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Impact of Varying Collision Avoidance Strategies on Human Stress Level in Human-Robot Interaction

Master Thesis

submitted to

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Faculty of Electrical Engineering and Information Technology

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by

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„*Das ist die Widmung / This is the dedication (optional)*“

Acknowledgement

Das ist die Danksagung / This is the acknowledgement (optional)

Abstract

Das ist die Kurzfassung (siehe Abschnitt 2.2) / This is the abstact (see section 2.2).

Inhaltsverzeichnis

Nomenclature

$\mathbf{x}$	State vector t
$\mathbf{x}(t)$	State vector at time t
t	Time
$u(t)$	Control input at time t
x, y, z	Spatial coordinates

Greek symbols

α	Greek letter

Abbreviations and Acronyms

Abrev.	Abbreviation
MPC	Model Predictive Control

Usage of generative AI models

$^{\ddagger_{\mathsf{CO}}}$	Code optimization: Optimization or restructuring of software function
$^{\ddagger_{\mathsf{CG}}}$	Code generation: Creating entire software functions from a detailed functional description.
$^{\ddagger_{\mathsf{CS}}}$	Substance generation in code: Generating entire software source code
$^{\ddagger_{\mathsf{MO}}}$	Media optimization: Correction, optimization, or restructuring of entire passages
$^{\ddagger_{\mathsf{MG}}}$	Media generation: Creating entire passages from given content.
$^{\ddagger_{\mathsf{MS}}}$	Substance generation in media: Generating entire sections
$^{\ddagger_{\mathsf{x}}}$	More

Explanations for the usage of generative AI models and its notation:
The bottommost level at which the identification is presented regarding the possible uses of generative AI models are subchapters of the 2nd order (e.g., 1.1.1, which may also appear without numbering), as otherwise, the identification would disrupt the reading flow due to frequent occurrences. Algorithms used for implementing generative AI models are mentioned at least in the text or provided as pseudo-code to facilitate appropriate identification.

1 Introduction

1.1 Motivation

Industry 4.0, also known as the Fourth Industrial Revolution, has brought about significant transformations within the industry, particularly in the manufacturing sector. This revolution has been characterized by the introduction of intelligent technologies such as the Internet of Things (IoT), cloud connectivity, big data, and human-robot collaboration, among others. These advancements have led to notable improvements and innovations, with the core principle and driving force of innovation in Industry 4.0 being the enhancement of efficiency and productivity. Human-robot collaboration, a key component of Industry 4.0, has played a huge role in this advancement by bringing humans closer together and facilitating more efficient and cooperative workflows.

Looking towards the future of the emerging Industry 5.0, the focus shifts towards a more human-centric approach. Industry 5.0 aims to strike a balance between technological advancements and human needs and interests, placing a strong emphasis on sustainable and resilient industrial practices. The goal is to merge the technological efficiency of Industry 4.0 with a greater emphasis on enhancing human well-being and personalizing the production process. Industry 5.0 brings back the human workforce to the factory, where humans and machines are paired to increase process efficiency by utilizing human brainpower and creativity through the integration of workflows with intelligent system (Nahavandi 2019). This shows a significant shift from purely efficiency-driven operations to those that also prioritize human factors and environmental sustainability.

Traditionally, industrial robots like manipulator arms, autonomous mobile robots, and gantry models have been kept separate from human workers primarily due to concerns regarding safety. These robots are typically characterized by their large size, substantial weight, and high speed, attributes that pose potential hazards when in close proximity to humans. Consequently, their design is predominantly focused on fulfilling specific tasks such as drilling, welding, or loading and unloading where their size and speed are necessary for efficiency but also necessitate isolation from human workers to ensure safety. This traditional approach prioritized the physical separation of robots and humans in industrial settings. However, advancements in Industry 4.0 have significantly increased the use of collaborative robots (cobots) , bringing them closer together to jointly accomplish tasks. This evolutionary progression has witnessed the transformation of robots from being seclu-

