Modelling and Control of Non-linear Multivariable System with Delay, Parametric Uncertainty & External Disturbances: An Experimental Validation with Soft Computing Approaches.

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Submitted By : Dr. Ajit Rambhau Laware

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PROPOSAL DETAILS

(SUR/2023/000852)

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Technical Details :

Scheme : State University Research Excellence (SERB SURE)

Research Area : Electrical Electronics & Computer Engineering (Engineering Sciences)

Duration : 36 Months

Contact No : +917420932662

Date of Birth : 01-Jun-1977

Nationality : INDIAN

Total Cost (INR) : 16,80,200

Project Summary :

Historically, the process industry accepted ‘automatic control’ for proper functioning of production process. Though 95% of industrial processes preferred proportional-Integral-Derivative (PID) control loops, certain characteristics such as delay, nonlinearities, time variant nature of processes, constraints and multivariable interactions are not intended/considered explicitly in the design of PID control loops. An accumulation of time-delays adversely affect the dynamic performance of many processes and reduces gain margin. Even, it destabilizes the closed-loop system. The problem of parametric uncertainty is a big challenge. Modeling a complex process is often difficult due to modeling errors. Sometimes, if an attempt is made to take into account all process dynamics and reduce modeling errors, a highly complex model came into existence which is too difficult for mathematical analysis and design of controller. External disturbances harm the system performance. Therefore, rejection of external disturbance is one key objective while designing the controller. In this project, multivariable processes (Flow-Temperature and Level-Temperature) will be fabricated and modeled as first-order plus dead-time (FOPDT) or second-order plus dead-time (SOPDT) processes. The typical control strategies such as PID, sliding mode control and its variants along with soft computing algorithms will proposed to address delays, parametric uncertainty and bounded external disturbances via simulation, and experimental tests. Two multivariable systems are considered which are Flow-Temperature and Level-Temperature. In this research project, following activities are planned: 1. Fabrication of multi-input multi-output (MIMO) plant. 2. Development of mathematical model. 3. Simulation algorithms using combination of typical control designs and soft computing algorithms. 4. Experimental validation of simulation tests. 5. Comparison with traditional control strategies. It is envisaged that the automation industries such as Tanfac Industries (Cuddatore, Tamilnadu, India), Rite water solution (Nagpur), Tata chemicals, Pidilite Industries, BASF India Ltd., UPL Limited, Coromandel International Ltd. etc., may be interested with the proposed research results.

Objectives :

- Fabrication of multivariable process system
- Study the dynamics of multi-input multi-output (MIMO) plant.
- Mathematical modelling of MIMO processes.
- Analyze interactions and behaviour of processes.
- Solve the problem of designing robust controller to delay, parametric uncertainty and external bounded disturbances from the use of typical controller designs and soft computing algorithms.
- Integrate the capabilities of traditional control design methods and soft computing techniques.
- Experimental validation of simulation tests for MIMO plant.
- To compare the control performance of classical controllers with soft computing methods.
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Keywords :

Multivariable process, Soft computing algorithms, Delay-time, Uncertainty and disturbances, Real time experimentation

Expected Output and Outcome of the proposal :

Outputs: As per earlier discussions, prevalent design methods for multivariable process with dead-time leads to unsatisfactory performance, frequent retuning of parameters, loop interactions etc. The important hurdle is the tuning of process and controller parameters. Using soft computing or intelligent mechanism, the expected outputsand outcomes are: 1. Easy tuning of multivariable system parameters. 2. Investigations on loop interactions, input-output parings. 3. Exploration of characteristic behavior of multivariable plant. 4. Stability and robustness issues are to be solved. 5. Better command-tracking and external bounded disturbance rejection capabilities. 6. Finally, time-domain and frequency domain metrics will be enhanced with the proposed strategies. Outcomes: 1. An alternative solution to the dead-time, parametric uncertainty and external bounded disturbances using virtues of classical controllers and soft computing techniques thereby making a significant contribution. 2. Control scheme formulation to work with time-delays and constraints in multivariable plants. 3. An integration of hybrid control design strategies to solve the problem of time-delays, parametric uncertainty, constraints and external disturbances in MIMO process systems. 4. Discussion on the results obtained with prevalent control design methods.

Any other relevant information:

NA

Suitability of the proposed work in major national initiatives of the Government:

Startup India, Innovate India

Theme of Proposed Work:

Energy

Collaboration Details for last 5 Years :

Planned Collaboration for the proposed work with any foreign scientist/ institution ? **No**

Other Technical Details

PROJECT TITLE: - Modelling and Control of Non-linear Multivariable System with Delay, Parametric Uncertainty & External Disturbances: An Experimental Validation with Soft Computing Approaches

1. **State of art:**

   It is well known that though the proportional-Integral-Derivative (PID) controller is widely used in process industries, it has certain drawbacks such as 'retuning' of gains in presence of time-delay, parametric uncertainty and external disturbances. Sometimes, it gives 'PD' kicks. Robustness and stability are the major issues related to PID controller. A robust controller like sliding mode controller (SMC) experiences 'chattering' due to switching element present in discontinuous control input to the plants though SMC shows satisfactory response under parametric uncertainty and external bounded disturbances.

   To alleviate/reduce the chattering, second-order/ higher-order SMC are used. However, it requires more information of first-order time derivative of sliding manifold. Relative degree on control input is two or more respectively. However, stability and robustness issues are inexplicable. To alleviate chattering, many researchers have been follows twisting, super-twisting, global & drift algorithms, observers etc. Moreover, in all variants, the performance depends on proper selection of gain coefficients of control input. Hence, some researchers have gone for fuzzy logic and time-varying surfaces etc.

