Kratek opis usposabljanja mladega raziskovalca (*Short description of the Young Researcher's training)*

1. Raziskovalna organizacija (*Research organisation)*:

Univerza v Ljubljani, Fakulteta za elektrotehniko (*University of Ljubljana, Faculty of Electrical Engineering)*

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

Igor Pušnik, e-mail naslov: igor.pusnik@fe.uni-lj.si

3. Šifra in naziv raziskovalnega področja (*Research field*):

2.15.04Tehnika/Meroslovje/Metrologije področij *(Engineering sciences and technologies/Metrology/Metrologies in areas)*

4. Kratek opis usposabljanja mladega raziskovalca (*Short description of the Young Researcher's training)*:

Navedite tudi morebitne druge zahteve, vezane na usposabljanje mladega raziskovalca (npr. znanje tujih jezikov, izkušnje z laboratorijskim delom, potrebne licence za usposabljanje…).

slo:

Sevalni termometri in termovizijske kamere so termometri, ki na osnovi zaznavanja prenosa toplote s sevanjem merijo temperaturo na brezkontakten način. Medtem ko sevalni termometri lahko merijo temperaturo z relativno dobro točnostjo (seveda slabšo od kontaktnih termometrov), so termovizijske kamere večinoma namenjene tehniški diagnostiki oziroma kvalitativnemu merjenju, za razliko od kvantitativnih merjenj, kjer sta točnost in negotovost zelo pomembna parametra meritve. Teorija brezkontaktnega merjenja temperature temelji na Planckovem zakonu, ki pa velja zgolj za idealen primer črnega telesa v vakuumu. V realnih razmerah merimo sevanje sivih teles (emisivnost <1), zato je potrebno na podlagi lastnosti merjenca (predvsem emisivnosti), prenosne poti (atmosfera) in merilnega instrumenta (optika, detektor) določiti prenosno funkcijo oziroma matematični model povezave med sevanjem površine in njeno pravo temperaturo. Pravo temperaturo posredno lahko izmerimo z merjenjem toka ali napetosti detektorja brezkontaktnega merilnika temperature ob pogoju, da v celoti poznamo prenosno funkcijo za sevanje iz merjene površine skozi prenosno pot do detektorja. Zagotavljanje sledljivosti do SI enot oziroma določitev popolnega merilnega rezultata je omogočeno s postopkom kalibracije, v katerem se izmeri referenčna vrednost temperature, na osnovi katere se izračuna korekcija izmerjene vrednosti ter oceni in/ali izračuna merilna negotovost.

Ciljev usposabljanja mladega raziskovalca je več. Prvi je analiza obstoječih postopkov kalibracije ali umerjanja brezkontaktnih termometrov in termovizijskih kamer v laboratorijskih pogojih. Posebej je pomembna analiza trenutne uporabe termovizijskih kamer s poudarkom na primerih kvantitativnega merjenja (prednosti, slabosti). Ovrednotiti je potrebno točnost in zanesljivost termovizijskih kamer glede na ločljivost detektorja v povezavi z vplivom velikosti vira. Sledi analiza uporabe brezkontaktnih merilnikov temperature v realnem okolju, kjer imajo merjene površine večinoma manjše emisivnosti od 1 in kjer se zastavlja vprašanje veljavnosti korekcij, pridobljenih v postopku laboratorijskega umerjanja. Ker je emisivnost pri brezkontaktnih merjenjih temperature eden izmed največjih vplivnih parametrov na točnost meritve, bi bilo idealno izvajati umerjanje v skladu s potrebami uporabnikov. To pomeni, da bi pri umerjanju morali uporabljali siva telesa s takšnimi emisivnostmi, kot jih uporabniki srečujejo v praksi, česar pa razen za površine z emisivnostjo 0,95 nimamo na voljo. Poleg tega merjenje površin z nižjimi emisivnostmi vnaša dodatne negotovosti v meritve (odboji, sevanje ozadja, kot opazovanja), ki jih je potrebno vsaj dobro oceniti. Površine z nižjimi emisivnostmi praviloma niso obstojne in se v praksi ne uporabljajo, zato je potrebno preučiti, kakšne materiale bi lahko uporabljali, da bi imeli v določenem temperaturnem območju relativno stabilno emisivnost. Problem emisivnosti je odvisnost od temperature, valovne dolžine in kota opazovanja. Če je slednji obvladljiv, je valovna dolžina določena in omejena z različnimi detektorji. V disertaciji bi se omejili na najbolj pogosto valovno dolžino 8 μm do 14 μm, ker večina obstoječih detektorjev brezkontaktnih merilnikov temperature deluje v tem območju infrardečega spektra. Velik problem predstavlja obstojnost površin z nizko emisivnostjo, ker praviloma oksidirajo, zaradi česar se jim posledično močno spremeni emisivnost, ki jo je potrebno dobro nadzorovati, da dosežemo željeno točnost. Eden izmed cilje je ugotoviti, kako stabilna je emisivnost površin z nizkimi emisivnostmi oziroma, kako se emisivnost površin spreminja s temperaturo in časom izpostavljenosti. Končni cilj disertacije je izdelava kalibratorja za brezkontaktne merilnike temperature v obliki sivega telesa, ki mu je možno izmenjevati siva telesa različnih emisivnosti. Za takšen kalibrator s sivimi telesi je potrebno izvesti analizo merilnih negotovosti pri umerjanju brezkontaktnega termometra in termovizijske kamere v primerjavi s črnim telesom.

