

LASERSKI MERILNI SISTEMI

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Laserski merilni sistemi
Course title:	Laser Measurement Systems
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri	Izbirnost
Strojništvo - Razvojno raziskovalni program, druga stopnja, magistrski	Mehatronika in laserska tehnika (smer)	2. letnik	1. semester	obvezni

Univerzitetna koda predmeta/University course code:	0566820
Koda učne enote na članici/UL Member course code:	6060-M

Predavanja /Lectures	Seminar /Seminar	Vaje /Tutorials	Klinične vaje /Clinical tutorials	Druge oblike študija /Other forms of study	Samostojno delo /Individual student work	ECTS
30		30			65	5

Nosilec predmeta/Lecturer:	prof. dr. Matija Jezeršek, doc. dr. Daniele Vella
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Izvajalci predavanj:	
Izvajalci seminarjev:	
Izvajalci vaj:	
Izvajalci kliničnih vaj:	
Izvajalci drugih oblik:	
Izvajalci praktičnega usposabljanja:	

Vrsta predmeta/Course type:	Obvezni strokovni predmet na smeri Mehatronika in laserska tehnika, ki je izbirni strokovni predmet na ostalih smereh./Compulsory specialised course in the study of Mechatronics and laser technology, which is an elective specialised course in other fields of study.
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Jeziki/Languages:	Predavanja/Lectures:	Slovenščina
	Vaje/Tutorial:	Slovenščina

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:

Prerequisites:

Izpolnjevanje pogojev za vpis v Magistrski študijski program II. stopnje Strojništvo - Razvojno raziskovalni program.	Meeting the enrollment conditions for the Master's study programme of Mechanical Engineering - Research and Development program.
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Vsebina:

Content (Syllabus outline):

1. Uvod in predstavitev predmeta - Pregled vsebine, ciljev in kompetenc - Predstavitev dela na laboratorijskih vajah - Predstavitev ocenjevanja 2. Interferenca - Kompleksni popis EM valovanja, - matematični popis, - tvorba in interpretacija interferogramov, - primeri. 3. Koherenca - Fizikalna razlaga, - Matematični popis, - vplivi na meritve. 4. Uklon svetlobe - Huygens-Fresnel-ov princip, - Fraunhoferjev uklon, - Fourierjev popis, - Primeri. 5. Laserska pegavost - Fizikalna razlaga, - matematični popis, - vplivi na meritve. 6. Laserski in alternativni svetlobni izvori - NEkoherentni izvori, - koherentni izvori, - temeljne lastnosti in primerjava uporabnosti 7. Detekcijski sistemi - Točkovni, linijski in ploskovni fotodetektorji detektorji, - enobarvna, večbarvna in hiperspektralna detekcija. 8. Računalniška obdelava optičnih signalov - Digitalizacija signalov, - predobdelava, - detekcija značilk (prehodov, vrhov, kontur). 9. Interferometrija - Konfiguracije: Newton, Fizeau, Twyman-Green, Mach-Zehnder. - Strižna interferometrija - Fazno zamikanje - Primeri uporabe 10. Laserska triangulacija - Klasifikacija, - princip merjenja, - zaznava svetlobnega vzorca, - rekonstrukcija v 3D obliko, - primeri uporabe. 11. Kalibracija laserskih 3D merilnikov - Parametri modela 3D rekonstrukcije, - izmera referenčnega telesa, - kriterijska funkcija, - numerična optimizacija. 12. Konfokalni merilni sistemi - Klasifikacija po merilnih principih, - enobarvni in večbarvni merilniki razdalje, - skenirni sistemi, - primeri uporabe. 13. 3D merjenje na osnovi časa preleta - klasifikacija,	1. Introduction and presentation of the course - Subject review, goals and competencies - Presentation of lab work - Presentation of assessment 2. Interference - Complex description of EM waves, - mathematical description, - creation and interpretation of interferograms, - examples. 3. Coherence - Physical interpretation, - Mathematical description, - effects on measurements. 4. Light diffraction - Huygens-Fresnel principle, - Fraunhofer diffraction, - Fourier diffraction, - Examples. 5. Laser speckles - Physical interpretation, - mathematical description, - effects on measurements. 6. Laser and alternative light sources - Non-coherent sources, - coherent sources, - basic features and usability comparison 7. Detection systems - Point, line and plane photodetectors detectors, - monochromatic, color and hyperspectral detection. 8. Computer processing of optical signals - Digitalization of signals, - pre-processing, - detection of features (transitions, peaks, contours) 9. Interferometry - Interferometer configurations: Newton, Fizeau, Twyman-Green, Mach-Zehnder. - Shearing interferometry - Phase-shifting techniques - Examples 10. Laser triangulation - Classification, - measurement principle, - detection of light pattern, - 3D reconstruction, - examples. 11. Calibration of Laser 3D Meters - 3D reconstruction model, - measurement of the reference body, - criterion function, - numerical optimization. 12. Confocal measurement systems - Classification by measurement principles, - monochrome and multicolor techniques, - scanning systems, - use cases. 13. Time-of-flight measurement - classification,
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- merilni principi, - enotočkovne metode, - matrične metode, - primeri uporabe. 14. Vlakenski senzorji - notranji/zunanji senzorji, - modulacija intenzitete, - faze in polarizacija, - primeri merilnikov tlakov, deformacij, temperature. 15. Lasersko merjenje hitrih pojavov - Tehnike hitrega osvetljevanja, optične konfiguracije (senčna, schlieren, interferometrična). - Primeri uporabe.	- measurement principles, - single point methods, - matrix methods, - use cases. 14. Fiber Sensors - internal / external sensors, - intensity modulation, - phases and polarization, - examples of pressure gauges, deformations, temperature. 15. Laser measurement of ultra-fast phenomena - Fast lighting techniques, optical configurations (shady, schlieren, interferometric). - examples.
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Temeljna literatura in viri/Readings:

1. Gasvik K.J. Optical metrology, 3rd ed. Chichester: John Wiley & Sons, 2002. [COBISS.SI-ID [11175195](#)]
2. Malacara, Optical Shop Testing, 3rd ed., Wiley, 2007. [COBISS.SI-ID [11174427](#)]
3. Toru Yoshizawa, Handbook of Optical Metrology: Principles and Applications, CRC Press, 2009. [COBISS.SI-ID [11174683](#)]

Cilji in kompetence:

Cilji: 1. Spoznati zakonitosti in pojave širjenja laserske svetlobe in njihovo uporabo v merilnih laserskih sistemih. 2. Spoznati metode razvoja laserskih merilnih sistemov s posebnim poudarkom na interdisciplinarnem pristopu, fizikalnem, matematičnem in numeričnem modeliranju. 3. Spoznati metode in postopke eksperimentalne evaluacije laserskih merilnih sistemov. Kompetence: 1. S1-MAG: Sposobnost za opredelitev, razumevanje temeljnih znanstvenih problemov in ustvarjalno reševanje strokovnih izzivov na področju laserskih merilnih sistemov. 2. S8-MAG in S9-MAG: Sposobnost iskanja virov, kritične presoje informacij, samostojnega nadgrajevanja pridobljenih znanj in poglobljanja znanja na področjih laserskih merilnih sistemov. Ter usposobljenost za delo v skupini in interdisciplinarno povezovanje. 3. P2-MAG: Obvladovanje temeljnih teoretičnih kakor tudi aplikativnih znanj, ki so bistvena za obvladovanje tehničnega področja laserskih merilnih sistemov.
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Objectives and competences:

Objectives: 1. To understand the laws and phenomena of laser light propagation and their application in laser measuring systems. 2. To learn the methods of development of laser measuring systems with special emphasis on interdisciplinary approach, physical, mathematical and numerical modeling. 3. To understand the methods and procedures of experimental evaluation of laser measuring systems. Competences: 1. S1-MAG: The ability to define and understand fundamental scientific problems and to creatively deal with professional challenges in the field of laser measurement systems. 2. S8-MAG and S9-MAG: The ability to find sources, critically evaluate information, independently upgrade the attained knowledge and deepen the knowledge in the individual specialized fields of laser measurement systems. The ability for teamwork and for interdisciplinary networking. 3. P2-MAG: Using the fundamental theoretical and applied knowledge, crucial for having command of technical field of laser measurement systems.

Predvideni študijski rezultati:

	Intended learning outcomes:
	Knowledge:

Znanja: Z2: Poglobljeno teoretično, metodološko in analitično znanje z elementi raziskovanja, ki je osnova za zelo zahtevno strokovno delo na področju laserskih merilnih sistemov. Spretnosti: S2.2 Načrtovanje in vodenje delovnega procesa na podlagi ustvarjalnega reševanja problemov, povezanih z laserskimi merilnimi sistemi.	Z2: Thorough theoretical, methodological and analytical knowledge with elements of a research work that form a basis for very demanding professional work in the field of laser measurement systems. Skills: S2.2 Planning and managing of the working process on the basis of creative solving of problems that are linked to the teaching and training of the laser measurement systems.
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Metode poučevanja in učenja:

P1 Avditorna predavanja z reševanjem izbranih - za področje značilnih - teoretičnih in praktično uporabnih primerov. P2 Obravnava snovi po urejeni in vnaprej razloženi sistematiki. P3 Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri. P4 Laboratorijske vaje z namenskimi didaktičnimi pripomočki (preklopno krmiljenje zapornice, tekočega traku, PID krmiljenje procesa, laserski merilni sistem, laserski obdelovalni sistem). P5 Uporaba študijskega gradiva v obliki e-verzij: predstavitev predavanj, zbirke nalog z vaj, navodil za izvedbo laboratorijskih vaj P14 Virtualni eksperimenti P15 Uporaba video vsebin kot priprava na vaje	Learning and teaching methods: P1 Auditorial lectures with solving selected field-specific theoretical and applied use cases. P2 Presenting the content according to the explained system. P3 Auditorial exercises, in which theoretical content from the lectures is supplemented with practical examples. P4 Laboratory exercises with special-purpose didactic devices (description needs to be added, max. two lines per device). P5 Application of study material (description needs to be added, max. one line per material, e.g. textbook, e-book, printed lecture presentations, etc.). P14 Virtual experiments. P15 Application of videos for preparations to the lectures and exercises.
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Načini ocenjevanja:

Delež/Weight

Assessment:

Skupno oceno predmeta tvori ocena teorije in vaj. Ocena teorije: - Računski del: 50%.	25,00 %	The course grade is combined of an exercise grade and a theory grade. Theory: - Practical part: 50%.
- Teoretični del: 50%.	25,00 %	- Theoretical part: 50%.
Ocena vaj: - Delo na laboratorijskih vajah (predpriprava, sodelovanje in samostojnost): 50%.	25,00 %	Exercises: - Work on exercises (preparation, colaboration, individual work): 50%.
- Poročilo o opravljenih vajah: 50%.	25,00 %	- Report for exercises: 50%.

Ocenjevalna lestvica:

Grading system:

5 - 10, pri čemer velja, da je pozitivna ocena od 6 - 10	5 - 10, a student passes the exam if he is graded from 6 to 10
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Reference nosilca/Lecturer's references:

Matija Jezeršek:

1. VELLA, Daniele, LUKAČ, Matjaž, JERNEJČIČ, Urban, LUKAČ, Nejc, KLANEČEK, Žan, MILANIČ, Matija, **JEZERŠEK, Matija**. Measurements of hair temperature avalanche effect with alexandrite and Nd:YAG hair removal lasers. *Lasers in surgery and medicine*. Jan. 2023, vol. 55, iss. 1, str. 1-10, ilustr. ISSN 1096-910 <https://onlinelibrary.wiley.com/doi/full/10.1002/lsm.23622>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=144340>, DOI: 10.1002/lsm.23622. [COBISS.SI-ID [133764611](#)]
2. ZUBALIC, Emil, VELLA, Daniele, BABNIK, Aleš, **JEZERŠEK, Matija**. Interferometric fiber optic probe for measurements of cavitation bubble expansion velocity and bubble oscillation time. *Sensors*. 2023, vol. 23, iss. 2, str. 1-10, ilustr. ISSN 1424-8220. <https://www.mdpi.com/1424-8220/23/2/771>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=143898>, DOI: 10.3390/s23020771. [COBISS.SI-ID [138271491](#)]
3. KRAVANJA, Gaia, BELYAEVA, Inna A., HRIBAR, Luka, DREVENŠEK OLENIK, Irena, **JEZERŠEK, Matija**, SHAMONIN, Mikhail. Tunable drop splashing on magnetoactive elastomers. *Advanced materials interfaces*. June 2021, vol. 8, iss. 11, str. 1-7, ilustr. ISSN 2196-7350. <https://onlinelibrary.wiley.com/doi/full/10.1002/admi.202100235>, DOI: 10.1002/admi.202100235. [COBISS.SI-ID [62237187](#)]
4. KOŠIR, Jure, VELLA, Daniele, LUKAČ, Matjaž, **JEZERŠEK, Matija**. Towards personalized and versatile monitoring of temperature fields within heterogeneous tissues during laser therapies. *Biomedical optics express*. 2021, vol. 12, iss. 7, str. 4530-4543, ilustr. ISSN 2156-7085. <https://www.osapublishing.org/boe/fulltext.cfm?uri=boe-12-7-4530&id=452861>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=128832>, DOI: 10.1364/BOE.428028. [COBISS.SI-ID [72307459](#)]
5. ROGELJ, Luka, SIMONČIČ, Urban, TOMANIČ, Tadej, **JEZERŠEK, Matija**, PAVLOVČIČ, Urban, STERGAR, Jošt, MILANIČ, Matija. Effect of curvature correction on parameters extracted from hyperspectral images. *Journal of biomedical optics*. 2021, vol. 26, iss. 9, str. 096003-1-096003-21, ilustr. ISSN 1083-3668. DOI: 10.1117/1.JBO.26.9.096003. [COBISS.SI-ID [75439875](#)]

