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Authors Information

Titel
Gaze Gesture-Based Human Robot Interface
A Multimodal Human-Robot-Interaction Scenario: Working Together with an Industrial Robot
Development of a wheelchair-based rehabilitation robotic system (KARES II) with various human-robot interaction interfaces for the disabled
Integration of a Rehabilitation Robotic System (KARES II) with Human-Friendly Man-Machine Interaction Units
Multimodal Control Architecture for Assistive Robotics
Proof of Concept of an Assistive Robotic Arm Control Using Artificial Stereovision and Eye-Tracking
Hybrid Manual and Gaze-Based Interaction With a Robotic Arm
Human-Machine Interface for Controlling a Light Robotic Arm by Persons with Special Needs
Gaze-based teleprosthetic enables intuitive continuous control of complex robot arm use: Writing & drawing
An EEG-/EOG-Based Hybrid Brain-Computer Interface: Application on Controlling an Integrated Wheelchair Robotic Arm System
Anticipatory robot control for efficient human-robot collaboration
Interface based on electrooculography for velocity control of a robot arm
Intelligent Multimodal Framework for Human Assistive Robotics Based on Computer Vision Algorithms
Symmetric Evaluation of Multimodal Human–Robot Interaction with Gaze and Standard Control

Electro-Occulogram Based Interactive Robotic Arm Interface for Partially Paralytic Patients

A Human-Robot Interface Using Eye-Gaze Tracking System for People with Motor Disabilities

3-D-Gaze-Based Robotic Grasping Through Mimicking Human Visuomotor Function for People With Motion Impairments

Demonstration of a semi-autonomous hybrid brain-machine interface using human intracranial EEG, eye tracking, and computer vision to control a robotic upper limb prosthetic

On the feasibility of using motor imagery EEG-based brain-computer interface in chronic tetraplegics for assistive robotic arm control: a clinical test and long-term post-trial follow-up

Indirect Robot Manipulation using Eye Gazing and Head Movement For Future of Work in Mixed Reality

A Custom EOG-Based HMI Using Neural Network Modeling to Real-Time for the Trajectory Tracking of a Manipulator Robot

Rotation Matrix to Operate a Robot Manipulator for 2D Analog Tracking Objects Using Electrooculography

Affine transform to reform pixel coordinates of EOG signals for controlling robot manipulators using gaze motions

Human–Robot Interaction through Eye Tracking for Artistic Drawing

A novel robotic system for painting with eyes

Eye Gaze Controlled Robotic Arm for Persons with Severe Speech and Motor Impairment

Comparing Two Safe Distance Maintenance Algorithms for a Gaze-Controlled HRI Involving Users with SSMI

Performance Analysis of a Head and Eye Motion-Based Control Interface for Assistive Robots

Eye-Gaze Control of a Wheelchair Mounted 6DOF Assistive Robot for Activities of Daily Living

3D gaze Cursor: continous calibration and end-point grasp control of robotic acuators

Wireless and Portable EOG-Based Interface for Assisting Disabled People

Continuous Shared Control for Robotic Arm Reaching Driven by a Hybrid Gaze-Brain Machine Interface

Hybrid gaze/EEG brain computer interface for robot arm control on a pick and place task

Using Visuomotor Tendencies to Increase Control Performance in Teleoperation

Towards Robust Robot Control in Cartesian Space Using an Infrastructureless Head- and Eye-Gaze Interface

Head-free, Human Gaze-driven Assistive Robotic System for Reaching and Grasping

A Human-Robot Interface using Vision-Based Eye Gaze estimation System

Closed-Loop Hybrid Gaze Brain-Machine Interface Based Robotic Arm Control with Augmented Reality Feedback