   To handle above difficulties, modern optimization techniques (soft computing algorithms) such as particle swarm optimization, ant colony, artificial bee colony Jaya optimization algorithms etc. are used. To improve the closed-loop response of multivariable plants, it is necessary to use soft computing algorithms and/or their hybrid combinations.

2. **Origin of the Proposal**

In most of industrial processes, design and implementation of control systems affirm a broader perspective in the design, not just single-loop controllers (SLCs) as it contains several manipulated and controlled variables. These industrial processes are termed as 'multivariable control systems'. Multivariable process control area has been drastically changed in the last two decades. This change is due to the complexity of plants and interactions among process variables. The tremendous increase in

prices of energy, there has been spurred activity to design efficient process control systems resulting complex plant structure and hereby the interactions. Control law must ensures the effective control in multivariable environment in which more than one controlled variable and manipulated variable exist.

SLCs can handle the problem of multivariable control via input-output variable pairings. However, each loop has to tune separately. Due to interactions among control loop and variables where single input affects its corresponding output andanother outputs of system. Hence, control of multivariable processes is a challenging work for the researchers. For small interactions between the control loops, the controller can be designed individually. However, for stronger interactions, controller has to retune each time to alleviate the oscillations.

The design and analysis of multivariable processes are mainly divided as centralized and decentralized strategies. The centralized multivariable control explores remarkable achievements. Effectively, it can handle the cross-loop interactions and provides optimal values of decision variables. However, controller designs and calculations are complex. The failure of the system may affect complete control loops.

Along with variable interactions, many processes possess ‘dead-time’ or ‘delay-time’ which is due to transportation of mass, energy or information etc. The effects of dead-time are:

1. Decrease in system phase.
2. Action in manipulating variable will get initiated on controlled variable after elapsing the dead-time.
3. Provides non-rational transfer function of process model making system more difficult to analyze
4. ‘Variability’ in the system parameters increases.

Researchers have attracted towards the design and analysis of decentralized multivariable dead-time processes. The decentralized strategy is easy to implement, tune and it is robust against plant perturbations, and external bounded disturbances.

The classical control methods can be incorporated for tuning decentralized multi-loop controllers. But, controller structure requires an accurate model of the plant to reduce/ eliminate the interactions and oscillations in control signal. Usually, this kind of strategy is simple to understand and failure of particular loop does not affect the other loops. It handles cross-loop interactions and input constraints

efficiently. However, performance of multivariable processes heavily reliant on the optimalsolutions of decision variables.

To find an optimal solution, soft computing methods such as fuzzy, artificial neural network,genetic algorithm, ant colony, particleswarm, artificial bee colony, Jaya optimization algorithms etc. received a lot of attention of researchers due to potential dealing with ill behaved complex engineering problems.

Though the modern control theory provides various design methodologies, in most of cases, state variables are unknown and immeasurable. This puts the limit on their applications in multivariable processes. Though the solution to this problem is design of observer, it is different from the original system as transient response to external disturbances is not same. Again, disturbance rejection is primary concern in process control systems which lead to poor performance. Moreover, compensator dynamics fails to be robust to external bounded disturbances, noise, unmodeled dynamics and fine tuning of controller parameters.

To facilitate the fine-tuning of controller parameters, soft computing/intelligent methods plays important role to improve time-domain or frequency-domain performance of closed-loop systems.

Following are highlights of the research problem

1. Loop interactions have to be carefully investigated in multivariable plants unlike single-input single-output (SISO) systems.
2. For control-loop stabilization and tracking, it is required to find optimal parameters of the controller by specifying search space dimensions.
3. Robustness and stability of the controller have to ensure in presence of system perturbations, external disturbances and dead-time in process model.
4. There may not be a guarantee of stability for different designs.
5. Unifying process design method has to adopt to design multivariable processes.
6. Decoupler design requires its type and proper selection.

Though the researchers have explored intelligence with typical control designs, they obtained offline optimum solutions of decision variables.

3. Review of Status: Research and Development in the Subject

The classical control methods may provide faithful response for single-input single output systems. However, they proven to be unfit for multivariable systems. The response of feedback control system depends on fine-tuning of system parameters. Earlier methods provide solutions in offline manner with different strategies. The offline solutions have to pass to real-time experimental set ups to evaluate the performance. Theoretical and experimental research on process control system has been made known in the literature survey. Some of the work is summarized as:

3.1 International Status

1. Juan Garrido et al., 2010 [1] explored inverted decoupling for centralized control of two-input two-output (TITO) processes to obtain free offset error and improved performance. For complex processes, the systems are modelled as first-order with dead time element (FOPDT). It was investigated that the decoupler complexity is independent of system size. ArjinNumsomran et al., 2011 [2] proposed inverted decoupling techniques to quadruple-tank process for minimizing the cross-coupling between inputs and outputs. They investigated that inverted decoupling with proportional-integral-derivative (PID) controller stabilize the unstable non-minimum phase plant against external disturbances and uncertainties.
2. PID controller based ABC algorithm tuning for continuous stirred tank reactor was devised by Wei-Der Chang, 2013 [3]. The effect of initial conditions has been explored through simulation tests. MJ Mahmoodabadi et al., 2015 [4] explored robust control performance of decoupled sliding mode control fused with particle swarm optimization technique, non-dominated sorting genetic algorithm II and sigma techniques for ball-and-beam system. They validated results using simulation tests to show optimum control inputs and lower tracking, and proportional errors.
3. Te-Jen et al., 2017 [5] were attempted to optimize the parameters of hybrid SMC using fireworks algorithm for inverted pendulum system. They used classical SMC and fast output sampling discrete SMC and compared results with PID controller, and linear quadratic regulator. Validation of the proposed methodwas done via simulation tests. R.Venkata Rao and AnkitSaroj2017 [6] used Jaya algorithm to optimize the performance of shell-tube heat exchangers. Experimental tests show the efficacy of Jaya algorithm over other approaches.
4. Qin Z.C. et al., 2017 [7]explored cell mapping techniquewith typical SMC for rotary arm system using numerical simulation and experimental tests.HosseinG.et al., 2018

[8]devisedintelligent algorithm as a BAT algorithm and bacterial foraging optimizer for optimizing fast recursive terminal SMC (TSMC) parameters to improve the response of non-holonomic systems. The numerical simulations are performed for robotic system to demonstrate an improvement over conventional TSMC methods.

