TRACE GASES ANALYSIS IN PULSED PHOTOACOUSTICS BASED ON SWARM INTELLIGENCE OPTIMIZATION

M. LUKIĆ[1], Ž. ĆOJBAŠIĆ[2], D. D. MARKUSHEV[3]

1 Faculty of Occupational Safety, University of Niš, Serbia
2 Mechanical Engineering Faculty, University of Niš, Serbia
3 Institute of Physics, University of Belgrade, Serbia

PURPOSE

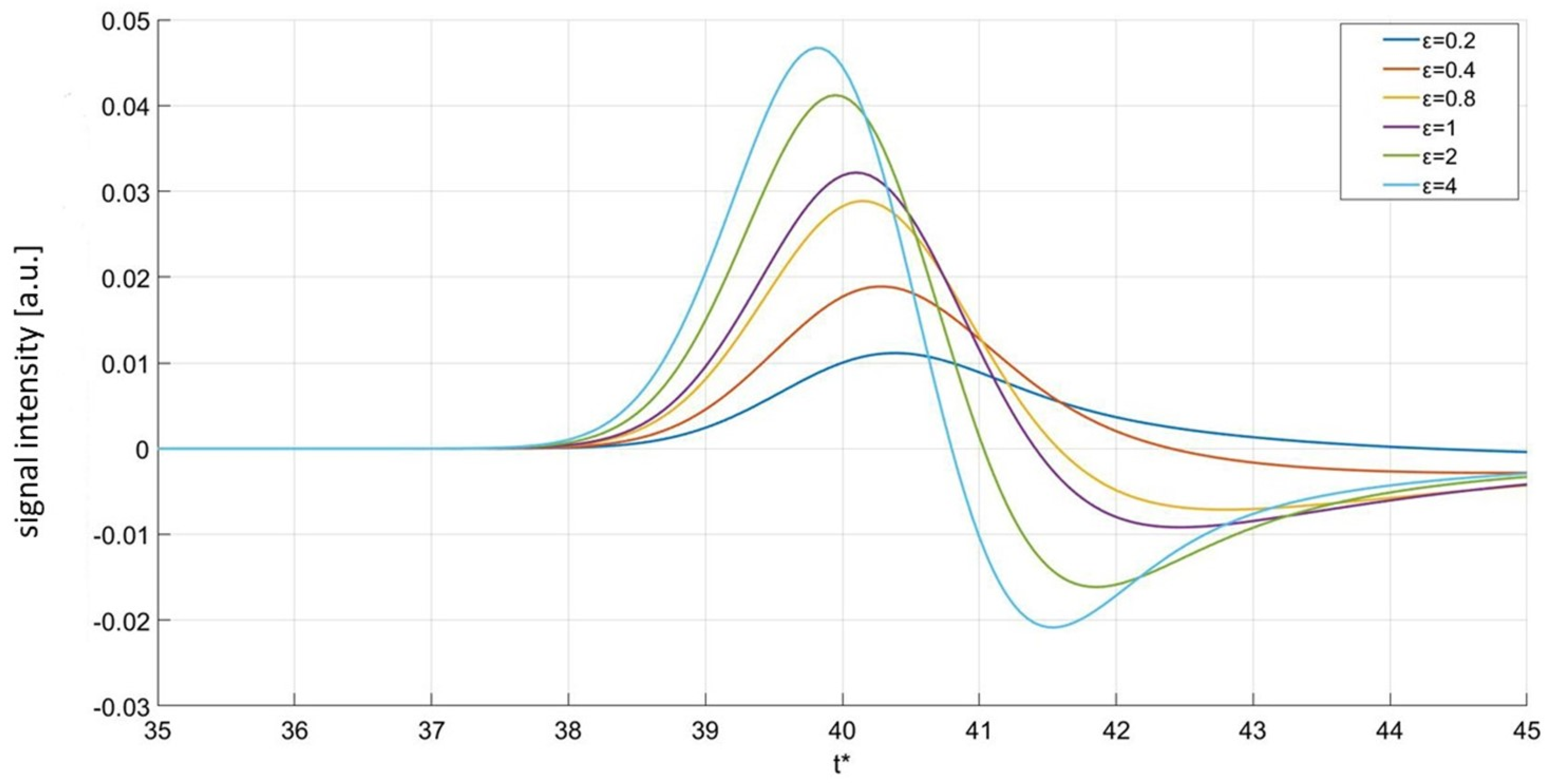
- **To improve photoacoustics (PA) equipment with appropriate software, for precisely estimation the PA signals parameters (laser beam profile type, vibration to translation relaxation time and energy density of laser radiation)**
- **To simplify PA equipment for in situ measurements and improve efficiency and accuracy through software modification.**

THEORETICAL BACKGROUND AND EXPERIMENTS

- Theoretical PA signals, are wave equation solutions obtained using Fourier transform method

$$\delta p(r^*,t^*) = \frac{RE_0}{C_v V}\int_0^\infty (l^2+\varepsilon^2)^{-1}[-\varepsilon exp(-\varepsilon t^*) + l sinlt^* + $$
$$+ \varepsilon coslt^*] J_0(lr^*)h(l)ldl$$

- Gauss laser beam profile $h_G(l) = \frac{1}{2}exp\left(-\frac{1}{4}l^2\right)$



- Experimental PA signals were generated in the SF6+Ar mixture in the multiphoton regime.

