the system will be arranged. So we have decided to choose existed springs as good as possible from the catalog (two in each side as it is shown in the figures), and they will be well choosen and fitted on the prototype. From the analysis made in MATLAB program it is shown, that the driving system (motor with planetary gear and one step wheel gear) should generate about 60–65 % of the maximum value of external gravitational force. Of course, if the mass will be less then 50 kg, this value will be a little less, but the driving system should generate the appropriate torque in every situation.

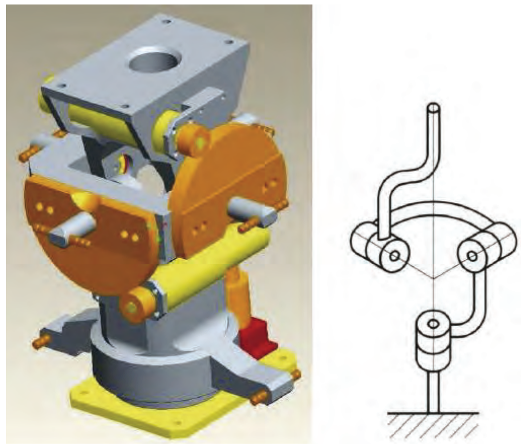

Fig. 4. Engineering drawing and scheme of the 3DOF neck

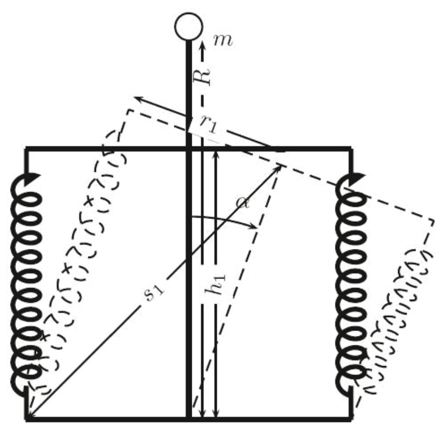

Fig. 5. The scheme of generating antigravitational torque

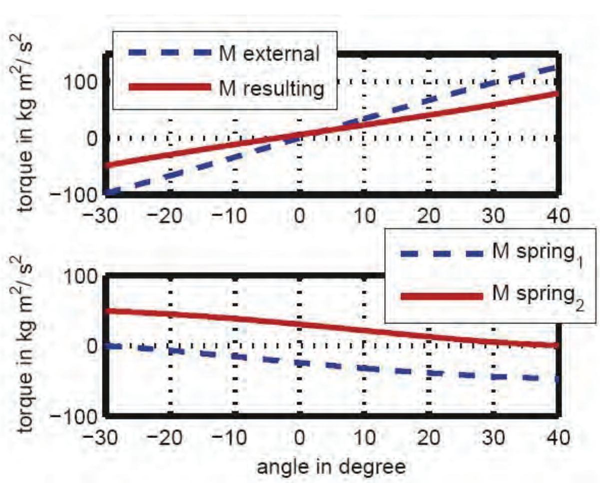

Fig. 6. Obtaining results of compensating the gravitational torque

One of the main aesthetic problem of the proposed solution was to integrate all applied mechanical/electric/electronic parts into one compact mechatronic system geometrically and functionally similar and mimic to the real human body. With using modern 3DComputer Aided Design system Pro Engineer Wild Fire with specialized modulus for assembly, animation, and dynamic simulation, this problem was solved in such a way, that in every step of the development of the design, specific animation and dynamic simulation has been executed. The last phase of this process is shown in Fig. 1.

Artificial spine with the frame of the corpus (body) and with the neck is shown on the animation with the shell-shape of human body. Then they was assembled together to show, how accurate the design was prepared. Of course there are some differences comes from technical and mechanical performances of the design, but in every step we was deeply investigated it behind and against of each even small fragment and then we was decided which solution will be good and better. It was a kind of optimization process under design circumstances and real limitations. As a result, very suitable and adequate to real nature solution has been obtained.

