MOTION AND EXPRESSION : FROM A HUMAN HEAD TO AN EMOTION-EXPRESSIVE ROBOT

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INTRODUCTION

- Emotional child-robot interaction helps to catch quickly a child's attention and enhance information perception during learning and verbalization in children with communication disorders;
- An approach to capture movements and expressions of a human head is proposed;
- A novel approach to process the raw data from IMU sensors;
- Transferring the motion and expression of the human head to a emotion-expressive robot;
- The humanoid robot NAO and the emotion-expressive robot EMOSAN were used in therapeutic session with children with communication disorders;
- This presentation is an extension and visual illustration of our previous paper [1].

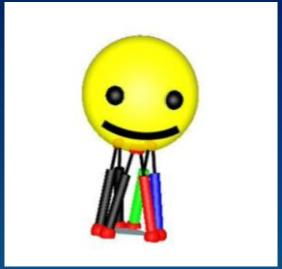
MOTION AND EXPRESSION CAPTURE OF THE HUMAN HEAD

EMOTIV EPOC+

The actor performs an emotion and wears Emotiv

Raw data

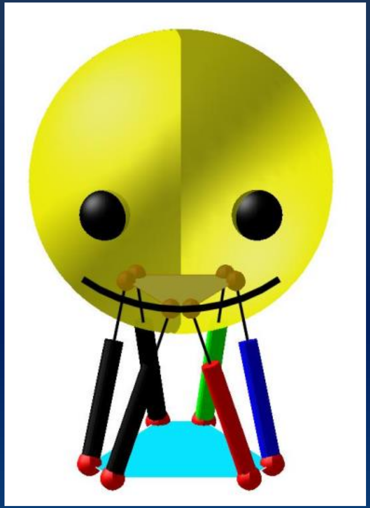
We have developed a novel and unique algorithm



Computer animation

Emosan– our prototype robot

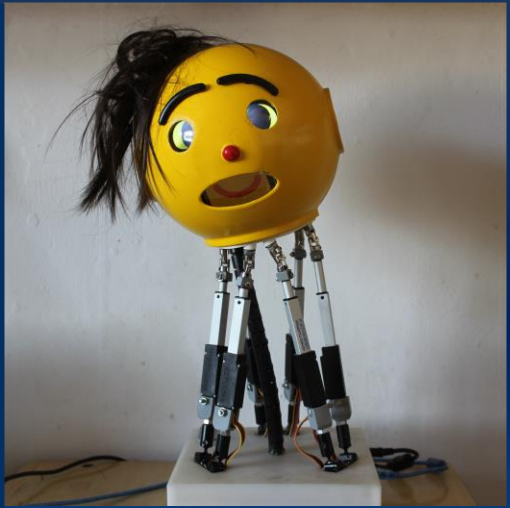
THE EMOTION-EXPRESSIVE ROBOT



Computer model of the robot

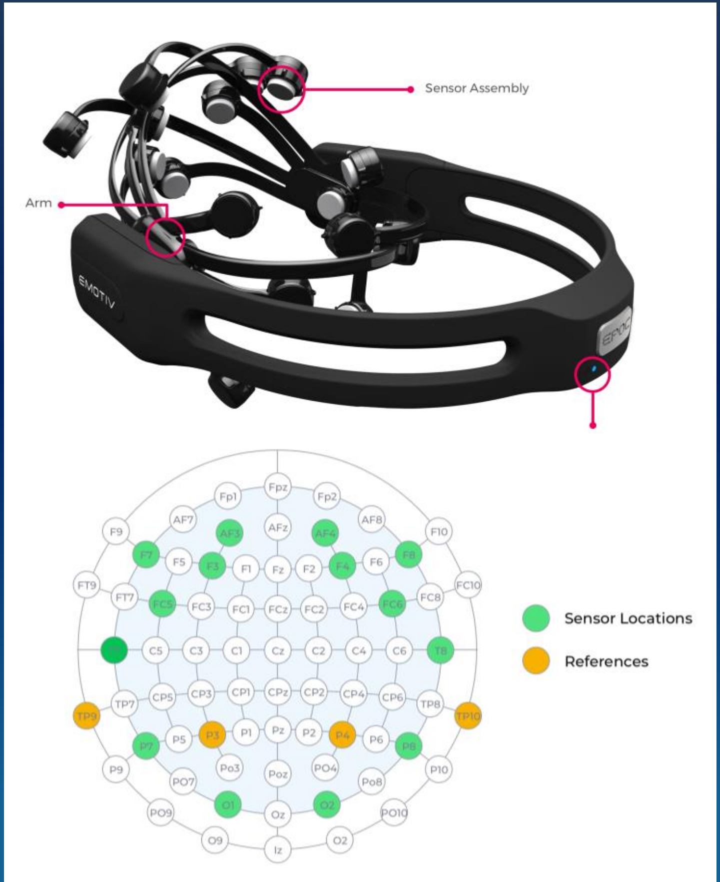
Features:

