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# A bio-inspired model of head stabilization implemented in a humanoid platform

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**Abstract**— The neuroscientific research shows that humans tend to stabilize their head orientation, while accomplishing a locomotor task.

In order to replicate head movement behaviors found in human walk it is necessary and sufficient to be able to control the orientation (roll, pitch and yaw) of the head in space. Based on these principles, a model based on an inverse kinematics controller has been designed. Verification of the proposed controller is conducted through experiments with a humanoid robot SABIAN. Results of the implementation on the robotic platform show the controller is able to stabilize the pitch head rotation during walking.

**Keywords**—Head stabilization, Inverse Kinematics controller.

## I. INTRODUCTION

Recent neurophysiological studies suggest that the head-fixed reference frame in humans plays a major role in body motion planning and execution [1]. It seems to be the privileged reference system where all sensory information is integrated and where whole-body motion planning occurs. This is one of the key concepts of “The Sense of Movement” [2] and that could simplify significantly motion planning and execution in complex kinematic structures like humans.

In humans, the vestibular system, perceiving rotational velocities and linear accelerations, provides perception information of the head movements and postures relative to space and gravity. It provides proprioceptive signals for the sense of movement. The central nervous system uses this information to generate a unified inertial reference frame, centered in the head that allows whole-body coordinated movements and head-oriented locomotion [2]. Pozzo and colleagues were the first to study the head behavior during locomotion [1]. Their experimentation revealed that vertical translation of the head is not stabilized to zero during human walking. The head always rotates in the opposite direction from head translation along the vertical axis. Hirasaki and colleagues [3] showed that the head oscillates up and down from about 4 centimeters during slow walking (0.8 m/s) to about 10 in fast walking (2 m/s) and about 5 centimeters from left to right in average in walking speeds between 1.4 and 1.8 m/s. From the robotic point of view there are some implementations of head stabilization model [4, 5, 6]. Yamada and colleagues [4] propose a method for the stabilization of the snake-like robot head based on the neck control. Another work on the head stabilization implementation on a robotic platform is proposed by Santos and colleagues [6]. In this work, the head movement is stabilized using Central Pattern Generator and a genetic algorithm tested on the AIBO robot. Another controller [5] for the head stabilization has been implemented on the Sony

AIBO robot. This controller is based on a machine learning algorithm able to learn the compensation for the head movements when no stabilization mechanism is present.

In this work we propose an implementation on a humanoid robot (SABIAN) of a bio-inspired human model for the head stabilization [7]. Results of the implementation on the robotic platform show the controller is able to stabilize the pitch head rotation during walking.

## II. HEAD STABILIZATION MODEL

The control of the head rotation during walking appears essential in order to keep a stable head centered reference frame. In this perspective, a model in which the head is stabilized has been proposed [7]. Three frames of reference are considered for the model: 1) the world reference frame  $O - xyz$ ; 2) and the head frame, fixed to the head, 3) and the trunk frame, fixed to the trunk. The head frame is composed by a rotation matrix  ${}^W_H R$  which describes the orientation of the head with respect to the world frame as well as by a matrix  ${}^T_H R$  which describes the orientation of the head with respect to the trunk. The trunk frame orientation is composed by a rotation matrix  ${}^W_T R$  which describes the orientation of the trunk with respect to the world frame. In this model, the matrix  ${}^W_T R$  depends on the motion during walking and can be considered as an external disturbance which affects the  ${}^W_H R$  matrix.

A controller using as feedback the actual absolute RPY angles of the head ( $v \phi \psi$ ), was designed to track an arbitrary reference orientation in space (not relative to the trunk) using Roll, Pitch and Yaw angles. The controller is able to follow a reference orientation ( $v^r, \phi^r, \psi^r$ ) spanning in the whole workspace of the head and reject the disturbance caused by trunk motion.