5. Bibhu Prasad Ganthia et al., 2020 [9]explored ant colony optimization based torque control of induction-motor using proportional-integral and SMC strategies. They illustrated the efficiency of reported method via simulation experiment and shows that proposed work is more stable and faster in variance. Fusion of fractional-order PID controller and Jaya algorithm was tested by Touqeer AhmedJumani 2020, [10] for voltage regulator system. The proposed strategy was compared with differential evaluation, particle swarm, artificial bee colony and grasshopper optimization algorithms. The performance of Jaya algorithm was better than reported strategies.

3.2 National Status

1. A.A. Khandekar 2013 [11] proposed a discrete-time SMC for higher order models withdead-time processes. A sliding surface is selected as a function of system states and error and the tuning parameters of SMC are determined using dominant pole-placement strategy. The existence of stable sliding mode is obtained by using Lyapunov function. The proposed design is applicable to HOPDT processes with oscillatory and integrating behaviour, open-loop instability or non-minimum phase characteristics and works satisfactory under the effect of parametric uncertainty. The simulation and experimentation results show that the proposed strategy ensures desired tracking dynamics.
2. A. R. Laware et al., 2018 [12] explored design of SMC with modern-optimization algorithms such as non-dominated sorting genetic algorithm II (NSGA-II) and multi-objective particle swarm optimization (MOPSO). A comparative analysis of performances of an optimal PI controller, PID controller, conventional SMC, NSGA-II based tuned SMC and SMC parameter tuning using MOPSO algorithm has been carried out through MATLAB/SIMULINK. The simulation and experimental trialsshows that SMC-NSGA-II schemeprovides superior performance as compared to other design methods.
3. Adikrak Kanchanaharuthai and EkkachaiMujjalinvimut 2017 [13] proposed a backstepping SMC for stabilization of power system-magnetic energy storage system using feedback control

law. Improved transient stability and voltage regulation were the key results obtained from their proposed work which was validated using simulation environment.

4. Amir Bagheri et al., 2021 [14] implemented artificial bee colony optimization based terminal sliding mode control strategy to micro grid load frequency control for finding the optimal parameters. They used fractional power sliding manifold to ensure convergence, finite-time stability and robustness. The proposed strategy was validated via simulation tests.
5. Mukesh G. Ghogare et al., 2022 [15] proposed optimization strategy for fast TSMC to level system. The proposed method was compared with NSGA-II-fast TSMC and NSGA-II-SMC and explored that NSGA-II-fast TSMC outperforms the prevalent strategies.

Note that none of above researcher has carried out any experimental validation of MIMO processes with soft computing techniques. Moreover, the project is prominent in following ways:

a) Hybrid control strategy to find optimal values of decision variables.
b) Experimental verification of simulation results for MIMO process control plant.

3.3 Importance of the proposed project in the context of current status

Most of the work in process control system is related to design of typical controllers such as PID controller, classical sliding mode control, H_2, H_∞ controller etc. for single-input single-output systems where there is no loop interactions. Very little work is devoted to the fusion of soft computing techniques with control design strategies. The implementation of prevalent control strategies to multivariable plants investigates some problems such as loop interactions, command tracking, stability, robustness issues and degraded performance of a system.

At equilibrium condition, system may give satisfactory response but at other conditions, due to perturbations and external bounded disturbances, the closed-loop response gets deviated. No unifying design process found for single-input-single-output and multivariable process systems. Parameter tuning is more for multivariable processes and tunings are time-consuming, tedious, and complicated task.

Some researchers have provided a set of tuning equations. However, error in steady-state condition is more. Gain coefficients of control law alter the dynamic behaviour of system. In presence of uncertainties and external bounded disturbances, classical controllers exhibit oscillatory and slow

response. The process may exhibit more overshoot, large settling time, large rise time, more delay in output and large reaching time.

Also, presence of dead-time reveals oscillations in control input largerly resulting premature wear and tear of actuators. The high frequency switching causes fatigue in mechanical systems. The parameter convergence is another challenge.

Owing to above discussion, challenges are summarized as:

1. How to select parameters of control law is a challenge in practical application.
2. How to make a judgement for implementation and steady-state condition, and dynamic performance is great challenge in practical situation.
3. The selection of control and algorithm specific parameters is not instinctive.
4. The tuning of controller parameters facilitates number of solutions. The selection of particular solutions is complicated.

To tackle above difficulties, soft computing techniques or modern optimization techniques can be used for obtaining fine-tuned parameters. The fusion of different control design methods with soft computations leads to better time-domain and frequency-domain metrics.

If the project is location specific, basis for selection of location be highlighted: NA

4. Work Plan

4.1 Methodology

The project development will take place in following stages:

1. **Literature Survey:** The existing approaches for MIMO plants are:
    - Classical PID controller
    - Robust controllers
    - Hybrid control designs

In above methods, mostly researchers have been designed single-loop controllers while some of them have gone for hybrid control design methods via the simulation tests only. At this stage, relevant bibliography on robust control designs and soft computing algorithms applied in MIMO process

systems will be reviewed. Besides the literature survey, material and videos related to recent developments of control strategies in order to solve control problems will be studied.