- Resembles the well-known symbol "Emoticon";
- The robot kinematic design is based on the Gough-Stewart platform;
- Parallel robot: the base and moving platforms of the robot are connected by six identical legs with SPU architecture;
- 6 degrees of freedom – the moving platform can be translated along three axes and rotated about these three axes;
- It has mouth, eyes and eyebrows.



Prototype of the robot

CAPTURING DEVICE - EMOTIV EPOC+



- **EEG sensors:**

14 channels: AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4

- EEG signals:
- Sampling method: Sequential sampling, single ADC
- Sampling Rate: 128 SPS / 256 SPS (2048 Hz internal)
- Connectivity: Proprietary 2.4GHz wireless, BLE and USB (Extender only)
- IMU part: Accelerometer, Gyroscope, Magnetometer, No Quaternions (only raw data)
- Motion Sampling: 32 / 64 / 128 Hz (User Defined)

Source[2]: https://www.emotiv.com/

THE ALGORITHM FOR THE MOTION CAPTURE – BASED ON THE GEOMETRIC ALGEBRA

Geometric Algebra – Key Features

- Geometric Algebra is a universal Language based on the mathematics of Clifford Algebra
- Provides a new product for vectors
- Generalizes complex numbers to arbitrary dimensions
- Treats points, lines, planes, etc. in a single algebra
- Simplifies the treatment of rotations
- Unites Euclidean, affine, projective, spherical, hyperbolic and conformal geometry

THE ALGORITHM FOR THE MOTION CAPTURE – BASED ON THE GEOMETRIC ALGEBRA

Why Geometric algebra?

- It handles the representation of the orientation
- Efficient for vector transformation
- Rotors have the advantages of quaternions
- We have previous experience in applying geometric algebra in robotics [3]

HISTORY OF THE GEOMETRIC ALGEBRA

- Foundations of geometric algebra (GA) were laid in the 19th Century
- Key scientists: Hamilton, Grassmann and Clifford
- Further developed and reintroduced to physics in the 70s by David Hestenes

- Hermann Gunther Grassmann (1809–1877) - He introduced the outer product
- William Rowan Hamilton (1805–1865) - Hamilton Introduced his quaternion algebra in 1844
- William Kingdon Clifford (1845–1879) - Clifford introduced the geometric product

GEOMETRIC ALGEBRA CONTINUED...

The geometric algebra $\mathcal{G}_n = \mathcal{G}(\mathcal{V}_n)$ is a 2^n -dimensional algebra.

$\mathcal{G}_n$ generates exactly 2^n linearly independent elements.

The **geometric product** of two vectors *a* and *b* can be decomposed into **symmetric** and **antisymmetric** parts:

$$ab = a \cdot b + a \wedge b$$

geometric product

inner product

$$a \cdot b = \frac{1}{2}(ab + ba)$$

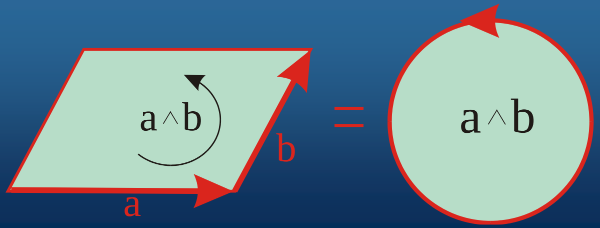
outer product

$$a \wedge b = \frac{1}{2}(ab - ba)$$

GEOMETRIC ALGEBRA - ELEMENTS

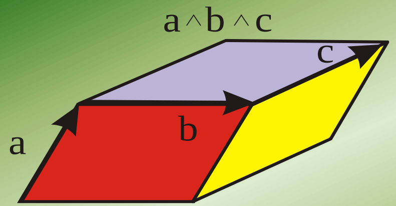
$a \cdot b$ is a scalar (grade 0)

