TUM

Investigation of multispectral imaging algorithm for temperature determination on a numerical experiment platform in Laser-based Powder Bed fusion of Metals

Untersuchung des multispektralen Bildgebungsverfahrens zur Temperaturbestimmung auf einer numerischen Experimentierplattform beim Laser-basierten Pulverbett-Schmelzverfahren von Metallen.

Semester Thesis

at the Department of Mechanical Engineering of the Technical University of Munich

Supervised by	Prof. Dr.-Ing. Katrin Wudy
	M.Sc. Ruihang Dai
	Laser-based Additive Manufacturing
Submitted by	Zhaoyong Wang
	Connollystr.3
	80809 München
Submitted on	July 31, 2023 in Garching

Scope of Work

Title of the Semester Thesis:

Investigation of multispectral imaging algorithm for temperature determination on a numerical experiment platform in Laser-based Powder Bed fusion of Metals

Author:	B.Sc. Zhaoyong Wang	**Supervisor:**	M.Sc. Ruihang Dai
Issuance:	15.03.2023	**Submission:**	31.12.2021

Setting:

Laser-based powder bed fusion of metals (PBF-LB/M) is an additive manufacturing process which produces components with a laser by successively melting metal powders applied in layers. This additive manufacturing process offers the advantage of a complex lightweight design. However, complicated thermal histories during laser-metal interaction can lead to process defects such as keyholing. Since the process is thermally driven, acquiring the absolute temperature distribution in the laser-material interaction zone is vital to gain a deeper understanding of the process. However, no measurement system in PBF-LB/M is currently available to determine the absolute temperature due to unknown emissivity. Multispectral Imaging (MSI) has the potential to determine the absolute temperature and emissivity simultaneously by capturing multiple wavelengths of radiance from the melt pool.

Objective:

This work aims to optimize the MSI algorithm to determine the absolute temperature accurately. Since the mapping between the digital value and radiance still needs to be investigated, direct optimization of the MSI algorithm based on the experimental data is challenging. Therefore, the first step is to develop a virtual experiment to obtain "ideal" radiance determined by the given temperature distribution and emissivity. This way, the MSI algorithm can be optimized based on the input and calculated temperature and emissivity. The virtual experiment platform will also allow for the investigation of various temperature distributions and emissivity models in a time- and cost-efficient manner.

Methodology:

The content of the present thesis can be subdivided into the following tasks

- Literature review regarding MSI, material emissivity model and curve fitting algorithms

- Development of a virtual experiment platform

- Generate virtual experiments with various emissivity models and temperature fields

- Optimization of the MSI algorithm based on virtual experiments

- Scientific documentation of the results

Declaration

I hereby confirm that this semester thesis was written independently by myself without the use of any sources beyond those cited, and all passages and ideas taken from other sources are cited accordingly.

....
Location, Date   Signature

With the supervision of Mr. Zhaoyong Wang by Mr. Ruihang Dai intellectual property of the Professorship Laser-based Additive Manufacturing (LBAM) flows into this work. A publication of the work or a passing on to third parties requires the permission of the head of the professorship. I agree to the archiving of the printed thesis in the LBAM library (which is only accessible to LBAM staff) and in LBAM's digital thesis database as a PDF document.

....
Location, Date   Signature

Abstract

Here could be your abstract. so where should i start with?[1]. haha[2]

Zusammenfassung

Hier könnte Ihre Kurzzusammenfassung stehen.

Contents

1 LaTeX-Tutorial

Dieses Tutorial liefert eine Kurzeinführung[1] in die Verwendung von Latex.

1.1 Titelseite

Die Titelseite wird in ./main.tex definiert. Der Studienarbeitstyp wird durch Ein- und Auskommentieren der Befehle

- `\IWBstudentthesisTitlePageCustomMastersThesis`,
- `\IWBstudentthesisTitlePageCustomBachelorsThesis` und
- `\IWBstudentthesisTitlePageCustomSemesterThesis`

ausgewählt und die Seite entsprechend der Argumente gesetzt. Die Professoren und Lehrstuhle können mittels der Makros

- `\IWBnamesProfReinhart \newline \IWBlangChairMWIWBLBM` oder
- `\IWBnamesProfZaeh \newline \IWBlangChairMWIWBLWF`

ausgewählt werden.