Human-robot Shared Control of Articulated Manipulator

Doi	Technology overview
-	Eye tracking controlling a collaborative robot.
https://doi.org/10.1007/978-3	Eyetracking, Speech recognition and Touch screen are used to control an industrial robot, mobilie platform and IoT.
https://doi.org/10.1109/AIM.2003.1225462	Eyetracking, EMG, haptic suit and a display are used to control a robot arm and a wheelchair. Further, mouth recognition is implemented for sensoring readyness to drink.
https://doi.org/10.1023/B:AURO.0000016864.12513.77	Eye tracking (eye-mouse), EMG, shoulder/head interface and a display are used to control a robot arm and a mobile platform. Further, face recognition is implemented.
http://dx.doi.org/10.1007/978-3-319-46669-9_85	Eye tracking is used to control an assistive robotic arm. Objects were tracked by an MOTIVE system (Optitrack).
https://doi.org/10.1109/TNSRE.2019.2950619	Eye tracking is used to control an assistive robotic arm.
https://doi.org/10.1109/ETFA45728.2021.9613371	Eye tracking and computer mouse are used to control an assistive robotic arm over a display.
http://dx.doi.org/10.1109/ICCC51557.2021.9454664	Eyetracking is used to control a collaborative robot and electric wheelchair over a display.
https://doi.org/10.1109/BIOROB.2016.7523807	Eye tracking is used to control a industrial robot arm. Head tracking is used to control the robot in the third direction (moving forward and backward).
https://doi.org/10.3389/fnins.2019.01243	hBCI, EEG and EOG is used to control an assistive robot arm over a display. Cameras are used to realize a shared control.
https://doi.org/10.1109/HRI.2016.7451737	Eye tracking and speech recognition are used to control a robot arm.
https://doi.org/10.1080/11762322.2010.503107	EOG is used to control a robot over a display.
https://doi.org/10.3390/s18082408	EEG and EOG are used to control an assisitve robotic arm. Additionally head and mouth tracking is used to accomplish a drinking task.
https://doi.org/10.3390/sym10120680	Eye tracking is used to control a research robot over a display.

-	EOG is used to control a robot.
-	Eye Tracking and Motion Tracking was used to contrl a robot.
https://doi.org/10.1109/TBME.2017.2677902	Eye tracking was used to control an assistive robotic arm.
https://doi.org/10.1109/tnsre.2013.2294685	hybrid BCI (EEG/Eye tracking)
https://doi.org/10.1038/sc.2012.14	EEG-BCI, head tracking and eye tracking were used to control an assistive robotic arm. Visual cues and feedback were given over a display.
https://doi.org/10.1109/VRW55335.2022.00107	Augemented Reality Glasses were used to control an industrial robot.
https://doi.org/10.3389/fnbot.2020.578834	EOG was used to control a robot.
https://doi.org/10.3390/robotics3030289	EOG was used to control a robot over a display.
https://doi.org/10.3390/s140610107	EOG was used to control a Robot. Two plates were used as a visual target.
https://doi.org/10.3390/robotics10020054	Eye tracking was used to control a Robot over a Display.
http://dx.doi.org/10.1007/978-3-030-55807-9_22	Eye tracking was used to control a Robot over a Display.
https://doi.org/10.1145/3379155.3391324	Eye tracking was used to control a Robot over a Display.
https://doi.org/10.1145/3530822	Eye tracking was used to control a Robot over a Display.
https://doi.org/10.3390/s20247162	Eye tracking and head tracking with MARG were seperately used to control a industrial robot over a display.
http://dx.doi.org/10.21203/rs.3.rs-829261/v1	Eye tracking was used to control a power wheelchair and a industrial robot over a display.
https://doi.org/10.1109/ICRA.2016.7487502	Eye tracking was used to control a research robot.

