SCIENTIFIC PEER REVIEW

On presentation in the competition for Associate Professor in the professional field 4.1. Physical Sciences, Scientific specialty "Optics of Wave Processes", Direction "Optical Metrology and Holography" announced by the Institute of Optical Materials and Technologies (IOMT) "Acad.I.Malinovski", BAS-Sofia,

Applicant: Chief Assistant Branimir Lyudmilov Ivanov, PhD at IOMT - BAS

Reviewer: Prof. DSc. Phys. and DSc. Eng. Marin Nenchev Nenchev at TU-Sofia and Br. Plovdiv

A research area of habilitation in which the applicant demonstrates the level of creativity, skills, and accomplishments necessary for the requested Associate Professor Habilitation. A selective summary of the applicant's performance

The candidate's scientific and applied results are divided into two parts - for habilitation to the competition and for obtaining the associate professor level. In total, the scientific publications with co-authorship of the applicant are 37 scientific articles with IF and SJR - **own equivalent ~ 10, of which he participates in the current competition with 24 - submitted 9 for habilitation and 15 for Associate Professor. He has participated in 9 projects (3 international). He has submitted a total list of 32 citations - in scientific publications. The results of the works with which he participated in the competition are related thematically to a certain direction of the competition. According to SCOPUS he has h-index 6, which I take as a very good indicator for the competition for Associate Professor. On the practical side, he has been involved in the preparation and organization of about 10 holographic exhibitions, with holograms created at IOMT and presenting Bulgarian artefacts, 3 abroad, which I also take as useful and reputable for Bulgaria practical scientific and applied activity.**

At the beginning, I consider it appropriate to systematize the wide range of scientific and applied activity and to present a summary of the applicant's achievements and evaluation, and then to give details. In my view, the applicant, both in the summary and in the distinction of the two parts - results and works for habilitation and for obtaining the associate professor level, **presents himself as a scientist with the necessary high qualifications in the requested field for habilitation as associate professor. For me this is proven by the group of his presented scientific and applied results in the field of interferometric systems, diffractive optics, digital holography and optical metrology.** The development of these methods and techniques, in particular and with the contributions of the applicant, has applicability in materials science, informatics, photonics, chemistry, biology, medicine. For practical applications, they offer as an advantage high resolution and information capacity, control and measurements are non-destructive and with the possibility of parallel recording of information, with applicability to dynamically evolving phenomena, to the study of mechanical deformations, topographic and tomographic imaging of micro- and macro-objects, process tracing, holographic recording and data storage. The noted development is understandably related to advances in computer technology and methods, knowledge of which and their use the applicant also demonstrates in his work - digital megapixel optical sensors (CCD or CMOS two-dimensional sensors) and spatial light modulators - as a significant milestone in the development of coherent optical metrology and the imaging of three-dimensional objects. White-light interferometers have established themselves as versatile, simpler, and more affordable tools for measuring spectra, surface profiles, mechanical displacements, and thicknesses of transparent materials, as well as for studying ultrafast relaxation processes in excited states of matter or in dispersion measurements. White-light interferometry is an

alternative to the technique with ultrashort laser pulses (femtosecond or picosecond), the generation of which is only possible in a limited spectral range. I find in the results of the candidate's work on the presented problems a manifestation of his serious competence and a definite attainment of the level of associate professor. I noted in my view the support of **his definitely significant activity in practical implementation**, related to exhibitions at home and abroad of Bulgarian holograms made in the IOMT with his contribution, mainly of Bulgarian history artefacts, which is a significant activity in promoting the reputation of Bulgaria.

In a brief note, I will point out that the applicant has from his student years an orientation to his subsequent long active work in the direction of modern optics and laser technology . He is a graduate of the well-known in Bulgaria Technical School "Lomonosov" in the field of optics and laser technology. After that he completed his higher education in the same direction at the Sofia University "Kliment Ohridski" as a final graduate of the Department of Quantum Electronics (with the specialization in Laser Engineering and Optics). He is now working as a physicist and research fellow at the Institute of Optics and Mechanical Technologies of the Bulgarian Academy of Sciences, with a thesis in the field of laser and optical technologies. The acquaintance with 37 scientific publications with his co-authorship in rank publications (with IF and IR) is in full agreement that the applicant is a formed specialist in the field of the claim for the associate professorship.

