PhD Thesis Abstract:
„Modal engineering of light for selected quantum technologies”

In the thesis we present a variety of results, which are related to the interference of classical and nonclassical states of light in the scenarios widely used in optical quantum technologies such as quantum enhaced interferometry or quantum fingerprinting.

In the first part of the thesis, we show that the low-noise sCMOS camera embedded with external image intensifier can be effectively used for measuring two-photon interference in Hong-Ou-Mandel setup. To the best of our knowledge, this is so far the first measurement of two-photon interference performed using a camera. We show that the camera is capable of registering the spatial positions of detected photon pairs with a high resolution. We present a detailed discussion of two-photon interferometry in both ideal and realistic scenarios, which is a canonical example of a quantum-enhanced measurement. We propose and theoretically analyse a novel technique, which allows to achieve sub-shot noise phase estimation precision in the two-photon interferometry even for partially distinguishable photon pairs in the spectral degree of freedom. The technique is verified by a laboratory demonstration that a suitable engineering of spatial modes combined with position-resolved coincidence detection restores entanglement-enhanced precision in the full operating range of a realistic two-photon Mach-Zehnder interferometer. The improvement relates also to interferometer operating points which otherwise does not even allow to attain the shot-noise limit. The last experiement described in this part of the thesis demonstrates hitherto unobserved sensitivity of two-photon interference to the local phase of photons transverse spatial wavefunctions. The sensitivity allowed us to devise a new technique for the reconstruction of photon's spatial wavefunction (i.e. its amplitude and phase), which relies on interfering the unknown photon with the previously characterized reference photon. Remarkably, the technique exploits the interference of two-photon probability amplitudes rather than the interference of classical electric fields.

The second part of the thesis is devoted to the quantum fingerprinting protocols and their optical implementations. We show that the quantum fingerprinting problem is equivalent to the determination of interference visibility of light sent by communicating parties. This allowed us to employ Chernoff information as a benchmark characterising the performance of the protocols in the limit of large number of trials. We propose and discuss three protocols, which contrary to hitherto employed schemes, do not require optical phase stability between communicating parties. The first two are analysed solely on theoretical basis. They both rely on either two-photon interference or the interference of N-photon Fock states. The last and most promising one is based on the interference of coherent states in carefully prepared optical modes, complemented with the subsequent measurement of joint photocounts statistics. This protocol has been also simulated in the experimental demonstration which stays in the full agreement with theoretical predictions.

In the last part of the thesis we introduce an optical method to measure radio-frequency electro-optic temporal phase modulation profiles. Such modulation is indispensable e.g. in quantum fingerprinting protocols or temporal lensing schemes. The method relies on spectrum-to-time mapping realised by highly chirped optical pulses. The viability of the proposed method is verified by the measurement of electro-optic phase modulation generated by electronic signal, originating from 12.5 GHz bandwidth photodiode.