2. **Tackling delay-time, parametric uncertainty and external disturbances in multivariable plants:**In this stage, strength and limitations of classical controllers under delay-time, parametric uncertainty and external bounded disturbances will be studied. Adequate plant structure will be studied for rejecting the disturbances while in case of delay-time, constraints of the system will be explored. Weighting factors of control efforts, sampling period etc. Will be evaluated for improving the performance of MIMO plants.
3. **Integration of different control design methods:** At this stage, classical control techniques and soft computing algorithms will be integrated and analysis will be done for improved performance. Steps 2 and 3 outline the simulations.
4. **Experimental validation:**The design methodology of controller adopted will be validated experimentally. The simulation tests/results are verified in a real-time environment. Step 4 is to verify the simulation results.
5. **Dissemination of results:** The controller developed will be disseminated to the scientific community. The disclosure is for international events and publications in referred journals.
6. **Final report:** Finally, a complete report of the research project will be made.

Fine-tuning of controller will be carried out with the help of soft computing or intelligent techniques. Finally, a comparison of proposed work with classical control design methods will be carried out with conclusions.

4.2 Time schedule of activities:

0—12 Months:

- Literature survey
- Analysis of flow-temperature and level-Temperature MIMO plants
- Up gradation of computing facilities
- Design of experimental set up

13-24 Months:

- Recruitment of JRF

- Fabrication of MIMO plant
- Analysis and study the dynamics of proposed plant
- Development of simulation algorithms and simulation results
- Real-time experimental tests

25-36 Months:

- Experiments with soft-computing techniques with typical controllers (Hybrid control strategies)
- Documentation

4.3 Time Schedule of activities giving milestones through BAR diagram

As per the adoption of methodology, following BAR diagram in Figure 1 devises the time schedule of activities for 3 years.

S. No.	**Year ----→**	1-Year		2-Year		3-Year	
	Months ---→	**1-6**	**7-12**	**13-18**	**19-24**	**25-30**	**31-36**
	Type of Work						
1	Literature survey						
2	Staff recruitment						
3	Computing facility up gradation						
4	Experiment development						
5	Validation						
7	Debugging & Report						
6	Publication (s)						

4.4 Suggested Plan of action for utilization of research outcome expected from the project.

Following summary of budget illustrates the plan of action for utilization of research outcomes expected from research project with justifications.

Budget Estimates: Summary

S. No.	Item	Budget			Total (in Rupees)
		1-Year	2-Year	3-Year	
A.	Recurring				
	Salaries/wages	---	1,83,600	1,83,600	3,67,200
	Consumables	10,000	30,000	30,000	70,000
	Travel	30,000	30,000	30,000	90,000
	Other costs	88,000	1,05,000	1,00,000	2,93,000
B.	Equipment	8,00,000	80,000	---	8,80,000
	Grand Total (A+B)	**9,28,000**	**4,28,600**	**3,43,600**	**17,00,200**

A) Budget for Salaries/Wages:

Designation No. of person	Monthly Emoluments	Budget			Total (in Rupees)
		1-Year	2-Year (month)	3-Year (month)	(12 month)
JRF	13,300	---	1,59,600 (12)	1,59,600 (12)	3,19,200 (24)
Attendant	4,000	---	24,000	24,000	48,000 (12)

			(6)	(6)	
Total		**---**	**1,83,600**	**1,83,600**	**3,67,200**

Justification: A person would be taken in second year onwards in order to carry out experiments. This is JRF category with pay of Rs. 9,500 per month. As there is provision of for paying rent and medical allowance, 40% additional amount is put in the budget.

A) Budget for Consumable Material:

	Budget			**Total**
	1-Year	**2-Year**	**3-Year**	**(in Rupees)**
	10,000	30,000	30,000	70,000
Total	**10,000**	**30,000**	**30,000**	**70,000**

Justification: Since integration of multivariable plant starts from 1st year, PVC, U-PVC material, stand, small parts, cables, printer papers, CDs, printer cartridges etc. are required.

A) Budget for Travel:

Travel	**Budget**			**Total**
	1-Year	**2-Year**	**3-Year**	**(in Rupees)**
(only inland)	30,000	30,000	30,000	90,000=00
Total	**30,000**	**30,000**	**30,000**	**90,000=00**

Justification: The trips/field visits are conceived to form an idea of the problem with expert personalities in MIMO domain, field visits where similar set ups are available, finalization of purchasing the equipment with suppliers, and attending conferences/symposium for the results

obtained. At 2-Year and 3-Year, travel budget is more as may be more trips to attend conferences or symposium etc.

A) Budget for Contingency: Other Costs

Contingency& Other costs	**Budget**			**Total (in Rupees)**
	1-Year	**2-Year**	**3-Year**	
Contingency costs	30,000	30,000	30,000	90,000
Consumables	8,000	15,000	10,000	33,000
Institute overhead (10%)	50,000	60,000	60,000	1,70,000
Total	**88,000**	**1,05,000**	**1,00,000**	**2,93,000**

Justification: Contingencies are kept for installation of MIMO plant, buying the books (if necessary) etc.

