

Opis raziskovalnega dela (Research work description)

1. Članica UL (UL member):

UL Fakulteta za strojništvo (UL Faculty of Mechanical Engineering)

2. Ime, priimek in elektronski naslov mentorja/ice (Mentor's name, surname and email):

Primož Potočnik, primoz.potocnik@fs.uni-lj.si

3. Raziskovalno področje (Research field):

Tehnološko usmerjena fizika (Technology driven physics)

4. Opis raziskovalnega dela (Research work description):

Vključuje morebitne dodatne pogoje, ki jih mora izpolnjevati kandidat/ka za mladega raziskovalca/ko, ki niso navedeni v razpisu za mlade raziskovalce (It includes any additional conditions that the candidate for a young researcher must meet, which are not listed in the call to tender for young researchers.).

Slov.:

Uvod

Raziskovalno delo bo potekalo na Fakulteti za strojništvo v Ljubljani v okviru Laboratorija za sinergetiko (LASIN), ki deluje na področju laserskih dodajalnih tehnologij, sistemov in procesov, ter inteligentnih sistemov vodenja procesov. Raziskave bodo usmerjene v laserske dodajalne procese (DED-LB), s poudarkom na direktni laserski depoziciji z žico (DLD-Wire), ter v integracijo metod strojnega učenja, nevronske mreže in prediktivnega vodenja za optimizacijo procesa v realnem času. DLD-Wire predstavlja eno izmed najperspektivnejših tehnologij za izdelavo in obnovo kovinskih komponent zaradi visokega materialnega izkoristka, nizke poroznosti in možnosti obdelave zahtevnih materialov.

Ekperimentalno delo

Ekperimentalno delo bo potekalo v laboratoriju LASIN na naprednem robotiziranem sistemu za direktno lasersko depozicijo (DLD) kovinske žice, ki vključuje:

- 6-osnega industrijskega robota ABB,
- namensko programsko okolje za krmiljenje robota (RobotStudio),
- lastno razvito lasersko glavo z anularnim (obročastim) profilom žarka,
- podajalni sistem za kovinsko žico,
- integrirano procesno senzoriko za spremljanje dinamike taline in lastnosti nanosa.

Ekperimentalno delo kandidata bo obsegalo:

- tehnično nadgradnjo sistema za izvajanje raziskovalnih eksperimentov,
- razvoj in implementacijo procesne senzorike (optični, IR, temperaturni in drugi senzori),
- razvoj regulatorja podajanja žice in sinhronizacije z laserskim virom,
- načrtovanje in izvajanje eksperimentov za sistematično analizo vpliva procesnih parametrov na stabilnost procesa in lastnosti nanosa,
- izdelavo testnih vzorcev z različno geometrijsko kompleksnostjo,
- analizo dimenzijske točnosti, mikrostrukture in mehanskih lastnosti izdelkov.

Cilji raziskovalnega dela

Osrednji cilj doktorskega raziskovanja je:

- razvoj inovativnih metod za izboljšanje stabilnosti procesa DLD,
- razvoj adaptivnega vodenja procesa v realnem času,
- izboljšanje dimenzijske natančnosti, ponovljivosti in metalurške kakovosti izdelkov.

Pri tem bo poseben poudarek na:

- podatkovno podprtem modeliranju procesa,
- razvoju digitalnega dvojčka procesa DLD,
- identifikaciji kritičnih procesnih parametrov,
- integraciji metod umetne inteligence v zaprtično regulacijo procesa,
- definiranju merljivih metrik stabilnosti in kakovosti procesa.

Glavne naloge doktorskega kandidata

- Raziskave, modeliranje in eksperimentalna validacija procesa direktne laserske depozicije z žico.
- Identifikacija ključnih procesnih spremenljivk ter razvoj sistema za njihovo sprotno merjenje in diagnostiko.
- Optimizacija procesnih parametrov (moč laserja, hitrost podajanja žice, hitrost gibanja robota, kavstika žarka ipd.) za doseganje stabilnosti procesa.
- Načrtovanje optimalnih poti nanašanja materiala glede na geometrijo izdelka ter zmanjševanje napak (prelivanje, poroznost, odstopanja).
- Razvoj metod strojnega učenja (regresijski modeli, nevronske mreže, hibridni fizikalno-podatkovni modeli) za napovedovanje stabilnosti in kakovosti nanosa.
- Implementacija prediktivnega / adaptivnega vodenja procesa v realnem času.
- Programiranje robotskega sistema (ABB, RAPID).
- Načrtovanje in izvedba eksperimentov ter analiza rezultatov.
- Priprava in objava znanstvenih člankov v mednarodnih znanstvenih revijah (najmanj dva članka v revijah Q1 ali Q2).
- Aktivno sodelovanje na mednarodnih konferencah in vključevanje v mednarodne raziskovalne projekte.

Zahtevane kvalifikacije

- Zaključen magistrski študij s področja strojništva, mehatronike, metalurgije, računalništva ali sorodnih tehničnih ved.
- Osnovno razumevanje laserskih dodajalnih procesov ali naprednih proizvodnih tehnologij.
- Poznavanje osnov metod strojnega učenja, numeričnega modeliranja ali regulacije sistemov.
- Zaželeno izkušnje s programskimi orodji: Python, MATLAB, ANSYS, SolidWorks.
- Zaželeno izkušnje z ABB RobotStudio in programiranjem v jeziku RAPID.
- Znanje obdelave eksperimentalnih podatkov in statistične analize.
- Aktivno znanje angleškega jezika (pisno in ustno).
- Visoka stopnja raziskovalne radovednosti, samostojnosti in analitičnega razmišljanja.
- Sposobnost znanstvenega pisanja ter priprave publikacij v mednarodnem okolju.