ded behind safety barriers to now operating side-by-side with their human counterparts, effectively capitalizing on their unique capabilities which combine human adaptability and decision-making skills with the precision and consistency offered by robots.
While technological advancements aim to optimize production, the comfort and well-being of human workers have not always been prioritized. This thesis aims to delve into the human aspect of human-robot interaction, considering how proximity to robots might affect the operator's physiological state. It aims to investigate how continuous interaction with robots impacts the stress levels experienced by humans and emphasizes the importance of monitoring and accurately assessing stress levels in human-robot collaborative environments. Sauppé und Mutlu (2015) have previously indicated that co-bots have the ability to influence the mental states of human workers, as they are often perceived as social entities. The close proximity of humans to robots in the workplace can lead to heightened levels of mental stress, particularly if the movements of the robot appear to be potentially harmful (Lasota und Shah 2015). For instance, if a co-robot swiftly moves towards a worker or follows an unpredictable path, it may induce feelings of anxiety or fear due to the perceived risk of sustaining an injury. This, in turn, can negatively impact both productivity and the efficacy of human-robot collaboration. Furthermore, it can impede the complete utilization of the advanced capabilities offered by collaborative robots. Identifying and addressing these stress factors is key to optimizing the human-robot collaboration for enhanced productivity and make the working environment effective, efficient and safe.

1.2 Aim of the Thesis

The aim of this thesis is to evaluate the impact of varying collision avoidance strategies on human stress levels in the context of human-robot interaction. Our objective was to conduct a study to collect and analyze data to understand the different stress levels in relation to varying robot collision avoidance strategies. This is done taking different collaboration levels and robot control strategies into account. We then used this data to create a predictive model that can identify and address sources of stress during human robot collaboration.
Specifically, the objectives of the thesis are:

- **Assessment of Human Stress Levels**: Develop a holistic approach for evaluating stress levels in human-robot interactions, combining both objective physiological measures and subjective experiences. Objectively, the study will employ various physiological indicators such as Galvanic Skin Response (GSR), Electrodermal Activity (EDA), Heart Rate(HR), and body posture analysis. These indicators will provide quantifiable data on the body's physiological response to robot interactions. Subjectively, the study aims to incorporate personal feedback from participants, gathered through questionnaires. This will offer insights into their personal feelings and perceptions regarding their interactions with robots. By blending these objective and subjective methods, the study aims to provide a comprehensive understanding of stress in human-robot interactions.
- **Development of Data Acquisition and Synchronization System:** Designing an acquisition system that successfully takes data from several sensors at different

frequencies and synchronizes it. Devices such as the Empatica E4 wristband are utilized for gathering data on Galvanic Skin Response (GSR), Electrodermal Activity (EDA), and other parameters, as well as a motion capture system to record human posture and movement. A vital aspect would be to synchronize these many data streams, ensuring accurate and consistent assessment of human physiological states across different robot interaction scenarios.

- **Data Collection and Evaluation**: Designing and conducting a subject study to collect data on participants' physiological responses while doing different assembly tasks under different robot-human interaction scenarios. These scenarios included three distinct levels of robot collision avoidance strategies: No Collision Avoidance, Dynamic Collision Avoidance, and Predictive Collision Avoidance as well as three different collaboration levels: Different Workspace with the cobot, Shared Workspace, and Shared Workspace with Direct Collaboration. The aim is to gather comprehensive data to analyze the impact of these varying robot control strategies on human stress levels.

- **Stress Prediction Model**: Developing a model for predicting and classifying stress levels during human robot collaboration. This model trained on the dataset of human physiological responses collected from the subject study.Various preprocessing techniques and feature engineering techniques are used to prepare the data for the model. Various machine learning models such as K-Nearest Neighbors (KNN), Support Vector Machines (SVM), and others, are evaluated to determine the best model for predicting stress levels.