A) Budget for Equipment:

S. No.	**Name of the equipment along with make & model**	**Imported/ Indigenous**	**Approx. Cost**
1	Desktop Computer, DELL Vestro 3471, 3471 SFF, 9th GEN, 8GB DDR4, 1 TB, Wired keyboard & mouse, 18.5" HD monitor +wifi	Indigenous	75,000=00
2	Process Tanks: 1): Cylindrical: Acrylic, transparent, capacity:3 lit, 1 Nos., 2): Conical: Acrylic, transparent, capacity:3 lit, 1 Nos., 3): Spherical: Acrylic, transparent, capacity:3 lit, 1 Nos., and 4): Triangular: Acrylic, transparent, capacity:3 lit, 1 Nos. Supply tank SS304, capacity: 30 lit	Indigenous	1,20,000=00
	Level transmitter: Make: WIKA, o/p: 4-20mA, supply 10-30VDC, range: 0-25mbar, Nos: 8	Indigenous	5,20,000=00

3	Flow transmitter and temperature transmitter, Nos: 4		
4	Power supply: Make Meanwel, o/p: 24V, 0-7 A, Nos: 2	Imported	5,000=00
5	Variable frequency drive, 0.75kW, 1ph, i/p: 230V, o/p: 3ph with v/f control, Nos.: 2	Imported	30,000=00
6	Plunger pump: Model PL2017, Flow 200LPH (SS 410 plungs and liquid head) with 3ph, 230V, 0.5HP AC motor, coupling, base frame and coup guard or one can opt Pneumatic control valve, Nos.: 04, I/P converters, Nos.:04, Air filter regulators, Nos: 2 and Pressure gauges, Nos.: 4	Imported	1,30,000=00
Total:			**8,80,000**

4.5 Environmental impact assessment and risk analysis: NA

5. Expertise:

5.1 Expertise available with the investigators in executing the project:

Following are the expertise area of PI and CO-PI.

PI: 1)Control system design, 2) Process control systems and 3) Optimizations.

CO-PI: 1) Control system engineering, 2) Artificial neural network, 3) Fluid mechanics

4.2 Summary of roles/responsibilities for all Investigators:

NameoftheInvestigators	Roles/Responsibilities
Dr. Laware Ajit Rambhau	1. Literature survey 2. Problem formulation 3. Process study 4. Development of mathematical models 5. Controller designs 6. Analysis of multi-tank system results 7. Result discussions and interpretation 8. Writing reports 9. Publications
Dr. Navthar Ravindra Rambhau	1. Study of process characteristics 2. Controller design 3. Design review 4. Result discussions 5. Checking- reports

4.3 Key publications published by the Investigators pertaining to the theme of the proposal during the last 5 years

Publications of PI: Dr. Laware Ajit Rambhau

A) Journal Publications

1. LawareAjit R., Joshi Sanjay B., BandalVitthal S. and TalangeDhananjay B. , 'Design and experimental Validation of Normal Terminal Sliding Mode Control for Level Tank System', Accepted by **International Journal of Industrial and System Engineering (IJISE) on 2/7/2023.**(Impact Factor: 1.09)
   https://doi.org/10.1504/IJISE.2023.10058295

2. LawareAjit R., BandalVitthal S., and TalangeDhananjay B. "An Optimization of a Robust Smith Predictor Control Strategy for Integrating Processes with Dead Time", **ECTI Transactions on Electrical Engineering, Electronics and Communications**, Vol. 21, No. 2, pp. 1-11, June 2023. 249821.(Impact Factor: 1.028)
   https://doi.org/10.37936/ecti-eec.2023212.249821.

3. A.R. Laware, B.J. Parvat and R.R. Navthar, "An Integral Augmented Sliding Mode Controller: The Experimental Application to Level Control Plant", Accepted by **International Journal of Automation and Control (IJAAC)** on 27/02/2023.(Impact Factor: 1.8)
   https://doi.org/10.1504/IJAAC.2024.10058538

4. LawareAjit R., AwazeSneha K., BandalVitthal S., and TalangeDhananjay B. "Experimental Evaluation of Non-Singular Terminal Sliding Mode Controller for Process Control System" submitted to **ECTI Transactions on Electrical Engineering, Electronics and Communications**, Vol. 21, No. 1, pp. 1-11.(Impact Factor: 1.028)
   https://doi.org/10.37936/ecti-eec.2023211.248563.

5. LawareAjit R., Patil Anita K., BandalVitthal S. and TalangeDhananjay B. "Design and Experimental Evaluation of Global Sliding Mode Controller" **International Journal of Systems, Communication and Control (IJSCC)**, Vol. 14, No. 1, pp. 40-59, 2023.(Impact Factor: 0.81)
   https://doi.org/10.1504/IJSCC.2022.10048704.

6. A.R. Laware, R.R. Navthar, V.S. Bandal and D.B. Talange, "Global optimization of second-order sliding mode controller parameters with new sliding surface: An application to process control systems", **Elsevier's ISA Transactions**, 126, pp. 498–512, 2022.(Impact Factor: 5.911)
   https://doi.org/10.1016/j.isatra.2021.08.013

7. M.G. Ghogare, A.R. Laware, S.L. Patil, C.Y. Patil, "Design and Analysis of Decentralized Dynamic Slding Mode Controller for TITO Process, **International Journal of Robotics and Control Systems**, Vol. 2, Issue 2, 2022 pp. 277-296. (Impact Factor: Other)
https://dx.doi.org/10.31763/ijrcs.v2i2.648

8. Patil Anita K. and LawareAjit R., Review : Application of Big Data and IOT protected mode in Agriculture, **International Journal for Engineering Applied Science and Technology**, April 2021, Volume5, Issue 12, **ISSN [ONLINE]: 2455-2143**

9. A. R. Laware, V. S. Bandal, M. G. Ghogare and D. B. Talange, "Design of LMI-based finite-time sliding mode controller: The convex optimization problem", **Journal of Engineering Sciences, UGC Care Approved Group II Multidisciplinary Journal,** Vol. 11, Issue 05, pp. 542-549, May 2020.
https://doi.org/10.15433.JES.2020.V11I5.43P.87

10. Laware A. R., Talange D. B. and Bandal V. S., "Experimental realization of constrained optimization of sliding mode controller parameters with modified objective functions", **International Journal of Software Computing and Testing,** Vol.6, No.1, pp. 8-25, April 2020.
https://doi.org/10.37628/ijosct.v6i1.594.