Vector
(grade 1)



$a \wedge b$

Bivector
(grade 2)



$a \wedge b \wedge c$

Trivector
(grade 3)

$a_1 \wedge a_2 \wedge \cdots \wedge a_k$

k-blade

k - dimensional directed volume

I_n – pseudosclar of $\mathcal{G}_n$

GEOMETRIC ALGEBRA CONTINUED…

- Although geometric algebra can be constructed in an entirely basis-free form, in this particular application (Euclidean geometric algebra with signature (n,0)) it is useful to introduce a set of basis vectors which obey the following:

$$e_i \cdot e_j = \begin{cases} 1, & i = j, \\ 0, & i \neq j. \end{cases}$$

$$e_i \wedge e_i = 0$$

- A generic element of the geometric algebra is called a *multivector*

$$M = \sum_{k=0}^{n} \langle M \rangle_k$$

where $\langle M \rangle_k$ denotes the *k*-vector part of *M*

GEOMETRIC ALGEBRA OF 3D SPACE

1	$\{e_1, e_2, e_3\}$	$e_1 \wedge e_2,\ e_2 \wedge e_3,\ e_3 \wedge e_1$	$e_1 e_2 e_3$
1 scalar	**3 vectors**	**3 bivectors**	**1 trivector**
Grade 0	**Grade 1**	**Grade 2**	**Grade 3**

All anticomute: $e_1 \wedge e_2 = - e_2 \wedge e_1$ …

3D pseudoscalar: $I = e_1 e_2 e_3$

$I^2 = -1$

ORIENTATION FROM GYROSCOPE DATA

The orientation of the rigid body can be tracked using the time dependent rotor $R(t)$

$$\dot{R} = -\frac{1}{2} R \, \Omega$$

$$\Omega = I_3 \boldsymbol{\omega} = \omega_x \, e_2 \wedge e_3 + \omega_y \, e_3 \wedge e_1 + \omega_z \, e_1 \wedge e_2$$

Integrating $\dot{R}$ to obtain the rotor $R = e^{-\left(\frac{\theta}{2}\right)B} = \cos\left(\frac{\theta}{2}\right) - B \sin\left(\frac{\theta}{2}\right)$

The rotor for the step j is then $Q_j = R Q_{j-1}$

ORIENTATION FROM ACCELEROMETER DATA

The direction of gravity is defined along the vertical (z) axis of the global (earth) frame: $g = -e_3$

The accelerometer gives the measured acceleration a_m

The predicted acceleration vector is $a_p = Q\,g\,\tilde{Q}$

Q is the rotor obtained from the gyroscope data (previous slide)

$\tilde{Q}$ is reverse of Q

In reality, a_m and a_p differ.

The rotor (R_c) which rotates the predicted acceleration vector in order that it will coincide with the measured one is to be obtained:

$$R_c = \frac{1 + a_m a_p}{\sqrt{2(1 + a_m \cdot a_p)}}$$

The final rotation for the *j-th* step is: $Q_c = R_c Q_j$

FUSION OF THE DATA

- Both, accelerometers and gyroscopes are prone to errors, including noise and drift, respectively.
- Data fusion is a technique to integrate different types of data to a single result.

Two rotors representing rotational position of the device are found – from the gyroscope (Q_j)and accelerometer data (Q_c).

The rotation from the initial rotor to the final one can be represented by:

$$Q_r = \frac{Q_c}{Q_j} = \frac{R_c Q_j}{Q_j} = R_c$$

$$Q_r \equiv R_c = e^{-\left(\frac{\Phi}{2}\right)A} = e^{-\left(\frac{\Psi}{2}\right)}$$