1.3 Structure of the thesis

Chapter 1 presents the motivation behind the study and the aims of the thesis. In Chapter 2, we delve into the fundamental concepts of stress and examine the relationship between stress and key physiological signals such as Electrodermal Activity(EDA), heart rate (HR) and Galvanic Skin Response (GSR)etc. Chapter 3 describes the data collection process of the subject study that was conducted to collect data on participants' physiological responses. Chapter 4 describes the data analysis process of the subject study to analyze the collected data and the different pre-processing techniques and feature selection used to build the model. Chapter 5 describes the results of the subject study and the different machine learning models that were evaluated to determine the best model for predicting stress levels. Chapter 6 concludes the thesis and outlines the future work and research directions.

2

Structure of the thesis

The thesis should focus on the documentation of your own contribution and scientific results, in which an analysis, interpretation and evaluation of the applied methodology and the results are of key importance.

In general, scientific publications start with a study and review of related literature. You should revisit the literature study throughout your thesis before engaging on a new investigation or issue. In addition to the TU Dortmund library, research literature on the internet from the following sites.

http://scholar.google.de/

http://www.sciencedirect.com/

http://citeseer.comp.nus.edu.sg/cs

http://ieeexplore.ieee.org/search/advsearch.jsp

http://www.springerlink.com/

Evaluate the quality and relevance of publications in relation to the topic of your thesis. The purpose of the literature study is to obtain an overview, sound knowledge and awareness on established related approaches, methodologies and solutions. Your thesis should only contain references that are relevant to the thesis assignment. The analysis of the literature and the practical requirements of the thesis provide guidance to formulate a concise and specific problem formulation. The thesis should start with a scientific problem formulation

The problem formulation consists of just one or two sentences and should clarify the research problem, you aim to address and to why and where it is relevant. The problem formulation is constitutes the core of your thesis and provides the beacon if you lose track during your investigations and writing of thesis.

In developing the solution of the tasks and the presentation of the results utilize the methods and knowledge that you acquired during your studies in related courses. Take care that the gathered data is described as objectively as possible and that your findings are supported by sufficient examinations and evidence. The presentation should allow others to comprehend and reproduce your results. The thesis should conclude with a discussion and interpretation of relevant findings. The scope of a bachelor thesis is about 30 pages, the scope of a master thesis about 60 pages. A more detailed guideline on how to structure and write a thesis and how to cite references and sources properly is provided Rossing und Praetsch (2005).

2.1 Title page

The title page provides information about the topic of the thesis, the chair, date of submission and the name of the author in the corresponding entries of the template.

2.2 Summary

The summary (abstract) of about half a page should provide a brief outline on the motivation, problem and content of the thesis. The scope and the main result should become clear.It has to be clear what the work is about and what the main results are.

2.3 Table of Contents

The table of contents represents the logical structure of the thesis. It helps to clarify the organization and framework of the thesis. The level of detail should be chosen appropriately and should normally not contain more than two levels (section, subsection) of granularity per chapter.

2.4 Nomenclature

The nomenclature includes the specification of all symbols, variables, abbreviations and their explanations throughout the thesis. The nomencl package automatically generates the entries of the symbols and facilitates managing the nomenclature. *http://www.ctan.org/tex-archive/macros/latex/contrib/nomencl/* or the glossaries package (recommended): *https://www.ctan.org/pkg/glossaries*. The switch can be made in the file *settings/settings.tex* with the variable *useNom*.

Glossaries (recommended)

To use Glossaries, no further changes need to be made to this template except for activation. The entries are made in the file *settings/glos.tex*. Sorting by variables (e.g., x, y, z), abbreviations (e.g., Abbreviation (Abrev.) or Model Predictive Control (MPC)), and Greek letters (e.g., α) has already been implemented.

Furthermore, there is a separate category for marking the use of generative AI models, which should **not** be modified. If a generative AI model is used, the corresponding entry from Glossaries should be used to indicate this. Use the elements with the command *\gls{<ki-label>}* (ki-labels are: *gptmo* ‡MO, *gptmg* ‡MG, *gptms* ‡MS, *gptco* ‡CO, *gptcg* ‡CG, *gptcs* ‡CS, *gptx* ‡X), and mark the corresponding box in Appendix 8.1.

To use the entries in the text, the command *\gls{<label>}* can be used in both text and math environments.