Daniele Vella:

1. Ali REZAEI, Diogo A. PEREIRA, Giuseppe Valerio BIANCO, Giovanni BRUNO, Aleš MRZEL, Luís ARNAUT, Carlos SERPA, Matija JEZERŠEK, **Daniele VELLA**, "Ultrafast subwavelength CVD-graphene nanoheater for the generation of broadband photoacoustic waves", *Photoacoustics*, 2026, vol. 47, [article no.] 100796, 12 str., ilustr., ISSN 2213-5979, <https://www.sciencedirect.com/science/article/pii/S2213597926000029?via%3Dihub>, [Repozitorij Univerze v Ljubljani – RUL](#), DOI: [10.1016/j.pacs.2026.100796](#). [COBISS.SI-ID [266484227](#)], [[Open Access](#), [JCR](#), [SNIP](#), [WoS](#), [Scopus](#)]
2. Dominik ŠAVLI, Aleš BABNIK, **Daniele VELLA**, Matija JEZERŠEK, "High-intensity focused pressure wave generation via Q-switched Er:YAG laser with a water layer formed by the coupled lens for optoacoustic conversion", *Applied sciences*, 2025, vol. 15, issue 19, [article no.] 10860, 17 str., ilustr., ISSN 2076-3417, <https://www.mdpi.com/2076-3417/15/19/10860>, [Repozitorij Univerze v Ljubljani – RUL](#), DOI: [10.3390/app151910860](#). [COBISS.SI-ID [252918019](#)], [[Open Access](#), [JCR](#), [SNIP](#), [WoS](#), [Scopus](#)]
3. **Daniele VELLA**, Damjan VENGUST, Polona UMEK, Ali REZAEI, Matija JEZERŠEK, Aleš MRZEL, "Efficient decoration of graphene oxide with a narrow size distribution of noble metal nanoparticles : green reduction and integration into a thermoelastic composite", *Synthetic metals*, Aug. 2025, vol. 313, [article no.] 117894, str. 1-10, ilustr., ISSN 1879-3290, <https://www.sciencedirect.com/science/article/pii/S0379677925000700?via%3Dihub>, [Repozitorij Univerze v Ljubljani – RUL](#), [DiRROS - Digitalni repozitorij raziskovalnih organizacij Slovenije](#), dCOBISS, DOI: [10.1016/j.synthmet.2025.117894](#). [COBISS.SI-ID [238129667](#)]
4. **Daniele VELLA**, Diogo A. PEREIRA, Aleš MRZEL, Damjan VENGUST, Aljaž DRNOVŠEK, Luís G. ARNAUT, Carlos SERPA, Matija JEZERŠEK, "Picosecond photoacoustic generation of ultrasounds with composites of graphene-decorated gold nanoparticles", *Nano energy*, [Online ed.], 2024, vol. 131, part a, art. 110236, str. 1-12, ilustr., ISSN 2211-

3282, <https://www.sciencedirect.com/science/article/pii/S2211285524009881>, [Repozitorij Univerze v Ljubljani – RUL](#), DOI: [10.1016/j.nanoen.2024.110236](https://doi.org/10.1016/j.nanoen.2024.110236). [COBISS.SI-ID [208436739](#)]

5. **Daniele VELLA**, Matjaž LUKAČ, Urban JERNEJČIČ, Nejc LUKAČ, Žan KLANEČEK, Matija MILANIČ, Matija JEZERŠEK, "Measurements of hair temperature avalanche effect with alexandrite and Nd:YAG hair removal lasers", *Lasers in surgery and medicine*, Jan. 2023, vol. 55, iss. 1, str. 1-10, ilustr., ISSN 1096-9101, <https://onlinelibrary.wiley.com/doi/full/10.1002/lsm.23622>, [Repozitorij Univerze v Ljubljani – RUL](#), DOI: [10.1002/lsm.23622](https://doi.org/10.1002/lsm.23622). [COBISS.SI-ID [133764611](#)]