11. A. R. Laware, D. B. Talange and V. S. Bandal, "Evolutionary optimization of sliding mode controller for level control system", **Elsevier's ISA Transactions** 83, pp. 199-213, 2018. (Impact Factor: 4.628)
https://doi.org/ 10.1016/j.isatra.2018.08.011

B) Conference Publications

1. Mukesh Ghogare, SanjayKumar Patil, ChetanKumar Patil, Ajit Lawar and Lalit Chaudhari, Design and Experimental Validation of Non-singular Terminal Sliding Mode Control for Level Control System, 2021 IEEE 18th India Council International Conference (IDICON), 2021, pp. 1-6.
https://doi.org/10.1109/INDICON52576.2021.9691606.

C) Book Chapter (s)

1. Book Chapter: "Optimization of Fast Terminal Sliding Mode Controller", Published by Weser Books. Authors: Dr. LawareAjit R. and Dr. NavtharRavindra R. **, ISBN: 978-3-96492-449-0**
https://doi.org/10.33545/wb.book.274

D) Communicated Paper (s)

1. Laware A.R., Nerkar M.H. and Bandal V.S., An Execution of Dynamic Sliding Mode Control with Dynamic Sliding Manifold to Control Systems, submitted to Journal of Control and Decision, Taylor and Francis Group on 11 August 2023.

E) UGC Care Journal (s)

1. LawareAjit, JadhavAkash, SolatYogesh, PadaleRushikesh and GhaytdakShubhangi, Design of Sliding Mode Control Strategy for Induction Motor, International Journal for Research in Applied Science and Engineering Technology (IJRASAT), Vol. 11, Issue V, pp. 7429-7434, 2023.
   https://doi.org/10.22214/ijraset.2023.53445.

2. LawareAjit, BhavsarVaishnavi, ShindePrerana, and LokhandeRutuja, Design of Sliding Mode Control Strategy for DC Motor, International Journal for Research in Applied Science and Engineering Technology (IJRASAT), Vol. 11, Issue V, pp. 7548-7552, 2023.
   https://doi.org/10.22214/ijraset.2023.53445.

Publications of CO-PI: Dr. Navthar Ravindra Rambhau

A) Journal and Conference Publications

1. Performance analysis of heat pump by retrofitting of HFC refrigerants, **International Journal of Academic Research and Development**, Vol. 3, No. 2, 2018, pp. 108-110**. ISSN: 2455-4197**
2. Optimization of tilting angle of parabolic solar dish for effective steam generation, **International Journal of Academic Research and Development**, Vol. 3, No. 2, 2018, pp. 73-78. **ISSN: 2455-4197.**
3. Design And Optimization Of Front Axle Of Heavy Truck, **International Journal of Engineering Applied Sciences and Technology**, Vol. 4, No. 4, 2019, pp. 183-191. **ISSN No. 2455-2143.**
4. Experimental investigation on enhancing the engine performance by preheating the air in SI engine, **International Journal of Academic Research and Development**, Vol. 3, No. 2, 2018, pp. 121-124. **ISSN: 2455-4197**
5. Performance analysis of single slope solar still with improved design, **International Journal of Ambient Energy**, Vol. 1, pp. 1-5. **DOI: 10.1080/01430750.2020.1722227.**
6. Effect of the pin temperature and SiC reinforcement on dry sliding tribological behavior of aluminium based silicon carbide metal matrix composite (Al-SiC) using Taguchi approach, Proceedings Of The Institution of Mechanical Engineers Part J-Journal Of Engineering Tribology, Volume 237,Issue 4, Page 979-991, **DOI : 10.1177/13506501221147367**

B) Patient Filled

A Signalling System for Reducing Rear End Collisions, Recording And Tracking Over-Speed Instances of a Vehicle. Application Number 63/MUM/2013, filled in Jan 2013.

C) Copyright Registered

1. Analyzing The Wear Rate Of Bearing Material By Using Composites, Diary Number: 1866/2019-CO/L Dated 02/05/2019.
2. Design And Optimization Of Front Axle Of Heavy Truck, Diary Number: 15033/2019-CO/L Dated 24/09/2019.
3. Wear Particle Analysis Using Ferrography, Diary Number: 15292/2019-CO/L Dated 26/09/2019.

4.4 Bibliography

1. Juan Garrido, Francisco Vazquez and Fernando Morilla, Centralized inverted decoupling control, Industrial and Engineering Chemistry Research, ACS Publications, pp. 1-12, 2013. **https://doi.org/ie400367m/Ind.Chem.**

2. ArjinNumsomran, VittayaTipsuwanporn, ThainitTrisuwannawat and KittiTirasesth, Design of PID controller for modified quadruple-tank process using inverted decoupling technique, 2011th International Conference on Control, Automation and Systems, pp. 1364-1368, 2011. **ISSN: 2093-7121.**

3. Wei-Der Chang, Non-linear CSTR control system design using an artificial bee colony algorithm, Simulation Modeling Practice and Theory, vol. 31, pp. 1-9, 2013. **https://doi.org/j.simpat.2012.11.002.**

4. MJ Mahmoodabadi, M. Taherkhorsandi, M. Talebipour and KK Castillo-Villar, Adaptive robust PID control subject to supervisory decoupled sliding mode control based upon genetic algorithm optimization, Transactions of the Institute of Measurement and Control, vol. 37, issue 4, pp. 505-514, 2015.**https://doi.org/10.1177/1042331214543295.**

5. Te-Jen, Shih-Ming Wang, Tsung-Ying Li, Sung-Tsun Shih and Van-Manh Hoang, Design of hybrid sliding mode controller based in fireworks algorithm for non-linear inverted pendulum system, Advances in Mechanical Engineering, vol. 9 (1), pp. 1-13, 2017. **https:// doi.org/10.1177/1687814016684273.**