With a summary of the distinction of publications given by him, I will note and discuss in more detail a sample of his leading results, in confirmation of the opinion expressed above on my view of an assessment of sufficiently significant and meaningful activity in the noted field for the award of an associate professorship.

Analyzing with competence the advantages and problems in the competing methods noted above, the applicant formulates his research program to overcome the problems associated with the application of: **1.** *Interferometric methods for determining the spectral characteristics of optical sources with noise correction;* **2.** *Holographic and interferometric methods for visualization and controlling samples;* **3.** *Numerical methods for the analysis of data from dynamic speckle measurements;* **4.** *Profilometric methods for remote determination of the shape and three-dimensional visualization of objects;* **5.** *Monitoring and control of drying processes through dynamic speckle analysis.*

Main scientific contributions to the competition

A) Publications on the requested habilitation (publications A1-A9):

Here, the contributions included in the indicator **B** are described by articles from **A1 to A9**, which are an equivalent substitute for the Habilitation Thesis.

I. Interferometric methods for determining the spectral characteristics of optical sources with noise correction – the works [A1-A3] from the list.

1. To this I refer the developed three-channel correlation Fourier spectrometer with a prototype of this spectrometer based on a Meikelson interferometer working on the Twyman-Green scheme with simultaneous recording of interferograms for the reference light source, for the working source and for the light from the sample under study. Using Monte-Carlo modelling, the sources of noise interference were identified. Real-time tracking of changes in the autocorrelation functions of different semiconductor light sources was simulated using the resulting interferograms. **A feedback system is proposed** to perform ongoing autocorrelation correction of the working light source after changes in the reference source to improve accuracy **[A1]**.

2. The recovery accuracy of a single absorption peak measured with a Fourier transform spectrometer **is evaluated** for the cases of additive noise in signal detection and noise that adds a fluctuating

component to the carrier frequency in the source and measurement channel of the interferometer. **The fluctuations are modelled** as colour noise with a Gaussian correlation function. **Results are obtained** from test measurements of the spectrum of the laser diode prototype three-channel Fourier spectrometer **[A2]** established in **[A1]**.

3. An improved method for precise measurement of the optical characteristics of various light sources using a Fourier spectrometer based on a classical Michelson interferometer with a moving mirror has been developed. **A procedure has been developed** for processing the recorded interferograms to improve the spectrum estimation. The effectiveness of the procedure is demonstrated by Monte-Carlo simulation of noisy interferograms. The time required to record the data and recover the spectrum is within a few seconds Different semiconductor sources have been tested. The good quality of the obtained spectra has been confirmed by comparison with measurements using an optical spectrum analyzer. This allows a current tuning of the investigated sources, which extends their possible applications in spectroscopy, optical communications, computer technology, etc **[A3]**.

II. Holographic and interferometric methods for visualizing and controlling samples [A4-A9].

1. The generation of 3D digital input data for two types of **holographic printers** that can be used to print analog reflective holograms of artefacts **is analyzed**. In the holographic **stereogram printer**, only angular and colour information of objects extracted from multiple images captured from different viewpoints are used as input data. The images are rearranged to form so-called perspective images with information about the direction of light rays from the object. A **wavefront** holographic printer for creating real bulk holograms from digital input data in the form of 2D arrays representing computer-generated holograms, where the direction, depth and colour information are encoded in the hologram, provides the ability to magnify the object and ensures realistic reproduction. **An accelerated method** for calculating the input data is given and the print quality is demonstrated with printed colour holograms **[A4].**

2. A combined phase-shift holographic polaryscope system with a coherent light **source is proposed and developed** for conducting photo-elastic coating measurements to determine mechanical stresses. Through simulation, the ability to accurately measure isochromatic and isoclinic phase maps that yield the locations of points with constant principal stress difference and constant principal stress direction, respectively, is demonstrated. By processing the experimental data, the conclusion that the accuracy of phase extraction of isochromats and isoclines from appropriately filtered and normalized interference maps is quite acceptable has been confirmed **[A5]**.