https://doi.org/10.1109/TMECH.2011.2160354	EOG was used to control a robot arm. A display (Interface) was used to start and stop the application in the test.
-	Hybrid BCI consisting of EEG and Eye Tracking was used to control an educational robot arm over a display.
https://doi.org/10.1109/EMBC.2015.7318649	Hybrid BCI consisting of EEG and Eye Tracking was used to control a robot arm over a display.
https://doi.org/10.1109/ACC.2016.7526794	Eye tracking and joy stick were used to control an assistive robotic arm over a display.
https://doi.org/10.3390/s21051798	Eye tracking and head tracking were used seperately to control a industrial robot. A motion capturing system was used to generate additional information in the experiment.
https://doi.org/10.23919/CCC52363.2021.9549800	Eye tracking was used to control a prosthesis.
https://doi.org/10.1109/IRDS.2002.1043896	Eyetracking was used to control a robot over a display.
https://doi.org/10.3389/fnbot.2017.00060	BCI and eye tracking was used to control an educational robot over a display.
https://doi.org/10.1109/ISAM.2013.6643493	EOG was used to control a robot with the help of a grid as visual marker.

System Information

Eye movement detection Device, Manufacturer	Type of Fixation at the eye	Dimension of the robot manipulation space
SMI eye tracking glasses, SensoMotoric Instruments GmbH	Head-Worn	3D
EyeSeeCam, EyeSeeTec GmbH	Head-worn	3D
Self-developedCCD camera-based wearable system	Head-worn	-
Eye-mouse interface (self developed, fixed on a cap for user friendliness)	head-worn	3D
Tobii Pro Glasses 2 , Tobii	Head-Worn	3D
Eye Tribe	Remote	3D
Tobii 4C, Tobii	Remote	3D
-	Remote	3D
Tobii Eye X Controller, Tobii	Remote	3D
-	Head-worn	3D
SMI eye tracking glasses, SensoMotoric Instruments GmbH	Head-Worn	-
NeuroScan, manifacturer not specified	head-worn	2D
Tobii Glasses, Tobii	Head-Worn	3D
Eye Tacker, TheEyeTribe	Remote	2D

RHA1016, Eye Sense	Head worn	3D
Selfmade CCD camera	Head-worn	3D
not specified	Head-worn (seen in figures)	3D
NeuroPort System, BlackRock Microsystems, Tobii PCEye, Tobii Technology	Remote	3D
BrainAmp128 DC, View Point Eye Tracker, Arrington Research	Head-worn	3D
Smart MR Glasses, not specified	Head-worn	3D
-	head -worn	3D
NF Instrument EOG, not specified	Head-Worn	2D
EOG instrument, not specified	Head-Worn	2D
Tobii Eye Tracker 4C, Tobii	Remote	3D
Tobii Eye Tracker 4C, Tobii	Remote	3D
Tobii PCEyeMini tracker, Tobii	Remote	3D
Laptop Webcam	Remote	-
Monocular eye tracker headset Pupil Core, Pupil Lab	Head-worn	3D
PCEye5, Tobii	remote	3D
GT3D binocular eye-tracker, not specified	Remote	3D

Self build EOG	Head-worn	2D
EyeX, Tobii AB Inc.	Remote	2D
Tobii X60, Tobii	remote	-
Tobii Rex eye tracker, Tobii	remote	3D
MARG-sensor for head position, not specified; Pupil core, Pupil Lab	Head-worn	3D
Modified Pupil Core, Pupil Labs	Head-worn	3D
CCD-Camera	Remote	3D
EyeX, Tobii AB Inc.	Remote	3D
Self build EOG	head-worn	2D

Type of robot, Manufacturer
LWA 3, Schunk; gripper PG70, Schunk
Mitsubishi robot RV-6SL., Mitsubishi
Self developed arm (6 DoF) PUMA Type
Self developed arm (6 DoF) PUMA Type
JACO, Kinova
JACO, Kinova
IRB 4600, ABB (Simulation)
Gen3, Kinova
UR10, Universal Robots
JACO, Kinova
MICO, Kinova
LR Mate 200iB, FANUC
JACO2, Kinova
WidowX Robot Arm, TrossenRobotics