6. R. VenkataRao and AnkitSaroj, Constrained economic optimization of shell and-tube heat-exchanger using elitist-Jaya algorithm, Energy, vol. 128, issue 1, pp. 785-800, 2017. **https://doi.org/10.1016/j.energy.2017.04.059.**

7. Zhi-Chang Qin, Fu-RuiXiong, Qian Ding, Carlos Hernandez, Jesus Fernandez and Oliver Schutze, Multi-objective optimal design of sliding mode control with parallel simple cell mapping method, Journal of Vibration and Control, vol. 23, issue 1, 2017. **https://doi.org/10.1077/1077546315574948.**

8. HosseinGhasemi, BehroozRezaie and ZaharaRahmani, Terminal sliding mode control with evolutionary algorithm for finite-time robust tracking of non-holonomic system, Journal of Information Technology and Control, vol. 47, issue 1, pp. 26-44, 2018. **https://doi.org/10.5755/j01.itc.47.1.15031.**

9. Bibhu Prasad Ganthia, Rosalin Pradhan, Rajashree Sahu and Aditya Kumar Patti, Artificial ant colony optimized direct torque control of mathematically modelled induction motor using PI and sliding mode controller, In Book: Recent Advances in Power Electronics and Drives, pp. 389-408, 2021. **https://doi.org/10.1007/978-981-15-8586-0-35.**

10. Touqeer Ahmed Jumani, Mohd. Wazir Mustafa, ZohaibHussain, Madihah Md. Rashid, Mohammad Salman Saeed, Mehran M. Memon, Ilyas Khan and KottakkaranSooppyNisar, Jaya optimization algorithm for transient response and stability enhancement of a fractional-order PID based automatic voltage regulator system, Alexadria Engineering Journal, vol. 59, issue 4, pp. 2429-2440, 2020. **https://doi.org/10.1016/j.aej.2020.03.005.**

11. A.A. Khandekar, G.M. Malwatkar and B.M. Patre, Discrete sliding mode control for robust tracking of higher-order delay time systems with experimental application, ISA Transactions, vol. 52, issue 1, pp. 36-44, 2013. **https://doi.org/10.1016/j.isatra.2012.09.002.**

12. A.R. Laware, D.B. Talnge and V.S. Bandal, Evolutionary optimization of sliding mode controller for level control system, ISA Transactions, 83, pp. 199-213, 2018. **https://doi.org/10.1016/j.isatra.2018.08.011.**

13. Adirak Kanchanaharuthai and Ekkachai Mujjalinvimut, An improved backsteeping sliding mode control for power systems with superconducting magnetic energy system, International Journal of Innovative Computing, Information and Control, vol. 15, no. 3, pp. 891-904, 2017. **https://doi.org/10.24507/ijicic.15.03.891.**

14. Amir Bagheri, Ali Jabhari and SalehMobayen, An intelligent ABC based terminal sliding mode controller for load-frequency control of islanded microgrid, Sustainable Cities and Society, vol. 64, 102544, 2021. **https://doi.org/10.1016/j.scs.2020.102544.**

15. Mukesh G. Ghogare, SanjayKumar L. Patil and ChetanKumar Y. Patil, Experimental validation of optimized fast terminal sliding mode control for level system, ISA Transactions, vol. 126, pp. 486-497. 2022.**https://doi.org/10.1016/j.isatra.2021.08.007.**

6.Listof Projectssubmitted/implementedbytheInvestigators

Detailsof Projects submittedto variousfundingagencies:

S. No	Title	Cost inLakh	Month ofsubmission	Role asPI/Co-PI	Agency	Status
NIL						

Detailsof Projectsunderimplementation

S. No	Title	Cost inLakh	Duration	Roleas PI/Co-PI	Agency
NIL					

Detailsof Projectscompletedduringthelast5years

S. No	Title	Cost inLakh	Duration	Roleas PI/Co-PI	Agency
NIL					

7.List of facilities being extended by parent institution (s) for the project implementation

7.1 Infrastructural Facilities

Sr.No.	InfrastructuralFacility	Yes/No/Notrequired Full or sharing basis
1.	WorkshopFacility	Yes
2.	Water&Electricity	Yes
3.	LaboratorySpace/ Furniture	Yes
4.	PowerGenerator	Yes
5.	AC Roomor AC	Yes
6.	Telecommunicationincludinge-mail&fax	Yes
7.	Transportation	Yes
8.	Administrative/Secretarialsupport	Yes
9.	Informationfacilitieslike Internet/Library	Yes
10.	Computationalfacilities	Yes
11.	Animal/GlassHouse	Not required
12.	Anyother special facilitybeingprovided	Not applicable

7.2 Equipment available with the Institute/Group/Department/Other Institutes for the project:

Equipment available with	GenericNameof Equipment	Model, Make &yearofpurchase	Remarks includingaccessories available andcurrentusageof equipment
PI&hisgroup	Universal Process control Trainer	M/s Apex Innovations Pvt. Ltd, Sangli, India. Code- 330 Process plant, compressor. 02/07/2012	Accessories are available and used for conducting practical of UG students of Mechanical and Electrical students (PID Controller)
	DCS. Trainer	Hybrid Controller and SCADA software Product code—329, Make—Honeywell, Model-H.C 900. 23/09/2010	Available. The equipment is used along with Universal Processcontrol Trainer to conduct the practical of T.E. Mechanical students.
	Level control Trainer (5c ADC)	M/s Apex Innovations Pvt.	Accessories are available and used for conducting practical of