Nomenclature

The tex files are scanned by *makenomenclature* after *nomencl* is invoked. The result is a file *struktur.nlo* containing the entries. The entries are processed with *makeindex.exe* and then included with *printnomenclature* into the main latex file. For an example, see section 2.7.

How to set up the nomenclature compiler

TeXstudio

Options → *Configure TeXstudio ...* → *Commands* → line *Makeindex*:

makeindex.exe %.nlo -s nomencl.ist -o %.nls

Test configuration: F11 or *Tools* → *Index*.
If successful, recreate PDF. *Makeindex* must be reinvoked each time the nomenclature changes.
See *nomenclature.tex* for examples of how to generate the nomenclature.

Visual Studio Code To use makeindex in Visual Studio Code, the settings.json file of the *Latex-workshop* Extension needs to be modified. In the *latex-workshop.latex.tools* section, the entry makeindex must be added: *{"name": "makeindex", "command": "makeindex", "args": []}*

Bugs If the spacings in the nomenclature are incorrect and thus the descriptions of the symbols are not displayed, it helps to set the indent manually. To do this, in the file *nomenclature.tex* extend the line with the command *\printnomenclature* to *\printnomenclature[<Einzug>]*. *<Einzug>* is the indentation size of the description. A collection of 4 cm. is similar to the default in this sample nomenclature (By default, the indent size is *\nomlabelwidth*. For more information, see the *nomencl* Pakets).

2.5 Thesis Structure and Organization

It is difficult to provide specific guidelines about thesis content and structure. Nevertheless, most scientific publications in engineering and natural sciences share a common structure of presentation. The proposed thesis organization may not apply in all cases, but is often a good starting point to structure your thesis. If in doubt, discuss the structure of your thesis with your supervisor. As an example, the content of the written paper may be structured as follows:

- introduction
- theoretical foundations
- your approach and investigations

- experimental/simulation results and analysis
- summary and outlook

The chapter on theoretical foundations discusses the state of the art and related approaches in detail. The basic concepts and methods are reported *briefly* with proper reference to the relevant literature for the interested reader. Please stick to the basic concepts and do not elaborate on derivations or proofs. The thesis is not a designated as a textbook for students but targets an audience with expert knowledge. Refer the reader to those references that are particular relevant in the context of the problem investigated in the thesis. Do not assume that there your problem is novel, it is almost certain that others investigated the very same or similar problem before. It is your obligation to familiarize yourself with the state of the art rather than to start with a blank sheet and attempt to reinvent the wheel metaphorically speaking. Explain and categorize the state of the art approaches and evaluate their relevance as an approach or solution for your problem at hand. From our experience at RST many theses suffer from an insufficient study and knowledge on the state of the art causing ill-defined ad hoc decisions in approaching the thesis.
The chapter on approach and investigations explains in detail the contribution in terms of what has been investigated or implemented (calculated, designed, programmed, ...). Your achievements are evaluated based on what you actually report in thesis not on what you might have done or not in your thesis work. The objective is to pursue the studies and investigations in a constructive, productive and critical manner guided by the state of the art in methodology, theory and software packages and implementations.
The final chapters of the thesis elaborates on the results. It is not sufficient to merely provide tables or figures it is far more important to analyze the results, ideally confirming or rejecting an initial hypothesis. This chapter should include a comparative analysis„ either comparing novel method with established methods, or showing that modifications or augmentations actually improve. The comparative analysis should not be limited to a single proprietary dataset or example. You find general guidelines for benchmarking in Hoffmann u. a. o. D. Illustrate your results with graphs and/or tables according to these general guidelines:

- Use statistics correctly! If possible repeat experiments several times to analyze the variation. Report mean in conjunction with the standard deviation. Etc.
- Quantitative results should be compared with default performance. The statement: „*The XY-controller reaches a rise time of* 15 ms.“ is worthless to the reader without comparison to an alternative method (e.g. classical PID controller). If possible, the state of the art or at least a simpler standard concept should serve as a reference. The sentence: „*The XY slider, with a rise time of* 15 ms *is more than twice as fast as a PID slider, which acquires a minimum of* 34 ms " is more suitable for an evaluation.
- Investigate the robustness of your results, e.g. w.r.t. to noise or model uncertainty. Which level of disturbance noise or model uncertainty is tolerated without degradation in performance?