For the implementation of this controller we had to find a relation between the joint velocities and the time derivatives of the head’s RPY angles. We decided to use the spatial Jacobian to build a controller which has a proportional term  $k$  and a feed-forward term consisting of the derivative of the reference ( $\dot{v}^r, \dot{\phi}^r, \dot{\psi}^r$ ). In order to obtain information about trunk motion, we can notice that, knowing the absolute orientation of the head  ${}^W_H R$  and the orientation relative to the trunk  ${}^T_H R$  we could estimate the rotation of the trunk,

$${}^W_H R = {}^W_T R ({}^T_H R)^T \quad (1)$$

and then, by differentiation, we could obtain the time derivatives of the trunk RPY angles which can be used to the estimation of trunk orientation angles  $\hat{v}^t, \hat{\phi}^t, \hat{\psi}^t$  and their derivatives  $\hat{v}^t, \hat{\phi}^t, \hat{\psi}^t$ .

The final control law becomes therefore:

$$\begin{aligned}\dot{v} &= k(v^r - v) + \dot{v}^r - \hat{v}^t, \\ \dot{\phi} &= k(\phi^r - \phi) + \dot{\phi}^r - \hat{\phi}^t \\ \dot{\psi} &= k(\psi^r - \psi) + \dot{\psi}^r - \hat{\psi}^t\end{aligned}\quad (2)$$

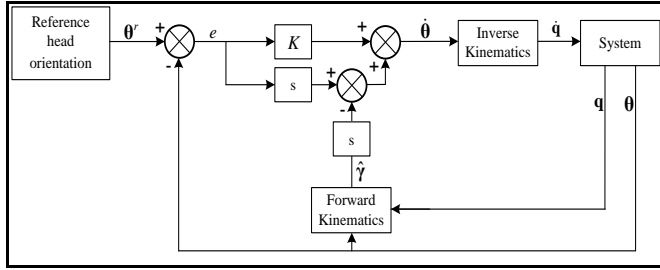


Fig. 1. Head Stabilization model with robotic controller implementation.

The feedback controller is depicted in Fig 1 and the symbols on the figure have the following meaning:

$\theta$  - denotes the vector containing the roll, pitch and yaw angles ( $v, \phi, \psi$ ) of the present head orientation

$\dot{\theta}$  - denotes the vector containing the derivative of roll, pitch and yaw angles ( $\dot{v}, \dot{\phi}, \dot{\psi}$ ) of the present head orientation

$\theta^r$  - denotes the vector containing the roll, pitch and yaw angles ( $v^r, \phi^r, \psi^r$ ) of the head orientation reference

$q$  - denotes the joint space configuration vector of the neck's serial kinematic chain

$\hat{\gamma}$  - denotes the vector ( $\hat{v}^t, \hat{\phi}^t, \hat{\psi}^t$ ) containing the estimates of roll, pitch and yaw angles of the present trunk orientation

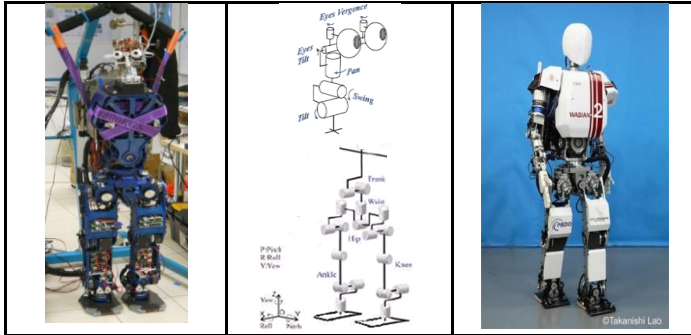


Fig. 2. SABIAN humanoid platform (left), head and body kinematics of the SABIAN (middle) and the WABIAN humanoid robot (right)

### III. SABIAN ROBOTIC PLATFORM

SABIAN (Sant'Anna BiPed humANoid) is a biped humanoid robot developed by the Robot-An Laboratory, at Scuola Superiore Sant'Anna. It is a copy of WABIAN (WAseda BiPed humANoid), [8]. Compared to most bipedal humanoid robots, which walk with bent knees, WABIAN is able to perform a human-like walking, with stretched knees, and to get the pelvis motion, raising the hip. WABIAN (Fig 2) is approximately the size of the average adult Japanese women. The SABIAN robot (Fig 2) has 7 degrees of freedom (DOF) in each leg, 2 DOF in the waist, which help the robot perform stretched knee walking, 2 DOF in the trunk. Every degree of freedom has a bio-inspired range of motion, defined in reference to human motion measurements. In order to reach the objectives of a visuo-guided locomotion, the iCub head

[9] has been mounted on the SABIAN platform. The iCub head contains a total of 6 DOFs: neck pan, tilt and swing and eye pan (independent) and tilt (common).