3. The ability of the dynamic speckle technique to detect changes in process rates following changes in humidity and chemical effects on plant leaves **is demonstrated** in two test experiments. The experiments confirm the potential of this approach to distinguish leaves subjected to different impacts **[A6]**.

4. The potential of dynamic speckle analysis as an effective tool for monitoring the cooling and aging process of bread and the ability of this approach to discriminate between different types of bread **is confirmed**. The method for characterizing the rate of the underlying processes is technically simple, non-destructive and allows real-time operation. A temporal structure function was used to estimate activity from speckle maps recorded sequentially **[A7, A8]**.

5. An approach to improve the visualization of regions of slower or faster changes on the surface of a diffuse reflecting object **is proposed**. The approach is based on an exponentially decreasing temporal correlation function of intensity fluctuations. The approach has been validated by an observed paint drying experiment where the temporal correlation function at a given point matches the adopted model, thus making it possible to describe the activity quantitatively **[A9]**.

B) Publications for obtaining associate professor level (indicator Г). Publications outside the habilitation thesis [B1-C15]

I. Development of numerical methods for the analysis of dynamic speckle measurement data [B1-B8].

1. The possibility of data compression in dynamic speckle analysis by coarser quantization of raw speckle images **is proposed and demonstrated.** The measurement data are sequences of time-correlated speckle pictures formed on the surface of the objects under study. The analysis relies on the high sensitivity of the speckle to micro-changes in the optical paths of light rays reflected from the object surface and recorded by the optical sensor.

To track the change in activity over time, the number of images captured must exceed the averaging interval many times when calculating the estimation. Thus, the computational complexity in terms of computational time consumption and computer memory size increases. Since the absolute intensity values in the speckle images are not important for the output result of the dynamic speckle analysis, a reduction in the number of quantization levels before statistical processing is proposed. The effectiveness of such speckle image compression is investigated by analyzing the output data obtained for a synthetic digital object under ideal conditions of uniform illumination and uniform reflectance and for a test object when the ideal conditions are not met. Both normalized and non-normalized algorithms were applied and it was found that quantization to 32 levels does not cause distortion in the resulting activity map.

The effectiveness of coarse intensity quantization in dynamic speckle analysis was verified by processing synthetic speckle images generated at low and high speckle contrast.

It is shown that for low contrast images, the intensity distribution is symmetric and uniform quantization works well. For high contrast images, the intensity distribution is highly asymmetric and uniform quantization is not suitable.

Non-uniform quantization is introduced by logarithmic transformation of the captured images, resulting in an activity map quality comparable to that for low contrast images. These results have been confirmed experimentally **[B1,B2]**.

2. A stream processing of the dynamic speckle images **is proposed** which results in a more contrasting two-dimensional map for the spatial characterization of the activity. In addition, the stream normalization of the estimation provides a reliable result for the most common case of non-uniform intensity distribution within the illumination beam and varying reflectance across the specimen surface. Conclusions are proved by simulation and experiment for the normalized temporal correlation and structure functions **[B3,B4].**

3. A dynamic speckle analysis method is proposed for non-destructive detection of physical or biological activity by converting the acquired speckle images into binary images with only two levels. The binarization of the initial intensity data was performed by introducing a threshold value. Significant fluctuations in the intensity flux due to the speckle nature of the data and the limited number of images used to estimate activity imposed the mean intensity value as the best choice of threshold. It is found that the proposed algorithm can also work with a non-stochastic threshold, in which case the difference between the averaged estimation and the input correlation function no longer depends on the number of captured images, and this is promising for measurement calibration. A disadvantage of the non-stochastic threshold is the wider distribution of fluctuations within the activity map, but the quality of the map remains acceptable for distinguishing areas of varying activity on the surface of the object.

It has been proven, by simulation and experiment, which the polar correlation function computed from binary data effectively, shows regions of different activity under both uniform and non-uniform intensity distributions in the illuminating laser beam without normalization **[B5, B6, B7]**.