- Analyze and compare your results! Merely reporting numbers is not sufficient. Is the designed system suitable for the task? What are its strengths, limitations and weaknesses? Do not hesitate to mention weaknesses of your approach or solutions, it rather enhances the credibility of your thesis.

The result of your thesis might be that the originally designated approach *does not* work or succeed as expected or hoped for. In this case, analyze the cause of the failure or limitations and suggest measures to overcome or mediate the weaknesses. If that is not possible report on lessons learned and propose a better alternative approach. The thesis summary should report the main findings and results of the thesis. The outlook suggest future investigations and remaining technical or scientific challenges.

2.6 Language and Style

Write the thesis in a comprehensive and precise language and style. Adapt the detail of presentation of a topic or concept to the scope of the thesis. Do not get lost in technical details of implementation. Introduce terms and concepts that are beyond engineering terminology properly. Write your thesis consistently in present tense even when you refer to experiments that you conducted in the past. Avoid to refer to the first person in your thesis and aim for clear and concise formulations. Proofreading by a third party is one way to increase the comprehensiveness of the thesis and to eliminate spelling and punctuation errors in advance. Utilize grammar tools such as grammarly or spell checkers to improve grammar and style and obey the following guidelines:

- formulate the text in present tense (exceptions are only made if the present tense distorts the meaning of the statement).
- avoid abbreviations such e.g. or etc. and filler words
- introduce abbreviations of terms before or with first appearance
- write terms in a consistent manner throughout the thesis (for example: either paretooptimal or pareto-optimal).

2.7 Equations

Equations, as well as figures and tables, are numbered in consecutive order. The individual terms of an equation are explained immediately before or after the equation, for example "The general form of the state differential equation is given in Equation 2.7.1, where $\mathbf{x}(t)$ denotes the state vector and $u(t)$ the input signal of the system."

$$\dot{\mathbf{x}}(t) = f(\mathbf{x}(t), u(t)) \tag{2.7.1}$$

Attention: Avoid the *eqnarray* environment for **multi-line equations** should (see explanation here: `http://tug.org/pracjourn/2006-4/madsen/madsen.pdf`). Rather utilize the environments of the *amsmath* package (e. g. *align* and *split*).

An example for align (each line obtains separate equation number, as long as enumeration is not explicitly suppressed (e.g., with align * or \nonumber))

$$\dot{\mathbf{x}}(t) = f(\mathbf{x}(t), u(t)) \tag{2.7.2}$$
$$x(t_0) = x_0 \tag{2.7.3}$$

Example of a multi-line equation with a single global equation number

$$\begin{aligned} \dot{\mathbf{x}}(t) &= f(\mathbf{x}(t), u(t)) \\ x(t_0) &= x_0 \end{aligned} \tag{2.7.4}$$

Here are more examples: `https://de.sharelatex.com/learn/Aligning_equations_with_amsmath`.
Use a consistent nomenclature for the representation of individual terms, for example scalar, vector and matrices should be clearly distinguished in terms of font type or small and large caps.

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{b}u \tag{2.7.5}$$

Table 2.1 provides some suggestions.

- If a number has a unit, it has to be declared. (There is a protected narrow space between the number and the unit.)
- Units are not variables and are therefore not written in italics.
- In addition to mean values also report the corresponding standard deviation (or variance).

To insert a formula directly from an image, website, article, or other sources into Latex file, Mathpix Snip can be used. Snip can be downloaded from `https://mathpix.com` and visit `https://mathpix.com/docs/snip/overview` to learn more about it.

2.8 Numbers and Units

The `siunitx` package is designated to represents the units specified in table 2.1 in a convenient way. This package is already pre-configured for the English and German languages. Units might appear in equations as well as in the text environment. A complete list of commands and units is provided found at `http://ftp.uni-erlangen.de/ctan/macros/latex/contrib/siunitx/siunitx.pdf`.