PULSED PHOTOACOUSTICS BY SWARM OPTIMIZATION

- **Why swarm intelligence algorithms application to photoacoustics?**
  - perform space and time computations; respond to environmental; produce a different responses; keep robustness under changing environment; adapts to external factors.
- **Swarm optimization applied to simultaneously determination the unknown parameters of the photoacoustic (PA) signal:**
  - **radius of the laser beam spatial profile (r_L)**
  - **vibrational-to-translational relaxation time (τ_{V-T}).**

PARTICLE SWARM OPTIMIZATION (PSO)

- Fundamental issues for PSO implementation: population size, acceleration coefficients, inertia coefficient, neighborhood size, number of iterations, function evaluations, and the weighting factors.
- Solution space defined by the Intervals for PA signal parameters: $r^* \in$ [30,50]], and $\varepsilon \in$ [0.5,5].
- Objective function χ^2 is defined as the sum of the square deviations representing deviation of the theoretical and simulated (experimental) PA signal.
- Several optimization procedures were performed for different values of the number of individuals in the population (20, 50 and 100).

ARTIFICIAL BEE COLONY OPTIMIZATION (ABC)

- Fundamental issues for ABC implementation: population size, population size, the number of food sources, limit and the maximum number of cycles.
- Solution space defined by the Intervals for PA signal parameters: $r^* \in$ [10,50]], and $\varepsilon \in$ [0.2,4] and $r^* \in$[30,50] и ε ∈[0.5,4].
- Objective function χ^2 is defined as the sum of the square deviations representing deviation of the theoretical and simulated (experimental) PA signal.
- Several optimization procedures were performed for different values of the number of individuals in the population (20, 50 and 100).
- Parameter limit is changed depending on the population size.

RESULTS

Table 1 Particle swarm optimization results

PSO algorithm parameters				PSO optimization results	
Number of iterations	Number of individuals	Range	Hybrid function	r^* ; ε	Best value f(x)
60	**20**	r^* [10 50] ε [0.2, 4]	fmincon	r^*= 40.00 ε = 3.20	1.138e-13
60	**50**	r^* [10 50] ε [0.2, 4]	fmincon	r^*= 40.00 ε = 3.19	2.976e-12
60	**100**	r^* [10 50] ε [0.2, 4]	fmincon	r^*= 40.00 ε = 3.19	3.285e-12

Unknown values of PA signal parameters for Gauss laser profile: r^*= 40.00, ε = 3.20

Table 2. Results of optimization by artificial bee colony algorithm

ABC algorithm parameters				ABC optimization results	
Number of iterations	Population	Range	Limit	r^* ; ε	Error
60	**20**	r^* [10 50] ε [0.2, 4]	2	r^*= 39.95 ε = 2.79	5.4036e-05
		r^* [10 50] ε [0.2, 4]	10	r^*= 40.01, ε = 3.48	1.4987e-05
		r^* [30 50] ε [0.5, 4]	10	r^*=40.00, ε = 3.31	3.756e-06
		r^* [10 50] ε [0.2, 4]	25	r^*= 39.95, ε = 2.74	5.6205e-05
60	**30**	r^* [10 50] ε [0.2, 4]	15	r^*= 40.03, ε = 3.68	2.6394e-05
60	**50**	r^* [10 50] ε [0.2, 4]	5	r^*= 40.05 ε = 3.37	0.00014723
		r^* [10 50] ε [0.2, 4]	25	r^*= 39.98, ε = 3.11	8.7166e-06
		r^* [30 50] ε [0.5, 4]	25	r^*= 40.00 ε = 3.21	1.1514e-08
		r^* [10 50] ε [0.2, 4]	50	r^*= 39.99, ε = 3.16	2.3439e-07
60	**100**	r^* [10 50] ε [0.2, 4]	25	r^*= 39.99, ε = 3.17	1.349e-07
60	**100**	r^* [30 50] ε [0.5, 4]	50	r^*= 40.00 ε = 3.20	1.2466e-10

Unknown values of PA signal parameters for Gauss laser profile: r^*= 40.00, ε = 3.20

CONCLUSIONS

- **Swarm intelligence algorithm have proven as promising techniques for PA in situ measurements.**
- **PSO algorithm estimated PA parameters efficiency and accurately due to faster convergence, relatively small number of evaluations function and stability in PA signals analysis in presence of noise.**
- **ABC algorithm although has less efficiency due to slower convergence, has small number of parameters for setting, which may be important in implementation phase and significant stability in dealing with noisy data.**