### IV. RESULTS AND CONCLUSIONS

The graph below (Fig 3) shows the results of the activation of the controller on the SABIAN robot during walking. The SABIAN robot performs 10 steps walking straight forward. Despite of the trunk pitch rotation, imposing a reference of 0 degrees, the controller is able to keep the pitch head rotation in a range value of  $\pm 0.5$  degrees. We tested the controller stabilization for the pitch head rotation also for curved path obtaining the same performances (a peak-to-peak error of 1 degree). These results proved that the proposed control model can be used to stabilize the head of the humanoid robot during locomotion. We plan to evaluate the influence of the head stabilization on the stability of the visual image acquired from on-board cameras and the impact on the resultant simplification of the visual reconstruction of the environment.

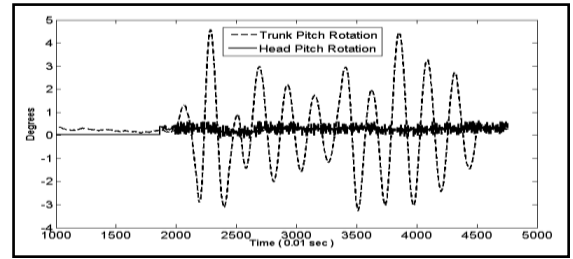


Fig. 3. Head pitch rotation stabilized during straight walking

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### REFERENCES

- [1] T. Pozzo, A. Berthoz, and L. Lefort, "Head stabilization during various locomotor tasks in humans. i. normal subjects." *Experimental Brain Research*, vol. 82, no. 1, pp. 97–106, 1990.
- [2] A. Berthoz, *The brain's sense of movement*, ser. Perspectives in cognitive neuroscience. Harvard University Press, 2002.
- [3] E. Hirasaki, S. T. Moore, T. Raphan, and B. Cohen, "Effects of walking velocity on vertical head and body movements during locomotion." *Experimental Brain Research*, vol. 127, no. 2, 1999.
- [4] H. Yamada, M. Mori, and S. Hirose, "Stabilization of the head of an undulating snake-like robot," in *Proc. IEEE/RSJ Int. Conf. Intelligent Robots and Systems IROS*, 2007, pp. 3566–3571.
- [5] M. Marcinkiewicz, R. Kaushik, I. Labutov, S. Parsons, and T. Raphan, "Learning to stabilize the head of a quadrupedal robot with an artificial vestibular system," in *Proc. IEEE Int. Conf. Robotics and Automation ICRA*, 2009, pp. 2512–2517.
- [6] C. P. Santos, M. Oliveira, A. M. A. C. Rocha, and L. Costa, "Head motion stabilization during quadruped robot locomotion: Combining dynamical systems and a genetic algorithm," in *Proc. IEEE Int. Conf. Robotics and Automation ICRA*, 2009, pp. 2294–2299.
- [7] E. Falotico, C. Laschi, P. Dario, D. Bernardin, and A. Berthoz, "Using trunk compensation to model head stabilization during locomotion", in *Proc. 11th IEEE-RAS Int Humanoid Robots Conf*, 2011
- [8] Yu Ogura, Hiroyuki Aikawa, Kazushi Shimomura, Hideki Kondo Akitoshi Morishima, Hun-ok Lim, Atsuo Takanishi, "Development of a New Humanoid Robot WABIAN-2", Proceedings of the 2006 IEEE International Conference on Robotics and Automation, May 2006
- [9] Beira R., Lopes M., Praça M., Santos-Victor J., Bernardino A., Metta G., Becchi F. Salazar R., (2006), "Design of the Robot-Cub (iCub) head", in *Proc. IEEE International Conference on Robotics and Automation*, Orlando, FL, May 15-19, 2006, pp.94-100