2.9 Figures

Figures are numbered consecutively, in the order of appearance. Each figure contains a caption and is referred to in the text. Figures should clarify the concepts in the text and appear on either the same or subseqeunt page as the text which refers to it. Images should be in gray-scale, and in high quality in terms of resolution. The font size and type should be readable and match the font size and type in the text as shown Figure 2.1.

Tabelle 2.1: Rules for variables, numbers, units and operators

Type	LaTeX code	Result
Small, italic variables	\$a+b=c\$	$a + b = c$
Small, bold vectors	\$\textbf{x}\$	$\mathbf{x}$
Capital, bold matrices	\$\textbf{A}\$	$\mathbf{A}$
Capital, italic values	\$M\$	M
The decimal separator is the point[a]	\$5.35\$	5.35
The thousand separator is the comma[a]	\$100{,}000\$	100,000
Standard operators as text	\$\sin(x)\$	$\sin(x)$
Other operators as text	\$\operatorname{nonstd}(x)\$	$\operatorname{nonstd}(x)$
Transposed matrix (recommended)	\$\textbf{M^\intercal}\$	$\mathbf{M}^\intercal$
Units as text with spaces[a]	\$5\,\textrm{kW}\$	5 kW
The star represents the convolution operator	\$f*g\$	$f * g$
Omit markings whenever possible	\$z=2xy\$	$z = 2xy$
Increased legibility through half-spaces	\$z=2\:x\:y\$	$z = 2\,x\,y$
Use a dot, if it is necessary[a]	\$4{,}2\cdot 10^9\$	$4.2 \cdot 10^9$

[a] If not the `siunitx` package is used

Tabelle 2.2: Commands for numbers and units

Type	LaTeX code	Result
Real number	\num{ 5.35 }	5.35
Power of 10	\num{ 2e2 }	2×10^2
Complex number	\complexnum{ 5+6i }	5+6j
Number with uncertainty	\num{ 1.234(5) }	1.234 ± 0.005
Fracture	\num[parse-numbers=false]{\frac{1}{2} }	$\frac{1}{2}$
Interval	\numrange{ 5 } { 100 }	5 bis 100
List	\numlist{ 0.1; 0.2; 0.3 }	0.1, 0.2 und 0.3
Angle (Grad)	\ang{ 5.1 }	5.1°
Angle (ext.)	\ang{ 6; 7; 6.5 }	$6^\circ\,7'\,6.5''$
Units Method I	\si{\kilogram\metre \per\second}	$\mathrm{kg\,m\,s^{-1}}$
Units Method II	\si{kg.m.s^{-1}}	$\mathrm{kg\,m\,s^{-1}}$
Number and unit I	\SI{3e5}{MHz}	$3 \times 10^5\,\mathrm{MHz}$
Number and unit II	\SI{1,0(2)}{\metre\per\second\squared}	$(1.0 \pm 0.2)\,\mathrm{m\,s^{-2}}$
Number-unit product	\qtyproduct{2 x 3 x 4}{\metre}	$(2 \times 3 \times 4)\,\mathrm{m}^3$

Tabelle 2.3: SI package in connection with tables (further information online)

Values	Values	Values	Values	Values
2.3	2.3	2.3 ± 0.5	2.3	2.3×10^8
34.23	34.23	34.23 ± 0.04	34.23	34.23
56.78	56.78	56.78 ± 0.03	-56.78	56.78×10^3
3.76	3.76	3.76 ± 0.02	± 3.76	10^6

- figures should be legible in black and white printouts.
- figures require a meaningful, comprehensive caption.
- figures are referenced and explained in the text.
- graphs should include axis labels (with unit)
- complex figures with multiple graphs should contain a legend, or be described in detail in the caption.
- text in figures has to be legible. Text sizes smaller than 80 % of the normal text are not allowed.
- figures should use the same font type and size as the text.
- pixel wise image representations are only allowed for photos. Graphics, figures or diagrams should be included as vector formats such as *eps*
- keep figures, illustrations and schemes simple. Avoid design elements such as shadows or gradients.
- design block diagrams and flowcharts according to standard nomenclature.

