**MASTER THESIS**

to obtain the academic degree

„Master of Science in Engineering“

in the study program „Embedded Systems”

**Arbeitstitel**

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**Abstract**

Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content

**Acknowledgement**

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**Table of Contents**

[1](#_heading=h.tyjcwt) Introduction 8

[2](#_heading=h.3dy6vkm) State of The Art 9

[2.1](#_heading=h.1t3h5sf) Features of Standard Computer Input Devices 9

[2.2](#_heading=h.2s8eyo1) Alternative Computer Input Devices for Disabled 9

[2.2.1](#_heading=h.17dp8vu) Mouth/Chin Controlled Joystick 10

[2.2.2](#_heading=h.26in1rg) Wearable Sensors 11

[2.2.3](#_heading=h.lnxbz9) Wearable Target Trackers 12

[2.2.4](#_heading=h.44sinio) Face Trackers 12

[2.2.5](#_heading=h.z337ya) Eye Trackers 12

[2.2.6](#_heading=h.3j2qqm3) Speech Recognition 13

[2.2.7](#_heading=h.1y810tw) Overview of Alternative Computer Input Devices 13

[2.3](#_heading=h.4i7ojhp) Input Recognition Methods 13

[2.3.1](#_heading=h.2xcytpi) Button Press 13

[2.3.2](#_heading=h.1ci93xb) Proximity Switch 13

[2.3.3](#_heading=h.3whwml4) Sip and Puff 13

[2.3.4](#_heading=h.2bn6wsx) Timing Based Selection 13

[2.3.5](#_heading=h.qsh70q) Visual Twinkle Recognition 13

[2.3.6](#_heading=h.3as4poj) Noise/Voice Recognition 13

[2.4](#_heading=h.1pxezwc) Comparison of Currently Available Devices and Costs 13

[3](#_heading=h.2p2csry) Problem Description and Used Methods 15

[3.1](#_heading=h.147n2zr) Assumptions about the User 15

[3.2](#_heading=h.3o7alnk) Überschrift Tiefe 2 15

[4](#_heading=h.23ckvvd) Results and Discussion 16

[4.1](#_heading=h.ihv636) Überschrift Tiefe 2 16

[5](#_heading=h.32hioqz) Summary and Outlook 17

[Literaturverzeichnis 18](#_heading=h.1hmsyys)

[Abbildungsverzeichnis 19](#_heading=h.41mghml)

[Tabellenverzeichnis 20](#_heading=h.2grqrue)

[Abkürzungsverzeichnis 21](#_heading=h.vx1227)

[Anhang A: Überschrift des ersten Anhangs 22](#_heading=h.3fwokq0)

[Anhang B: Überschrift des zweiten Anhangs 23](#_heading=h.1v1yuxt)

[6](#_heading=h.3q5sasy) References 23

# Introduction

General description of the thesis topic, and thesis structure.

# State of The Art

Rough summary of the state of the art.

## Features of Standard Computer Input Devices

This chapter gives a summary of typical features of commonly used computer input devices.

Computer mouses fulfil the following use cases (see Figure 1):

* Curser movement
* Left klick
* Double left klick
* Right klick
* Scroll
* Drag and drop (different left-klick durations)

Diagram

Description automatically generated

Figure 1: Use cases of a computer mouse (modified taken from [1])

Computer keyboards fulfil the following use cases:

* Write characters (letter, numbers, punctuation marks, additional signs like spaces, brackets and others)
* Delete characters
* Confirm input (enter-key)
* Choose special actions such as copy and paste (Control (Ctrl) key)

## Alternative Computer Input Devices for Disabled

The scientific life sciences community already discovered several methods to enable severely disabled persons to control computers and other devices, which would usually require hands to do so. These devices track and interpret either mouth/head/eye movements, face expressions, or speech. Already discovered methods are categorized into six major groups: [2]

* Mouth/Chin controlled joysticks
* Wearable sensors
* Wearable target trackers
* Face trackers
* Eye trackers
* Speech Recognition

### Mouth/Chin Controlled Joystick

There exist two methods to implement joystick-controlled computer input devices:

* Standard joystick controlled by the lip. An extra mechanism for triggering mouse events is necessary.
* Special joystick with integrated sip-and-puff mechanism for triggering mouse events.