-
-
MICO, Kinova
MPL modular Prosthetic limb, not further specified
Assistive Robotic Manipulator, Exact Dynamics
-
antropomorphic robot, not specified
2DoF self build planar robot
-
UR5, Universal Robotics
UR10, Universal Robotics
Curious Arm, Kit4Curious
Dobot Magician, Variobotic
UR5, Univeral Robots; gripper 2F-85, Robotiq
xArm 6, UFactory
WidowX Robot Arm, TrossenRobotics

LRMate 200iB, Fanuc
Dobot Arm, Shenzhen Yuejiang Technology Co Inc.
-
MICO, Kinova
Dual Arm UR-5, Universal Robots; gripper 2F-85, Robotiq
Prosthesis, Not specified
-
Dobot, ShenzhenYuejiang TechnologyCo Inc.
-

Desc
Algorithms and models used in the approach
TFST (Timed Finite State Machine), Normalized Cross Correlation (NCC)
-
Self written: Gabor-filter based Gaussian weighted feature for mouth recognition, modified log-polar mapping to detect near motion, Fuzzy min max neural networks (FMMNN)-based classification for shouledr/head movement recognition.
Self written: Gabor-filter based Gaussian weighted feature for mouth recognition, modified log-polar mapping to detect near motion, Fuzzy min max neural networks (FMMNN)-based classification for shouledr/head movement recognition.
-
A*-Algorithm (for pathplanning and Collision-Avoidance)
-
-
-
Description of EEG Signal processing
Anticipatory motion planning
-
YOLOV2 was trained with the COCO image database. LINEMOD for Detection and Pose estimation
-

-

-

Two stages of graspplanning: 1. sliding window filter to locate object and ist pose 2. Gaussian Mixture Model (GMM) to generate visuomotor grasping model.

self written, computer vision algorithms and EEG signal processing was used. Point Cloud Library was used

-

RetinaNet

Fuzzy inference system, EOG modeled by means of a MNN, implementing descending backpropagation using Widrow-Hoff technique. Objective function is obtained by means of the neural network, optimized by genetic algorithms. Gaussian membershipm functions

Rotational matrice for EOG-signals

self written: Rotation and translation matrices
a moving average filter, and an interpolation with B-spline curves is used for filtering the gaze positions and segment filtering

a moving average filter, and an interpolation with B-spline curves is used for filtering the gaze positions and segment filtering

CNN for face channel, AGE-Net architecture. records gaze coordinates and uses a median filter and Bezier curve to smoothly move a cursor based on eye gaze movement [Biswas 2016]. Computer vision algorithms (not specified)
Hand detection (google) to avoid danger to users.AGE-Net architecture for calculating degrees of visual angle of accuracy for MPI-IGaze and RT-GENE datasets with nearly 108M parameters.

Authors referenced to other literature for details.

Denavit-Hartemberg and inverse Kinematic for robot control

OpenCV,Gaussian Processes (GP) Regression for calibration

-
-
Two-stage model of gaze trajectories based on HMM, Euclidean cluster extraction method (for locating the object)
-
Selfmade, head tracking via visual markers (tilt in the video). Use of PID to control Robot (automated trajectory)
Selfmade, servo control for obstacle avoidance by peoples fixation and selfmade 3D-estimation of gaze coordinates
Self-made GUI and algorithm to evaluate glints on the cornea
-
-

:ribing Parameters of the Algorithm

Programmed with …

iViewNGTM SDK (to detect gaze direction), ARToolKitPlus SDK (to determine gaze position to markers)

-

-

-

ROS, MOTIVE Optitrack

GraspIt (ROS, for Grasping), OpenCV (for 3D Scene aquisition)

Tobii Core SDK.

-

moveit ROS

Matlab for accuracy calculation

MoveIt! ROS

API from Matlab, C++ application

-

All these devices were integrated through a MATLAB interface.