3.2. Eyes

The construction of the eyes should be compact and lightweight since space is limited. They must be able to move the eyeballs independently up/down and left/right. The upper eyelid has

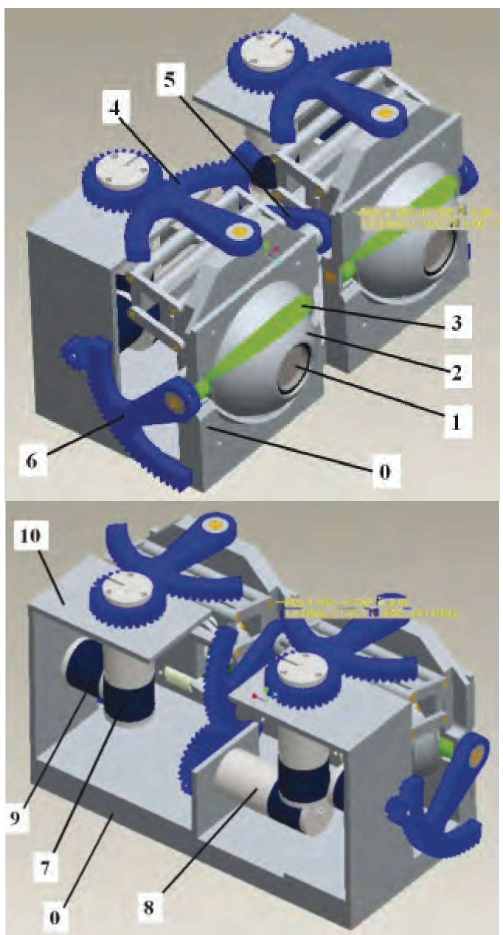

Fig. 7. New version of the artificial eyes

to movable to assist the expression of emotions. Additionally a small camera has to be integrated in the eyeball which is connected to the exterior electronic parts with a flexible cable.

The image on Fig. 7 shows an assembly of eyes with the eyeballs, gearwheels and the motors with their attachments. The eyeball has 3 movable axes: eyeball up/down and left/right and the upper lid. The eyeball rotates in an external attachment, while up/down rotational motion is realize with using special planar parallelogram as it is shown in Fig. 8.

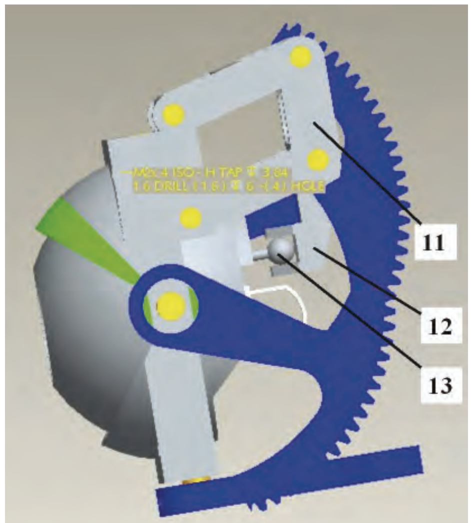

Fig. 8. External parallelogram mechanism for decoupling motions of an eye ball

4. CONCLUSION AND OUTLOOK

Described in this paper design has been realized to obtain the reduced weight of the body and head and by using springs partially eliminate the influence of gravity, which is similar to human muscle tonus, and introduce the decoupling of an eye rotational up/down – left/right motions. A main topic of the camera system will be the detection, tracking and recognition of humans in the environment of the robot. Besides the cameras it is very important to include several other sensor systems like microphones. The sound system and the localization of sound is an important factor in the communication process between humans and robots. Additional sensors like smell sensors and inertial system have to be incorporated into the mechanical design of the robot. Besides the hardware system several software aspects concerning man-machine interaction will be integrated. A humanoid head should be able speak which requires a speech synthesis technique. Additionally it would be interesting to integrate a speech recognition software to realize first interactive dialogs.

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