A picture containing person, output device, computer, indoor

Description automatically generated

Figure 2: Joystick controlled device…

1. …without mouse event recognition (modified taken from [3])
2. …with sip-and-puff mouse event recognition (taken from [4])

The first type uses a lip-joystick which can only be used for mouse position control, shown on Figure 2 i). Implementations differ in which part of the lips are used: Either both lips, which is easier to use and more accurate, or only the lower lip, which comes with improved hygienic circumstances due to less contamination with saliva. Nevertheless, an external mechanism to trigger mouse events is needed. [3]

The second type is a special version of joystick which consists of a small pipe including a mechanism for triggering mouse events. For example, a sip-and-puff (see Figure 2 ii)) or teeth pressure recognition system. [4, 5]

### Wearable Sensors

Wearable sensors are based on an IMU (Inertia Measurement Unit) which tracks movements of the head. These motions can either be interpreted as cursor movements (left, right, up, down) or trigger any other mouse-event (see chapter 2.1). To do so, specific head movement patterns must be trained and correctly recognized by the tracking software. [10]

In terms of accuracy and cursor drift, it makes a difference which type of IMU is used. Basically, three IMU types exist: [11, 12]

* *3-axis IMU*: Consists of a gyroscope which measures the rotation of X-, Y- and Z-axis. [11]
* *6-axis IMU*: Adds a 3-axis accelerometer which measures the motion in direction of X-, Y- and Z-axis.
* *9-axis IMU*: Adds a 3-axis compass which measures the relative orientation to the earth’s magnetic field.

IMU calibration [13]

Table 1: Comparison of 3-, 6- and 9-axis IMU

| **IMU Type** | **Functional Principle** | **Pros** | **Cons** |
| --- | --- | --- | --- |
| 3-Axis | Gyroscope |  |  |
| 6-Axis | Gyroscope  + accelerometer |  |  |
| 9-Axis | Gyroscope  + accelerometer  + compass |  |  |

### Wearable Target Trackers

Wearable target trackers are based on visual processing algorithms. A sensor - placed in front of the user - tracks the movement of a reflective feature, for example a red sticker on the user’s head, and translates it into cursor movements.

There exist three basic methods to implement wearable target trackers:

* Infrared feature detection
* Ultrasound feature detection
* Camera feature detection

*Infrared sensor* based tracking is similar to a hand-controlled joystick with the difference that it is operated by the users head. For this reason, infrared light emitting diodes (IR-LEDs) are used to radiate light rays invisible to the human’s eye. These rays are, in return, detected by an array of photodetectors. Depending on the received light intensity on the detector-matrix, the users head position can be determined which is then used to emulate a typical computer mouse. [14]

Figure 4 shows the radiation pattern of the head-mounted LEDs. In the middle of the four LEDs the highest light density occurs due to interference of the emitted rays. This facilitates the determination of the user’s head angle.

A picture containing sketch, drawing, line art, illustration

Description automatically generated

Figure 3: IR-radiation pattern of the LEDs mounted on the users head

*Ultrasound sensor* based devices use, similar to IR-LEDs, emitting and receiving components (see Figure 4). In comparison, these systems measure the distance between emitter and receiver instead of light intensity. As the receivers are arranged in a triangle, the position of the user can be determined by calculating the three distances between the transmitter and receiver components. For example, if all distances are equal then the user’s head is centric to the receivers. [15]

A picture containing sketch, text, newspaper, human face

Description automatically generated

Figure 4: Attachment of ultrasonic transmitters and receivers for position monitoring (taken from [15])

*Camera* based systems usually use a webcam or similar to track visual features which are attached to the user’s head. These features can be stickers in shape of a rectangle or dot and a defined (reflective) colour. [16, 17]

A child sitting in front of a computer

Description automatically generated with low confidence

Figure 5: Target tracker with reflective dot and camera (taken from [16])

All of these three technologies have major usablility disadvantages. While camera-systems are dependent on stable ambient light, the IR-system can be easily disturbed by any other IR-source such as sunlight. Furthermore, the user must always sit right in front of the detector, otherwise, it is not able to track the head movements. Also an additional selection mechanism for mouse events needs to be attached. Nevertheless, especially camera target trackers are highly affordable due to low hardware costs and easy set up.