-

freecell

Robotic Operation System (ROS)

ROS, Matlab GUI

-

-

-

-

-

Matlab

Matlab

-

Markov decision process (MDP) avoid hand collision

-

PyQt5 for virtual buttons on graphical user interface
C++ Interfaces, to connect everything, Matlab gaussian
processes regression for machine learning toolbox

-

POpenVibe Toolbox for BMI, OpenCV

-

Matlab

Robot Operating System (ROS), ORB SLAM 2 for visual odometry estimation, Pupil Labs Pupil Service

Robot Operating System (ROS),Moveit!

-

OpenVibe toolbox for EEG, Image Processing for Task automation. OpenCV and OpenGL for AR Feedback

-

Type of Eye movement used to control the system
Saccades and Fixations
Fixation
-
Fixation
Fixation, Dwell Time optimized to Fitts' Law
Fixation
Fixation
Fixation
Fixation and Wink
eye blinks and eyebrow raise. Addition control over hand motor imagery
-
Fixation for velocity control and direction, and Blink for target selection
Fixation
Fixation

Saccades

Fixation

Fixation

Fixation

Fixation

Fixation to search for the object and Head movement to select the object

Fixation

Fixation of dots

Fixation

Saccade and fixation

Saccade and Fixation

Fixation

Fixation, Dwell-time on buttons (500ms)

Saccades and Fixations

Fixation

Fixation and Wink

Rapid Saccades

-

Fixation: 100ms Dwell-time

Fixation

Wink, fixation

Fixation, Sliding window with dwell-time 700ms

Fixation

Fixation

Saccades

D
Task description
Two columns were presented Two subtasks were executed. The user should control the robot to grasp the first cube from the first column and put it on the second column behind it (first subtask), then grasp the other cube from the third column and put it on the first one (second subtask).
No User Study was conducted.
No User Study was conducted.
The experiment tested the performance of the system in a drinking task.
No User Study was conducted.
No User Study was conducted.
The participants were asked to execute joint movemnts by using their gaze.
No User Study was conducted.
The task contained tele-writing or painting: Participants were asked to imagine writing a text with the pen and look where the pen would be going. They were asked to write letters as fast and as accurate as possible, with a given letter size template.
The study thested a self-drinking task. Participants were asked to move a wheelchair to a table (EEG), manipulating the robotic arm via EOG to grasp a bottle and drink with a straw, placing the bottle back and navigating back through multiple obstacles and a door.
Participants had to choose a smoothie out of 12 ingredients. The robot system has to anticipate the choices by the eye gaze and grasp the right item and place it infront of the user.
Moving the robot over certain targets.
The participants were asked to select three kinds of objects by gaze (a glass, a bottle, and a fork) wearing the Tobii Glasses.
Participants were asked to play chess in three different difficulties (number of moves, number of figures), and 3 different modalities (eye tracking, controller, multimodal (combined))

No User Study was conducted.
The participant were asked to push buttons by gazing on them, yet the study did represent a proof of concept. No descriptions on participants were given. Other tests with playing FreeCell.
2 staged grasping approach by fixating locations on the object. The evaluation was quantified from two aspects: 1) the success rate of the grasping task and 2) subjective evaluation using questionnaires.
Participants were asked to conduct a reach-grasp-and-drop task, with 3 different balls. It was shown in an objective measurement that up to 8 objects could be detected by the computer vision algorithm with eye tracking.

Participants were told to visually focus on a glass and activate the BCI system by performing the agreed-to ‘grab’ class (the first of the feedback class pair). After the robot grab action sequence was completed, they were instructed to place the glass back.

No User Study was conducted.

Experiement 1: Standard calibration with inexpert and expert users, Experiment 2: Customized Calibration With Inexpert Users

The participants were told to focus 20 different points on a display.
The participants were told to fixate 24 visual markers. After training they conducted certain germetrical patters to evaluate the mathematical model.