4. A method is proposed to improve the quality of determining the two-dimensional velocity distribution (activity map) of processes in diffuse reflecting objects from changing speckle patterns, on their surface by filtering this distribution. A dynamic laser speckle measurement with intensity-based processing is used, which enables point estimation and needs a simple experimental setup. To select a filter, the statistics of the fluctuations in the activity maps constructed for three temporal structure function estimation algorithms were examined. The signal-dependent nature of the fluctuations **is**

demonstrated, showing that their distribution depends on the activity even when the distribution of the speckle intensity fluctuations is uniform across the object under study. Bilateral filters with Gaussian kernels have been applied to the activity maps The contrast and resolution of the activity map have been improved by filtering and the two-dimensional quantification of short-term activity changes has been largely relaxed **[B8]**.

5. A phase spatial light modulator **has been implemented** as an optical speckle simulator with controllable spatially varying time evolution for testing algorithms in dynamic speckle metrology of physical or biological activity.

The possibility of spatial light-based testing of algorithms in dynamic speckle analysis **has been confirmed [B9, B10]**.

6. The feasibility of normalization of estimates in dynamic intensity-based speckle analysis for processing speckle image data with spatially varying statistics, such as non-uniform sample illumination, **is investigated**. Existing correlation-based algorithms are analyzed where normalization is performed using the variance estimate at each point. Modifications of algorithms that use the moment sum of two intensity or single intensity values for normalization are proposed. The effectiveness of these algorithms is verified by applying them to simulated low- and high-contrast speckle data for processing binary and compressed-format images. It has been shown that streaming algorithms, in which normalization is performed at each time point using one or two intensity values, are more efficient than algorithms applying time-averaged estimations of the mean and dispersion of speckle intensities **[B11]**.

II. Profilometric methods for remote shape determination and visualization of threedimensional objects [B12-B13].

1. The design of a sinusoidal phase grating for projection profilometry with sinusoidal fringes **is analysed.** A low-contrast sinusoidal phase grating can project focused sinusoidal fringes with satisfactory contrast over a large spatial region under coherent beam divergence illumination. The distortions in the projected fringes due to phase quantization are analyzed when the phase grating is generated by an 8-bit phase modulator. It is shown that there can exist a distortion due to the phase encoding of the complex amplitude of the grating, modelled as a gamma distortion with time-invariant behaviour at small values of the modulation parameter. It is removed by proper band pass correction after polyspectral analysis. Experiments with an 8-bit spatial-light modulator with $\pi/2$ phase range were performed, which confirmed the ability of this optical element to project sinusoidal fringes with high spectral purity **[B12].**

2. The reduction of speckle noise in fringes projected with a sinusoidal phase grating set to a spatially light modulator using a low-coherence point light source **has been proved [B13].**

III. Monitoring and control of drying processes through dynamic speckle analysis [B14-B15].

1. The dynamic speckle technique **was applied** to monitor the drying process of azo polymer solutions. Time changes in droplets of such solutions of different sizes **are demonstrated** by constructing two-dimensional maps of a given statistical evaluation.

The timescales of the drying process **have been determined** by tracking the time variation of the radius of correlation of intensity fluctuations within the speckle formed on the surface of the object **[B14, B15].**

CONCLUSION: A summary of the results and the reviewer's assessment of them was given at the beginning. It consists in the reviewer's evaluation that the applicant's performance and results meet very well the requirements for the award of the title of Associate Professor and for the position of Associate Professor. The high h-index (6) according to SCOPUS was also noted, which is a very good presentation for the competition, also taking into account the

fulfillment of the national requirements for the award of the scientific rank of Associate Professor to the applicant. The review evaluated the totality and detailing of the material presented by the candidate for the competition, showing the necessary qualifications and publication activity (24 scientific publications in ranked journals - with IF and SJR, total citations of the applicant - 37), participation in the preparation and main organizer of 10 international events - exhibitions and presentations of holograms of historical Bulgarian artefacts created in IOMT - BAS Bulgaria. The latter enhances the reputation of Bulgaria as a country with good scientific activity and historical path. I have no significant remarks.

The whole of the scientific results, well reflected in the scientific publications and the noted presentations, I find as a definitely good representation in the competition and I recommend to the Honourable Scientific Jury to award "DOCENT" to assist. Prof. Dr. Branimir Lyudmilov Ivanov.

Sofia 29.1.2023 r.

Reviewer / Signature / :

Prof. DSc. Phys DSc. Eng. Marin Nenchev Nenchev