Abbildung 2.1: RST-Logo

Always cite the original source in the caption for those graphics that you did not generate yourself (see illustration 2.2).

Abbildung 2.2: Official TU Dortmund University logo (TUD o. D.)

2.10 Algorithms

Algorithm 2.10.1, shows the implementation of a depth search to explore all possible paths between a start and end point.

Algorithm 2.10.1.: Search all possible paths in the HKP graph

Require: G: acyclic graph, B: List of visited nodes (empty), z: target position, P: List of all paths (empty)

```
1:  function SUCHEPFADE(G, B, z, P)
2:      b ← B.back()                                  ▷ Last visited nodes
3:      for each adjacent node v at node b in G do
4:          if v ∈ B then                             ▷ Already met
5:              continue
6:          if v == z then                            ▷ Goal achieved
7:              B.append(v)                           ▷ Add destination to complete path
8:              P.append(B)                           ▷ Save full path
9:              break
10:     for each adjacent node v at node b in G do
11:         if v ∈ B or v == z then                   ▷ already met or goal achieved
12:             continue
13:         B.append(v)          ▷ This is an example of a very long comment in pseudo-
                                   code, which by default will continue at the beginning
                                   of the next line without this setting.
14:         SUCHEPFADE(G, B, z, P)                    ▷ Recursion
15:         B.pop(v)
```

2.11 Tables

Tables, as figures, are numbered sequentially. Refer and explain tables in the text. Font size and line width should be uniform and legible

2.12 Bibliography

The bibliography contains all the relevant work and the complete details of all sources used throughout the thesis. References are cited in the corresponding location in the text.

Tabelle 2.4: Example table

Configuration	Parameter set
1	$\{p_1, p_2, p_5\}$
2	$\{p_1, p_4, p_5\}$
3	$\{p_2, p_3, p_4\}$

Attention, the classic latex command `\cite` should not be used as it is incompatible with the Biblatex package!

Citations are included with the following commands

```
\textcite[Seitenangabe]{Bibtex-Key}
```

```
\textcite{Bibtex-Key}
```

That means, the quote is integrated as part of the sentence.
For example: Junior (1985, S. 123 ff.) developed a method to ...
For multiple sources, the Bibtex keys are separated by commas.

```
\textcite{Bibtex-Key1,Bibtex-Key2}
```

For example: Junior (1985) und Mustermann (1985) deal with ...
For sources that are not integrated into the document, the source of the literature is mentioned in brackets with the commands

```
\parencite[Seitenangabe]{Bibtex-Key}
```

and

```
\parencite{Bibtex-Key1,Bibtex-Key2}
```

For example: Corresponding methods are known from the literature (Junior 1985; Mustermann 1985).
This template provides an example of a proper bibliography.
Attention: Citations **Wikipedia** do not constitute a scientifically authorized (peer reviewed) source. In addition, the contents at Wikipedia are dynamic. Wikipedia therefore does not constitute a legitimate scientific source and **should not be included as a citation**. Nevertheless, Wikipedia is useful as a starting to identify relevant literature and original scientific sources listed in the **Proofs of Authors** of each entry.
If some reason you need to cite Wikipedia use „citation“, which generates the corresponding Bibtex entries.
Note: If you do not see any bibliography, try to compile it separately. E.g. in TeXstudio: Tools - Bibliographie (F8)

2.13 Appendix

The appendix includes the information that is not directly related to the main content and presentation, but it is nevertheless relevant to reproduce your results and findings (pseudo code, component description, maps, additional measurement results, etc.). An appendix is optional.
The final pages of the thesis document include the thesis assignment (without signatures) and the affidavit.

2.14 Template, printing and binding and very long section names

This template is designed for two-sided print in DIN A4 format. In the printed version, the page numbers are always on the outside of the title bar. On the inner side of the header, chapter number and chapter name are located on the left side for easier navigation, and on the right, the number and name of the current section. New chapters start on the right side and have the page number in the middle of the footer. If the chapter or section name is too long for the header or table of contents, find a more concise term, or define a short name as described in this section.
For the binding of the final version of the work, you receive from your supervisor covers and backs of appropriately printed colored cardboard. These cover pages are not included the template. The binding is done by a (black) glue binding. An additional cover (plastic wrap or cardboard) is not provided.