1.2 Zitation

Zum Zitieren stehen die Standartbefehle `\textcite` und `\parencite` zur Verfügung. Soll der Autorename im Satz verwendet werden, eignet sich ersteres, z.B. Bayerlein, Bodensteiner, Zeller, Hofmann, and Zaeh [3, pp. 2–3] bezieht sich auf Bayerlein, Zeller, Wunderer, Weirather, Schmid, Seidel, Zaeh, Hessert, Schlick, Uihlein, and Hofmann [4]. Soll das Zitat in Klammern nach die Aussage gestellt werden empfiehlt sich zweiteres [5]. Sammelzitationen am Satzende schreiben sich wie folgt [1], [6], [7]. Die Zitation von Online-Quellen kann schwierig sein, da nicht immer der Autor und das Erscheinungsjahr verfügbar sind. Vergleicht man Heuss and Roder [8] und *iwb-Startseite* [9], stellt man fest, dass bei zweiteren der Seitentitel statt des bekannten Schemas eingesetzt wird.

Normen werden als *DIN ISO EN 10218-2* [10] dargestellt. Im Bibtex-Export des verwendeten Literaturverwaltungsprogramm sind bestimmte Einstellungen vorzunehmen. Dokumententyp ist "@book" mit folgenden Einträgen:

- Normtyp und Nummer als "title"
- Langtitel als "subtitle"
- Verlag als "publisher"
- Jahr als "date"
- "author" darf nicht belegt werden!

1.3 Abkürzungen

In ./source/abbreviations.tex können Abkürzungen definiert werden. Es gibt Besonderheiten zu Ausdrücken, deren Pluralendung nicht auf s endet. Hier müssen ggf. Kurz- und Langformen des Ausdrucks auch für den Plural definiert werden.

- \gls{ros}: schreibt beim ersten Auftreten im Dokument ausführlich Robot Operating System (ROS), ab dem zweiten Auftreten wird abgekürzt ROS

- \glspl{ap} verwendet den Plural in Langform Arbeitspakete (APs) und danach in Kurzform APs

1.4 Glossar

In ./source/glossary.tex können Begriffe erklärt, abgegrenzt oder definiert werden. Begriffe erhalten einen Namen und eine Beschreibung als Glossareintrag sowie ein Lable zum Referenzieren im Text. Ein Glossar ist Optional.

- \gls{latex}: Schreibt den Namen aus dem Glossarverzeichnis mit Verweis auf den Glossareintrag Latex

1.5 Abbildungen

Graphiken und Bilder können in beliebigen Dateiformaten eingebunden werden, vergleiche fig. 1. Vektorgraphiken sind im Allgemeinen Pixelgraphiken in Schärfe und Speicherbedarf überlegen.

Figure 1: Beschreibung des Bilds. Außerdem machen wir nun die Bildunterschrift unnötig lang um die Formatierung zu testen.
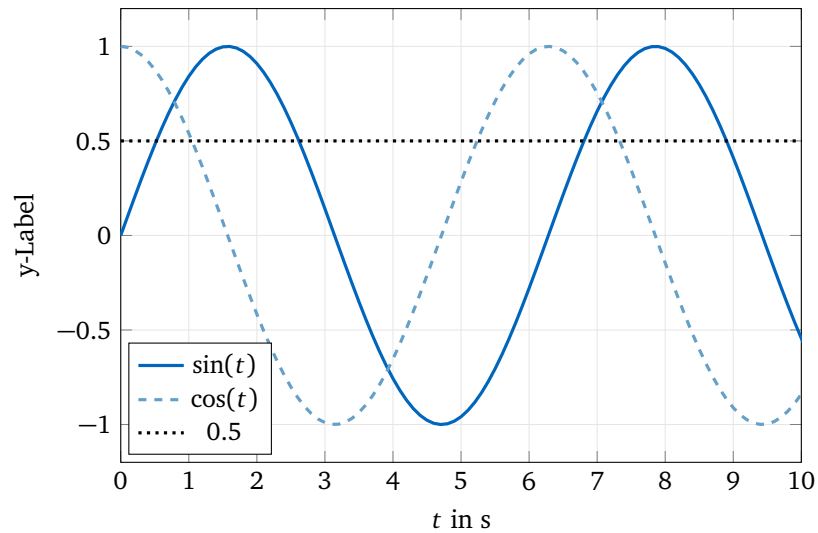
Figure 2: Beschreibung des Plots. Außerdem machen wir nun die Bildunterschrift unnötig lang um die Formatierung zu testen.