### Face Trackers

Face trackers are based on visual feature detection which is used to detect and interpret facial expressions. Each facial expression encodes a specific mouse action. Figure 4 shows an example of a typical landmark-set for facial expression detection.

Chart, scatter chart

Description automatically generated

Figure 6: Landmarks example for facial expression detection (taken from [18])

Evaluation of vision based head tracking systems [19]

### Eye Trackers

Eye tracking systems use a camera which is placed in front of the user (e.g. laptop webcam). Using obstacle detection algorithms, pupil-movement of the users eyes are tracked. The cursor position on the device screen is calculated based on the distance between the user’s head and the screen as well as the deflection angle of his/her pupils from their central position. [21]

### Speech Recognition

[21]

### Overview of Alternative Computer Input Devices

[2]

## Input Recognition Methods

### Button Press

### Proximity Switch

### Sip and Puff

Integramouse [22]

### Timing Based Selection

### Visual Twinkle Recognition

### Noise/Voice Recognition

[23]

## Comparison of Currently Available Devices and Costs

At the moment, there are multiple hands-free computer input devices available on the market. Nevertheless, severely disabled persons often cannot afford them due to high costs. In the following paragraphs, an overview of currently available products is given. Furthermore, they are analysed according to their useability and costs. [24]

Table 2: Costs of wearable, IMU-based computer input devices

| **Product Family** | **Product Name** | **Costs** | **Pros** | **Cons** |
| --- | --- | --- | --- | --- |
| Wearable sensor | Glassouse Link | 499 € |  |  |
| Wearable sensor | GlassOuse V1.4 | 599 € |  |  |
| Wearable sensor | GlassOuse Pro | 799 € |  |  |
| Wearable sensor | Quha Zono | 1 365 € |  |  |
| Wearable sensor | EnPathia | 249 € |  | Probably not available in Austria |
| Wearable sensor | eeZee Switch | 749 € |  |  |
|  |  |  |  |  |
| Wearable Target Trackers | TrackerPro 2 |  |  |  |
|  | HeadMouse Nano |  |  |  |
|  |  |  |  |  |
| Face Trackers | Sesame Enable |  |  |  |
|  | SmyleMouse |  |  |  |
|  | ViVo Mouse |  |  |  |
|  | Camera Mouse |  |  |  |
|  | Enable Viacam |  |  |  |
|  | iTracker |  |  |  |
|  |  |  |  |  |
| Eye Trackers | PCEye Plus |  |  |  |
|  | PCEye Mini |  |  |  |
|  | Tobii 4C |  |  |  |
|  | IrisBond Duo |  |  |  |
|  |  |  |  |  |
| Lip/Chin Joystick | IntegraMouse+ |  |  |  |
|  | Jouse3 |  |  |  |
|  | QuadJoy |  |  |  |
|  | BJOY Chin |  |  |  |
|  | TetraMouse XA2 |  |  |  |
|  |  |  |  |  |
| Speech Recognition | Dragon Home |  |  |  |
|  | Windows Speech Recognition | |  |  |
|  | Mac OS X Voice Control |  |  |  |

# Problem Description and Used Methods

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## Assumptions about the User

* Must be able to move his/her head
* …

## HeadMouse Design Principles

* The “mouse” should work as a standard mouse and require no custom driver software to run on the computer.
* The “mouse” should work with both standard desktop computers and laptops.
* The “mouse” should be reliable. More specifically it should be unaffected by, or at the very least recover from, alterations in the physical environment such as: changes in the level or spectrum of ambient light; changes to the local electromagnetic field; changes in the distance between the user and the computer; and alterations in the orientation of a user and his/her computer.
* There should be no physical connection between the user and his/her computer, i.e., it should be wireless.
* Ideally the system should not require the user to have to “wear” any equipment. However, a number of practical approaches, including our own, do have this requirement. If the user has to “wear” some equipment this should be aesthetically pleasing, small, light, and comfortable.
* It is desirable that the clicking of mouse buttons be integrated with the operational approach. However, in many cases this is not practical and some other form of mouse button activation either by appropriate switches or by “dwelling” can be provided. If switches are used, the device should permit these switches to be connected to it and the switch depression mapped to mouse-button clicks appropriately.
* In addition, a “head-operated mouse” will be subject to cost requirements, such as low initial purchase cost and a low cost of ownership. [14]

## **Usability** Analysis GlassOuse Pro

## IMU Benchmarking

Methods for IMU comparison.