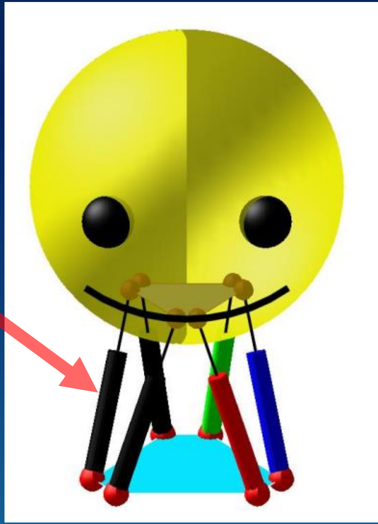
Fusion rotor: $$Q_f = \left[\cos\left(\frac{\alpha\phi}{2}\right) - A\sin\left(\frac{\alpha\phi}{2}\right)\right]Q_j$$ SLERP (spherical - linear interpolation)

$\alpha = [0, 1]$ is a scalar

TRANSFERRING THE CAPTURED MOTION TO THE ROBOT

The process of motion capture results in the derivation of the fusion rotor. Next, the path of the motion of the head is to be transferred to the robot as a set of orientations.

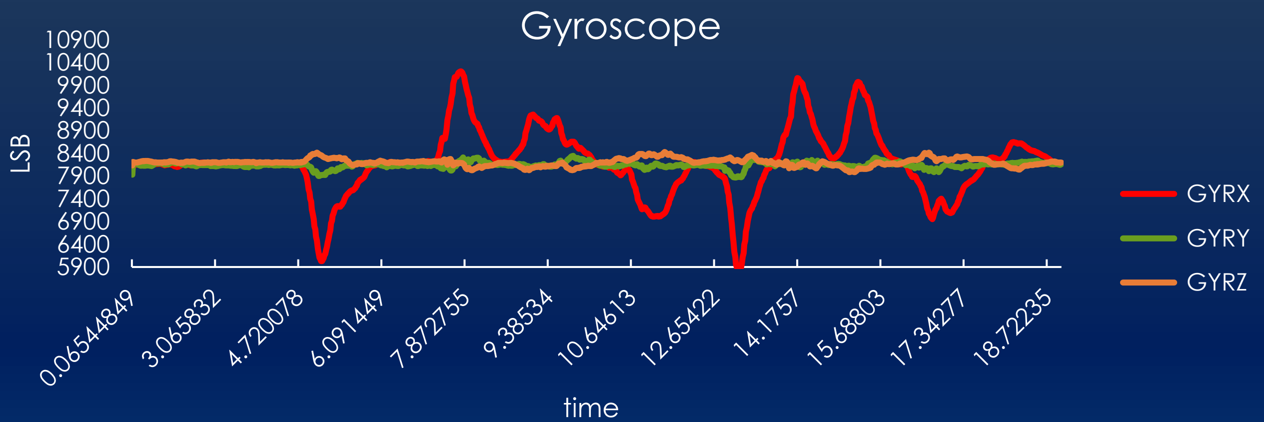
The motion of the moving platform of the robot is realized by the length variation of the six legs which connect the two platforms (the base and the moving platforms) of the robot. In order to control the robot, the lengths of the six legs have to be obtained.