Changes or modifications to the LaTeXtemplate should be coordinated with your supervisor!

2.15 Submission of thesis

You can either submit your thesis in a printed form or in electronic form.
This paragraph only applies to students of the Faculty of Electrical Engineering and Information Technology of the TU Dortmund. (2019).
The student has to submit **three bounded copies** no later than the deadline **in the dean's office**. In addition, a digital version must be submitted (CD or DVD). The disk must contain the work as a PDF. Of course, additional data may be stored. Outside business hours the deadline mailbox is available in front of the building *Department for Student Services Emil-Figge-Straße 61.* It shuts a flap at 24 o'clock, thus keeping the insertion date. Please bring an A4 envelope with you.
These copies are forwarded to the chair of RST and supervisor and form the basis of the evaluation.
You decide to either to print in color or black and white. We recommend black and white printing for cost reasons. The RST chair prints additional copies in black and white. Therefore, ensure that figures are legible in gray scale.

Starting from 2019 it is possible to submit the thesis in electronic form only. Indicate this option on the thesis registration form.

3

Theoretical foundation

3.1 Stress Framework/Biosignals

3.1.1 Photoplethysmogram-PPG

3.1.2 Electrodermal Activity-EDA

3.1.3 Motion Capture

4

Data Collection-Subject Study

4.1 Design of Experiments

4.2 Devices Used

4.3 Procedure/Protocol

5
Stress Detection Methodology

5.1 Pre-Processing

5.2 Feature Extraction

5.3 Classification /Stress Detection/

Latex

- *http://miktex.org/*
  Windows Latex Distribution
- *https://tug.org/mactex/*
  Os X Latex Distribution
- *http://texstudio.sourceforge.net/*
  TeXstudio Development environment (recommended)
- *http://www.texniccenter.org/*
  TeXnicCenter Development environment
- *http://de.wikipedia.org/wiki/Hilfe:TeX*
  Collection of mathematical commands
- *http://www.ctan.org/*
  Documentation of all packages
- *http://en.wikibooks.org/wiki/LaTeX/*
  HILFE
- *http://www.texify.com/*
  Try Latex Code by Copy/Paste (Formulas)

Graphics

- *http://www.inkscape.org/*
  Vector graphics

- *http://www.imagemagick.org/*
  converted from *.* to eps

Matlab

- *http://www.mathworks.com/matlabcentral/fileexchange/22022-matlab2tikz*
  exported figure to tikz
- *http://www.mathworks.com/matlabcentral/fileexchange/21286-matlabfrag*
  exported figure to eps + tags
- *http://www.mathworks.com/matlabcentral/fileexchange/23604-fixlines*
  replaces ” Matlab ” lines with ” reasonable ” lines
- *http://www.mathworks.com/matlabcentral/fileexchange/23629-exportfig*
  exported figure to eps, pdf, etc. (with fixlines, without tagging)

6
Result

7

Discussion and Conclusion

Literatur

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8 Appendix

Das ist der Anhang (siehe Abschnitt 2.13) / This is the appendix (see section 2.13)

8.1 Usage of generative AI - Affidavit

☐ not at all

☒ for correcting, optimizing, or restructuring the entire work (This eliminates the need for explicit marking of individual passages or sections, as this type of usage refers to the entire written work. Explicit marking in the text is not necessary, as this serves as the global indication.)

☐ Code optimization: Optimization or restructuring of software function

☐ Code generation: Creating entire software functions from a detailed functional description.

☐ Substance generation in code: Generating entire software source code

☐ Media optimization: Correction, optimization, or restructuring of entire passages

☐ Media generation: Creating entire passages from given content.

☐ Substance generation in media: Generating entire sections

☐ More, namely:

I assure that I have provided all usages completely. Missing or incorrect information may be considered an attempt to deceive.

place, date

Jane Doe