No User Study was conducted.
The participants were asked to draw with their eyes on basis of AI-generated pictures. The eye movements were interpreted in two ways. While focussing on a location the participant could paint a point, when saccades were performed a line was drawn.
Participants were asked to pick and drop a Badminton shuttlecock. In the first study the participants could bring the robotic arm at any random point within the field of reach of the robotic arm. In the second task directional arrows were given to move the robot.
The participant was asked to perform the task of reaching the designated target for a print on cloths twice. The target positions were randomized for each trial and participant.
The participants were asked to perform abutton activation task to assess discrete control (event-based control) and a Fitts’s Law task. The usability study was related to a use-case scenario with a collaborative robot assisting a drinking action.
Participants were asked to perform activities of daily living (ADL), which included picking objects from the upper shelf, pick an object from a table, picking an object from the ground.
Participants were told to execute a reaching and grasping task with the robot.

Participants were asked to perform trajectories between fixed visual markers by "drawing" these trajectories with their eyes.

Participants were asked to accomplish a reach task with eye tracking and BCI. In this study three paradigms were tested, which could be controlled by the participant: 1) The system with shared control both in speed and direction 2) with shared control in speed only 3) with shared control in direction only.

The Participants were asked to sort two objects colored red and blue in their individual colored spaces by using motor imagery to control the robot.

The task was described as picking up a tennis ball.

The participant randomly gazes at five different target points inside a robots working area for 20 min in total. The user blinks with the left eye to send the gaze point to the robot control pipeline upon which the robot moves to this point.

Experiment I: By fixating on the scissors, the robot would reach for it and bring it toward the user. Experiment II: By fixation on the scissors, the robot would reach the scissors and catch the scissors. Then plan the motion trajectory of the robotic arm through a series of fixations to avoid obstacles on the table and finally bring it to the user.

The user controlled the robot over a display in which he focused on buttons. The display was separated in squares to facilitate the evaluation.

For each online trial, the BMI user operates the robotic arm to transfer a cuboid to the target area in the same color while avoiding the virtual obstacle in the middle of the workspace.

Participants were asked to control a robot along a grid on which a given path was shown.

escribing Parameters of the Empirical Study

Number of Participants	Number of Repetions
10,of which 1 is diagnosed with multiple sclerosis and is paralyzed from the neck down.	-
-	-
-	-
6 impaired participants with C4/c5 lesions	-
-	-
-	-
7 participants	-
-	-
8 Subjects	5
22 participants in total, 5 participants in the self drinking task (robot manipulation)	3
26 participants	-
3 participants	-
10 participants	20
20 participants	3

-	-
-	-
-	>4
2 participants	28 and 31 regarding the task
9 chronic impaired participants	-
-	-
30 participants (experiment 1) and 30 participants (Experiment2)	20
3 participants	20
3 participants (operators)	-
-	-
-	-
Study 1: In total 18 participants (9 healthy, 9 impaired), Study 2: 12 (6 healthy, 6 impaired)	2 repetitions in each trial
13 participants (7 healthy, 6 disabled)	-
10 participants +1 ALS patient	3 Tests, each participant had to reach 33 correct trials.
10 participants	5 trials and 3 manipulation tasks
7 participants	-

6 participants	-
6 participants	3 paradigms each 10 trials
8 participants	-
5 participants	5
3 participants	10
5 participants	2 tests with each 5 trials
-	200 trials in total
8 participants	30 trials: 15 with and 15 without feedback
4 participants	-

Performed empirical Test
Nasa TLX
-
-
Satisfaction degree in percent in form of a questionnaire
-
-
SUS
-
-
-
Questionnaire for perceived awareness and intentionality of the robot.
-
-
NASA TLX, together with 5 point Likert scale.

-

-

USE Questionnair

-

Empiric evaluation of the health status of each patient via sensory AIS score. Clinical Questionaire about perception of the system.

-

-

-

-

-

-

-

-

NASA TLX (RTLX Version) and subjective questionnaire

Not standardized test

Measurements to cognitive load, not specified

-

-

-

USE-questionnaire

-

QUEST

-

-

-