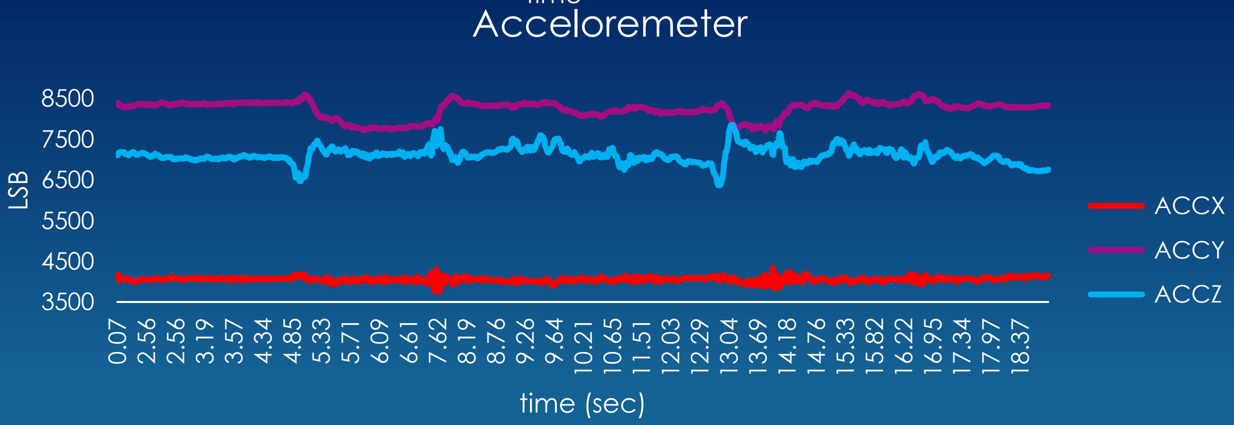
TESTING AND CALIBRATING THE ALGORITHM

- Several simple motions were captured in order to test and calibrate the algorithm.
- Here, a simple rotation of the head is presented:
  - *raw data form the Emotiv device are presented;*
  - *the processed data (components of the rotor and rotation angles) are illustrated;*
  - *the process* is illustrated by a video clip.
- A comparison of the human head motion and the generated computer animation of the robot, after processing the raw data, is given.

RAW DATA

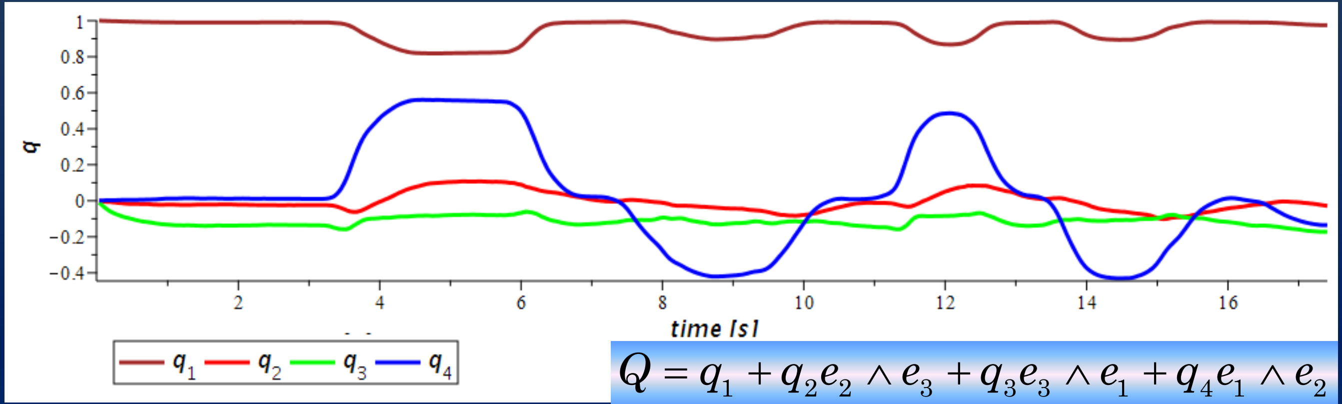


Gyroscope
10900
10400
9900
9400
8900
8400
7900
7400
6900
6400
5900
LSB
0.06544849
3.065832
4.720078
6.091449
7.872755
9.38534
10.64613
12.65422
14.1757
15.68803
17.34277
18.72235
time
GYRX
GYRY
GYRZ