Für Nutzer mit perfektionistischen Anspruch empfiehlt sich die Nutzung von Ti*k*Z. Vorteil ist, dass die Erzeugung von Daten und die Darstellung komplett getrennt werden. Die Darstellung erfolgt einheitlich gemäß eines generischen Mark-Ups, vergleiche figs. 2 and 3.

Figure 3: Beschreibung des Plots. Außerdem machen wir nun die Bildunterschrift unnötig lang um die Formatierung zu testen.

2 Introduction

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

2.1 Section Introduction

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2.1.1 Subsection Introduction

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

2.2 Another Section Introduction

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

2.3 Many Section Introductions

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Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language. And one more for good measure.
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2.5   Testing the Continuous Figure Numbering

Here we have a graph which should have a continuous caption numbering i. e. it should say Figure 4 or Figure 5, instead of Figure 2.1 or Figure 2.2.
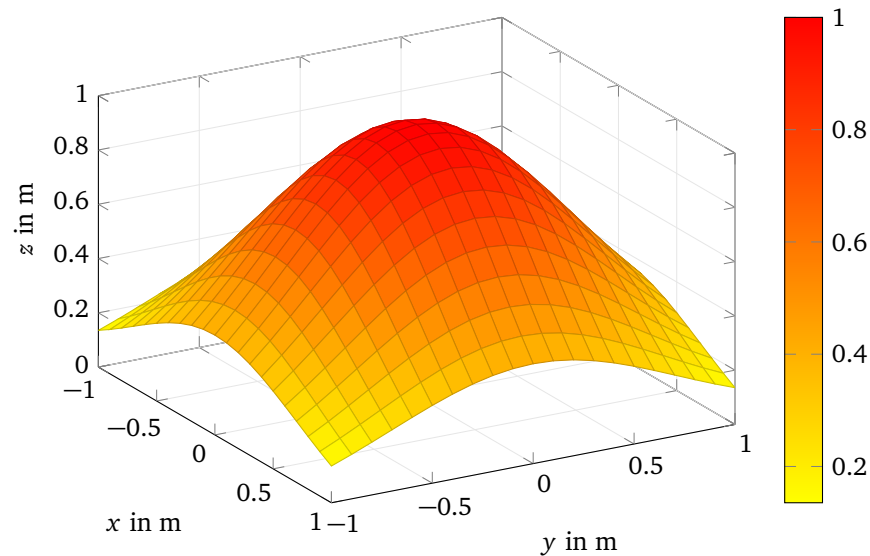

Figure 4: Beschreibung des Plots. Außerdem machen wir nun die Bildunterschrift unnötig lang um die Formatierung zu testen.

2.6   Now Let's test tables

The table 1 should have captions above the table instead of captions below, like Figures.

Table 1: This table caption should be above the table. Otherwise DIN is going to judge you...

Col1	Col2	Col2	Col3
1	6	87837	787
2	7	78	5415
3	545	778	7507
4	545	18744	7560
5	88	788	6344

3 Kapitelname

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

3.1 Abschnittname

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A Appendices

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This is the second paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

And after the second paragraph follows the third paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

After this fourth paragraph, we start a new paragraph sequence. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

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Glossary

Latex   Generische Mark-up-Sprache zum Erstellen wissenschaftlicher Texte. Sie ist in jeder Hinsicht Word überlegen, welches einem visuellen Mark-Up entspricht. Das X von LaTeX wird als ç (Stimmloser palataler Frikativ) ausgesprochen, vergleiche deutsche Aussprache von *ch*.

TikZ   Frontend-Paket, das auf PGF-Plot aufbaut und zum Erstellen von Graphiken dient.

Tutorial   Kurze Gebrauchsanleitung welche ein Thema, einen gewissen Vorgang oder eine Funktion erklärt. Hat nicht den Anspruch auf Vollständigkeit.

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[9]   (). "Iwb-startseite", [Online]. Available: http://www.mw.tum.de/startseite/ (visited on 02/10/2019).

[10]   *DIN ISO EN 10218-2, Industrieroboter - Sicherheitsanforderungen - Teil 2: Robotersysteme und Integration (ISO 10218-2:2011)*. Berlin: Beuth Verlag GmbH, 2012. DOI: 10.31030/1626163.

List of Abbreviations

AP   Arbeitspaket

LBAM   Professorship Laser-based Additive Manufacturing

ROS   Robot Operating System

Disclaimer

I hereby declare that this thesis is entirely the result of my own work except where otherwise indicated. I have only used the resources given in the list of references.

Garching, July 31, 2023

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(Signature)