## Battery Life Benchmarking

Method to evaluate battery life time.

## Usability Benchmarking

Method for evaluation of computer input device efficiency usability: *“Fitts’ law as a research and design tool in human– computer interaction”*

## Economic Assessment

Full costs of production for 1, 10 and 50 devices.

Including:

* PCB components (and assembly)
* Enclosure
* Battery + power supply unit
* Overall assembly (automated and hand-crafted hourly rate)
* Printed manual
* Packaging

Comparison of PCB hand solder and automated assembly.

Comparison of european and asian PCB manufacturers.

# HeadMouse Design Implementation

Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text

# Feature Overview

Features:

* Bluetooth communication
* Battery powered (rechargeable)
* UI:
  + 1 LED for device status
  + 1 LED for battery status
  + 1 button to switch between hosts or pair a new device
  + 3 jacks for user input buttons (left-,right-click, scroll)
  + Sip & puff sensor input for alternative control mechanism
* 6+9 axis IMU for comparison
* ESP32-S3-WROOM for control

# Hardware

* + 1. Power and Battery Charging Management

ESP32 power management and battery charging schematic is based on ESP32 thing from Sparkfun: <https://cdn.sparkfun.com/assets/learn_tutorials/5/0/7/esp32-thing-schematic.pdf>

* + 1. Physical User Interface

# Software

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# Enclosure

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# Results and Discussion

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## Usability Analysis GlassOuse Pro

Ich hab die **Glassouse** mal getestet und das Ding ist echt super durchdacht. einfaches Plug&Play und meiner Meinung auch tolle Usability. Die default-Einstellungen sind so gut, dass man das Gerät direkt als vollwertige Maus verwenden kann (inkl. 3-Button System für Rechts-/Links-Klick und Scroll). Wirklich beachten muss man lediglich die Kalibrierung beim Geräte-Startup. Hab mich krumm und dämlich geärgert über den Mauszeigerdrift, bis ich gemerkt hab, dass man das Ding beim Start 3 Sekunden eben liegen lassen muss. Dann funktionierts auch :D

Folgende Dinge möchte ich gerne übernehmen:

a) *3 mögliche Anschlüsse* für Buttons etc. für Rechts-/Links-Klick und Scroll (kann man auch beliebig konfigurieren).

b) Einen *Button zum Switchen* des verbundenen Hosts (es können mehrere Hosts hinterlegt werden).

c) Einen *Button zum Umschalten unterschiedlicher Sensitivitäten* (kann man evtl. auch weglassen, wird vermutlich sowieso nur 1x konfiguriert).

d) Eine *LED für die Ladestandsanzeige* (3 Zustände).

d) Die verwenden eine *9 Achsen IMU* (also Gyro, Transl.-Bescheunigung und Magnetometer), um den Drift besser ausgleichen zu können. Ich teste mal unsere 6 Achsen IMU und werd mir dann ansehen, ob 9 Achsen Sinn machen könnten.

## IMU Benchmarking

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## **Design** Implementation

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## Battery Life Benchmarking

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## Usability Benchmarking

Feature Benchmarking compared to GlassOuse Pro and standard computer mouse.

## Economic Assessment

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# Summary and Outlook

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Abbildungsverzeichnis

Abbildung 1: Beispiel für die Beschriftung eines Buchrückens. [8](#_heading=h.25b2l0r)

ANMERKUNG: Dieses Abbildungsverzeichnis generiert sich selbst.

Tabellenverzeichnis

Tabelle 1: Semesterplan der Lehrveranstaltung „Angewandte Mathematik“ [8](#_heading=h.kgcv8k)

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Abkürzungsverzeichnis

| IMU | Interia Measurement Unit |
| --- | --- |
| LED | Light Emitting Diode |
| IR | Infra Red |
|  |  |
|  |  |
|  |  |
|  |  |
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ANMERKUNG: Sortieren Sie die Liste mit der Funktion „Tabelle sortieren“.

Anhang A: Überschrift des ersten Anhangs

Anhang B: Überschrift des zweiten Anhangs

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