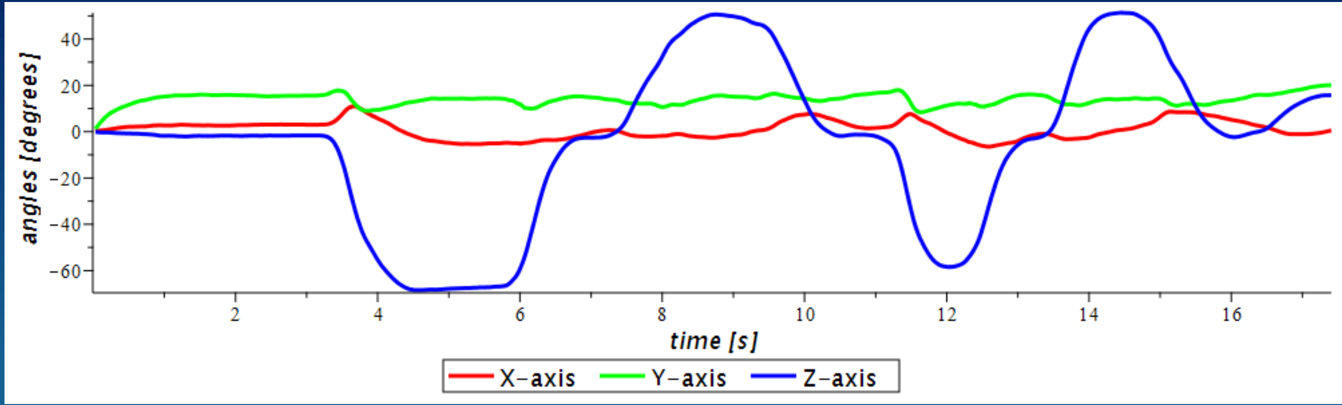


Acceloremeter
8500
7500
6500
5500
4500
3500
LSB
0.07
2.56
2.56
3.19
3.57
4.34
4.85
5.33
5.71
6.09
6.61
7.62
8.19
8.76
9.26
9.64
10.21
10.65
11.51
12.03
12.29
13.04
13.69
14.18
14.76
15.33
15.82
16.22
16.95
17.34
17.97
18.37
time (sec)
ACCX
ACCY
ACCZ