Kandidat mora poznati osnove znanstvenih eksperimentov. Imeti mora dovolj tehničnega znanja in fizikalnih osnov za študij brezkontaktne termometrije, biti računalniško pismen, in tekoče obvladati angleški jezik. Imeti mora sposobnost kritične interpretacije merjenj in empirično pridobljenih podatkov, na osnovi katerih mora izdelati relevantne analize in pripadajoče sinteze. Ugotovitve in spoznanja mora znati samostojno opisati v obliki znanstvenih publikacij. Biti mora sposoben sodelovanja z raziskovalci drugih ved v intenzivno interdisciplinarnem okolju ter v okviru raziskovalne ekipe.

eng:

Radiation thermometers and thermal imaging cameras are thermometers that measure temperature in a non-contact manner based on the detection of heat transfer by radiation. While radiation thermometers can measure temperature with relatively good accuracy (worse than contact thermometers, of course), thermal imaging cameras are mostly intended for technical diagnostics or qualitative measurement, unlike quantitative measurements, where accuracy and uncertainty are very important measurement parameters. The theory of non-contact temperature measurement is based on Planck's law, which is only an ideal example of a black body in a vacuum. In real conditions, we measure the radiation of gray bodies (emissivity <1) therefore, it is necessary to determine the transfer function or mathematical model of the relation between the measurand (surface radiation its true temperature and emissivity), transmission path (atmosphere) and measuring instrument (optics, detector). The true temperature can be indirectly measured by measuring the current or voltage of the detector in a non-contact thermometer, provided that the transfer function for radiation from the measured surface through the transmission path to the detector is fully known. The assurance of traceability to SI units or the determination of a complete measurement result is made possible by a calibration procedure in which the reference value of temperature is measured, on the basis of which the correction of the measured value is calculated and the measurement uncertainty is estimeted and/or calculated.

Training of a young researcher comprises several goals. The first is an analysis of existing calibration procedures for non-contact thermometers and thermal imaging cameras under laboratory conditions. Of particular importance is the analysis of the current use of thermal imaging cameras with emphasis on examples of quantitative measurement (advantages, disadvantages). It is necessary to evaluate the accuracy and reliability of thermal imaging cameras with respect to the resolution of the detector in relation to the size of source effect. The following is an analysis of the use of non-contact temperature meters in a real environment, where the measured surfaces in general have emissivity less than 1 and where the validity of the corrections obtained in the laboratory calibration process is raised. Since emissivity in non-contact temperature measurements is one of the biggest influencing parameters on the measurement accuracy, it would be ideal to perform calibration according to the needs of users. This means that we should use gray bodies with such emissivity as users encounter in practical measurements, which is not available except for surfaces with an emissivity of 0.95. In addition, the measurement of surfaces with lower emissisivity introduces additional uncertainties into the measurements (reflections, background radiation, angle of observations), which need to be at least well estimated. As a rule, surfaces with lower emissivity are not stable and are not used in practice, so it is necessary to consider what materials could be used in order to have relatively stable emissivity in a given temperature range. The emissivity problem is the dependence on temperature, wavelength, and observation angle. If the latter is manageable, the wavelength is determined and limited by different detectors. In the dissertation, we would limit ourselves to the most common wavelength of 8 μm to 14 μm, since most existing non-contact temperature detectors work in this infrared range. A major problem is the durability of surfaces with low emissivity, because they usually oxidize, which in turn results in a strong change in emissivity, which must be well controlled to achieve the desired accuracy. One goal is to determine how stable the emissivity of low-emissivity surfaces is, or how the emissivity of surfaces varies with temperature and exposure time. The final goal of the dissertation is to make a calibrator for non-contact temperature meters in the form of a gray body, which can be exchanged for gray bodies of different emissivity. For such a gray body calibrator, an analysis of the measurement uncertainties in the calibration of a non-contact thermometer and a thermal imaging camera compared to a black body is required.

The candidate must know the basics of scientific experiments. He must have sufficient technical knowledge and physical foundations to study non-contact thermometry, have a computer literacy, and be fluent in English. He must have the ability to critically interpret measurements and empirically obtained data, on the basis of which he must make relevant analyzes and associated syntheses. He must be able to describe findings independently in the form of scientific publications. He must be able to work with researchers in other sciences in an intensively interdisciplinary environment and within a research team.