Eng.:

Introduction

The research will be conducted at the Faculty of Mechanical Engineering in Ljubljana, within the Laboratory of Synergetics (LASIN), which specializes in laser additive technologies, systems and processes, as well as intelligent process control systems. The focus of the research will be on laser-directed energy deposition (DED-LB) processes, with a particular emphasis on direct laser wire deposition (DLD-Wire), and on the integration of machine learning, neural networks, and predictive control for real-time process optimization. DLD-Wire is one of the most promising technologies for manufacturing and repairing metal components due to its high material efficiency, low porosity, and capability to process challenging materials.

Experimental Work

The experimental work will be carried out in the LASIN laboratory on an advanced robotic system for direct laser deposition (DLD) of metal wire, which includes:

- a 6-axis ABB industrial robot,
- a dedicated RobotStudio environment for robot control,
- an in-house developed laser head with an annular beam profile,
- a wire feeding system for metal wire,
- integrated process sensors for monitoring melt pool dynamics and deposition properties.

The candidate's experimental tasks will include:

- technical upgrades of the system to support research experiments,
- development and implementation of process sensing (optical, IR, temperature, and other sensors),
- development of a wire-feeding controller and synchronization with the laser source,
- planning and conducting experiments for a systematic analysis of process parameter influence on process stability and deposition quality,
- production of test samples with varying geometric complexity,
- analysis of dimensional accuracy, microstructure, and mechanical properties of the manufactured parts.

Research Objectives

The main objectives of the doctoral research are:

- development of innovative methods for improving DLD process stability,
- development of adaptive real-time process control,
- improving dimensional accuracy, repeatability, and metallurgical quality of the products.

Special emphasis will be placed on:

- data-driven process modeling,
- development of a digital twin of the DLD process,
- identification of critical process parameters,
- integration of artificial intelligence methods into closed-loop process control,
- defining measurable metrics of process stability and quality.

Main Tasks of the Doctoral Candidate

- Research, modeling, and experimental validation of the direct laser wire deposition process.
- Identification of key process variables and development of a system for their real-time measurement and diagnostics.
- Optimization of process parameters (laser power, wire feed speed, robot travel speed, beam caustics, etc.) to achieve process stability.
- Planning optimal material deposition paths according to part geometry and minimizing defects (overdeposition, porosity, deviations).
- Development of machine learning methods (regression models, neural networks, hybrid physics-informed/data-driven models) for predicting process stability and deposition quality.
- Implementation of predictive/adaptive real-time process control.
- Programming of the robotic system (ABB, RAPID).
- Planning and execution of experiments and analysis of results.
- Preparation and publication of scientific papers in international journals (at least two papers in Q1 or Q2 journals).
- Active participation in international conferences and involvement in international research projects.

Required Qualifications

- Completed master's degree in mechanical engineering, mechatronics, metallurgy, computer science, or related technical fields.
- Basic understanding of laser additive processes or advanced manufacturing technologies.
- Knowledge of basic machine learning methods, numerical modeling, or systems control.
- Appreciated experience with software tools such as Python, MATLAB, ANSYS, SolidWorks.
- Appreciated experience with ABB RobotStudio and programming in RAPID.
- Skills in experimental data processing and statistical analysis.
- Proficiency in English (written and spoken).
- High level of research curiosity, independence, and analytical thinking.
- Ability to write scientific texts and prepare publications in an international environment.

5. Priloge, ki jih je treba priložiti ob prijavi (*Documents required to be submitted with the application*):

potrdilo o doseženi izobrazbi (*proof of completed education*)

- kandidat z zaključenim magistrskim študijskim programom (2. bolonjska stopnja) (*candidate who has completed a Master's degree (2nd Bologna level)*):
 - diplomska listina / potrdilo o zaključku študijskega programa (*diploma certificate / certificate of completion of the study programme*)
 - priloga k diplomi / potrdilo o opravljenih obveznostih (*diploma supplement / official transcript of records containing all grades obtained in the study programme*)
- kandidat, ki še ni zaključil študija na 2. stopnji (*candidate who has not yet completed a Master's degree*):

- potrdilo o do sedaj opravljenih obveznostih z ocenami magistrskega študijskega programa, s katerim se bo kandidat prijavil na doktorski študij
(official transcript of records listing all courses and grades obtained so far in the Master's degree programme on the basis of which the candidate will apply for enrollment in a doctoral degree programme.)

nagrade – univerzitetna Prešernova nagrada ali Prešernova nagrada članice Univerze v Ljubljani oz. druga enakovredna nagrada (*awards, e.g. Prešeren Prize of the University of Ljubljana, Prešeren Prize of a University of Ljubljana member and/or another equivalent award*)

bibliografija (*bibliography*)

življenjepis (*CV*)

motivacijsko pismo (*motivation letter*)

opis dosedanjega sodelovanja pri raziskovalnem delu (*description of the candidate's research work*)

osnutek idejne zasnove raziskovalnega dela (*preliminary research proposal*)

priporočilno pismo (*letter of recommendation*)

druge priloge (*other attachments*):