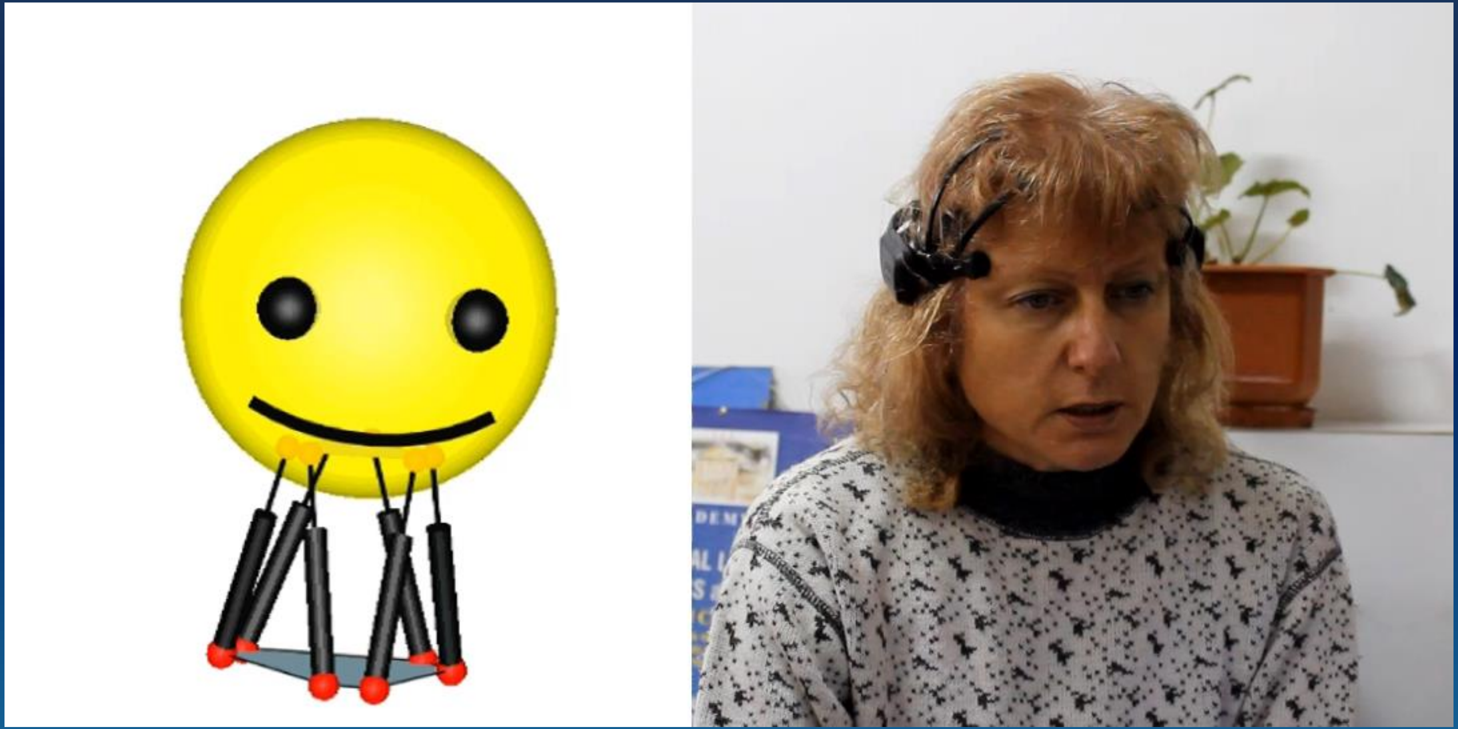
PROCESSED DATA



$$Q = q_1 + q_2 e_2 \wedge e_3 + q_3 e_3 \wedge e_1 + q_4 e_1 \wedge e_2$$



TESTING AND CALIBRATING THE ALGORITHM - SIMPLE MOTION CAPTURE



EXPRESSION CAPTURE

The EMOTIV device records facial expressions and movements. The recorded facial movements:
isBlink, isLeftWink, isRightWink, isEyesOpen, isLookingUp, isLookingDown, leftEye, rightEye, eyebrowExtent, smileExtent, clenchExten, upperFaceAction and lowerFaceAction.

Three main facial expressions are transferred to the robot:

- happy
- neutral
- sad (angry).

These three expressions are extracted from:

- upperFaceAction,
- lowerFaceAction
- clenchExtent

EMOTIONS

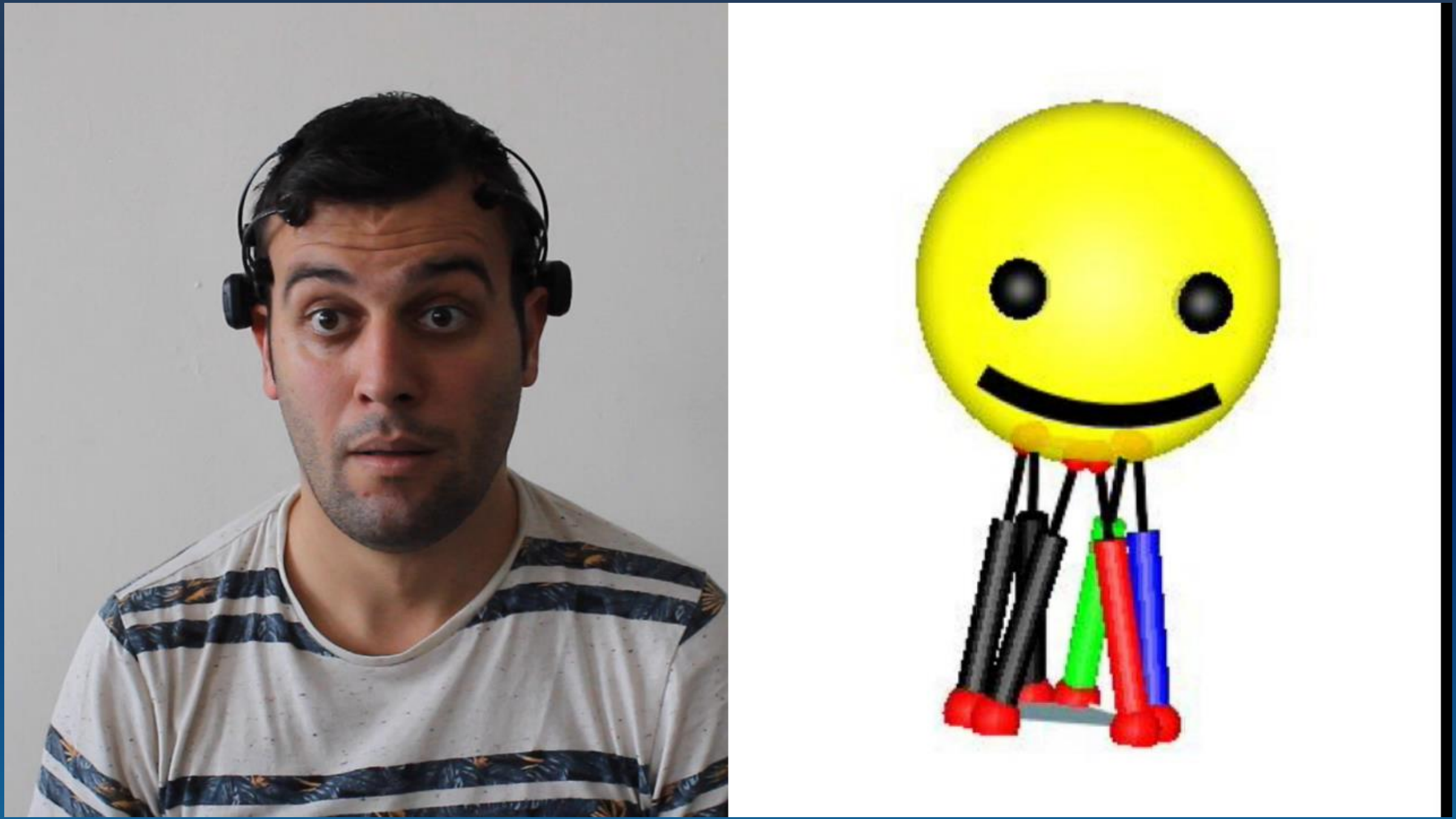
Basic emotions have been performed by actors and captured by EMOTIV EPOC+ device:

- fear
- joy
- surprise
- sadness
- disgust
- anger

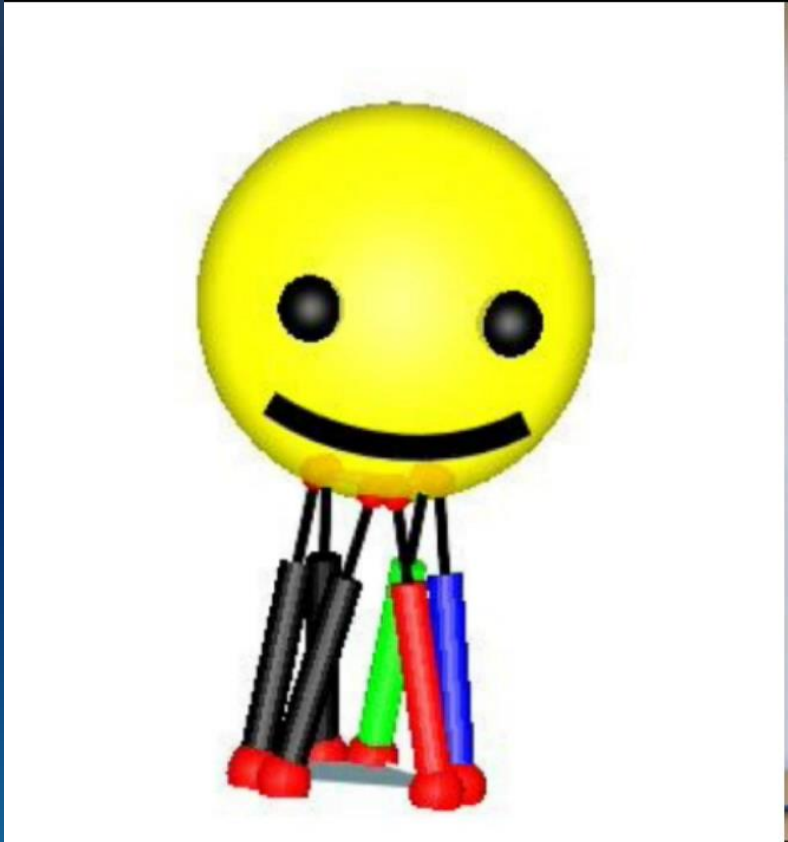
We employ actors from the "Tsvete" Educational Theatre – Sofia to perform these emotions.

An example of capturing and reproducing the "surprise" emotion follows.

"Surprise" emotion



“Surprise” emotion



A THERAPEUTIC SESSION

The humanoid robot NAO and the emotion-expressive robot EMOSAN was used in therapeutic session with children with communication disorders in a Speech and Language Therapy Centre.

REFERENCES

1. Tanev, T.K., Lekova, (2022) A. Implementation of Actors' Emotional Talent into Social Robots Through Capture of Human Head's Motion and Basic Expression. Int J of Soc Robotics 14, 1749–1766. https://doi.org/10.1007/s12369-022-00910-0

2. https://www.emotiv.com/

3. Tanev T. K. (2008) Geometric algebra approach to singularity of parallel manipulators with limited mobility. In: Advances in Robot Kinematics, Analysis and Design, Lenarcic J. and Wenger P. (Eds), Springer-Verlag, pp 39{48

THANK YOU FOR THE ATTENTION