PI's	product	Ltd, Sangli, India. code- 313A 27/11/2011	UG students of Electrical students (PID Controller)
	Temperature Control Trainer	M/s Apex Innovation P Ltd. Sangali, India. 06/07/2007	Accessories are available and used for conducting practical of UG students of Electrical students (PID Controller)
	Flow control Trainer computerized operation,Auto tuning close loop water circulation.	M/s Apex Innovation P Ltd. Sangali, India. 06/07/2007	Accessories are available and used for conducting practical of UG students of Electrical students (PID Controller)
	SCADA software Wonderware in touch	M/s Apex Innovation P Ltd. Sangali, India. 23/07/2007	The software is used for listed control trainers.
Other Institute(s)in	NIL		

8. Name and address of experts/institution interested in the subject/outcome of the project.

S.No.	Name of expert	Name of Institution/Industry	Contact details
1.	Prof. Parvat B.J.	KBT College of Engineering, Nashik	9922170663
2.	Mr. Kanawade T.S.	YashAutotech, Ahmednagar	9822658591
3.	Prof. Ghogare M.G.	D.Y. Patil College of Engineering, Pune	9822230089
4	Mr. BhausahebSarode	Padmashri Dr. VithalraoVikhePatil sugar factory, Pravaranagar.	+91 2422 273700 +91 2422 273527 +91 2422 273698

9. Previous Projects Details (IfAny)

S. No	Project Title	PIName	CO-PI Name	Amount	Status	Date ofStart	Date OfCompletion	Funding Agency
NIL								

Budget Details

Institution wise Budget Breakup :

Budget Head	Dr.Vithalrao Vikhe Patil College of Engineering	Total
Research Personnel	3,67,200	**3,67,200**
Consumables	70,000	**70,000**
Travel	90,000	**90,000**
Equipment	8,80,000	**8,80,000**
Contingencies	90,000	**90,000**
Other cost	33,000	**33,000**
Overhead	1,50,000	**1,50,000**
Total	**16,80,200**	**16,80,200**

Institute Name : ***Dr.Vithalrao Vikhe Patil College of Engineering***

Year Wise Budget Summary (Amount in INR) :

Budget Head	Year-1	Year-2	Year-3	Total
Research Personnel	0	1,83,600	1,83,600	**3,67,200**
Consumables	10,000	30,000	30,000	**70,000**
Travel	30,000	30,000	30,000	**90,000**
Equipments	8,80,000	0	0	**8,80,000**
Contingencies	30,000	30,000	30,000	**90,000**
Other cost	8,000	15,000	10,000	**33,000**
Overhead	50,000	50,000	50,000	**1,50,000**
Grand Total	**10,08,000**	**3,38,600**	**3,33,600**	**16,80,200**

Research Personnel Budget Detail (Amount in INR) :

Designation	Year-1	Year-2	Year-3	Total
Attendant *An attendant is required for non-technical work*	0	24,000	24,000	**48,000**
Junior Research Fellow *A person would be taken in second year onwards in order to carry out experiments. This is JRF category with pay of Rs. 9,500 per month. As there is provision of for paying rent and medical allowance, 40% additional amount is put in the budget.*	0	1,59,600	1,59,600	**3,19,200**

Consumable Budget Detail (Amount in INR) :

Justification	Year-1	Year-2	Year-3	Total
Since integration of multivariable plant starts from 1st year, PVC, U-PVC material, stand, small parts, cables, printer papers, CDs, printer cartridges etc. are required.	10,000	30,000	30,000	**70,000**

Travel Budget Detail (Amount in INR) :

Justification (Inland Travel)	Year-1	Year-2	Year-3	Total
The trips/field visits are conceived to form an idea of the problem with expert personalities in MIMO domain, field visits where similar set ups are available, finalization of purchasing the equipment with suppliers, and attending conferences/symposium for the results obtained. At 2-Year and 3-Year, travel budget is more as may be more trips to attend conferences or symposium etc.	30,000	30,000	30,000	**90,000**

Equipment Budget Detail (Amount in INR) :

Generic Name ,Model No. , (Make)/ Justification	Quantity	Spare time	Estimated Cost
Plunger pump Model PL2017 (Advanced control equipments, sangali, India) *Plunger pump: Model PL2017, Flow 200LPH (SS 410 plungs and liquid head) with 3ph, 230V, 0.5HP AC motor, coupling, base frame and coup guard or one can opt Pneumatic control valve, Nos.: 04, I/P converters, Nos.:04, Air filter regulators, Nos: 2 and Pressure gauges, Nos.: 4*	1	20 %	**1,30,000**
Process Tanks and Supply Tank Cylindrical, Conical, Spherical and Triangular Tanks of Acrylic & Transparent, Supply Tank of SS304 (Advanced Control Equipments, Miraj, Sangali, India) *Process Tanks: 1): Cylindrical: Acrylic, transpakent, capacity:3 lit, 1 Nos., 2): Conical: acrylic transparent, capacity:3 lit, 1 Nos., 3): Spherical: Acrylic, transparent, capacity:3 lit, 1 Nos., and 4): Triangular: Acrylic, transparent, capacity:3 lit, 1 Nos. Supply tank SS304, capacity: 30 lit*	1	30 %	**1,20,000**
Level, Flow and Temperature Transmitters o/p: 4-20mA, supply 10-30VDC, range: 0-25mbar. (WIKA) *Level transmitter: Make: WIKA, o/p: 4-20mA, supply 10-30VDC, range: 0-25mbar, Nos: 4* *Flow transmitter and temperature transmitter, Nos: 4*	1	30 %	**5,20,000**
Desktop Computer, DELL Vestro 3471, 3471 SFF, 9th GEN, 8GB DDR4, 1 TB, Wired keyboard & mouse, 18.5" HD monitor +wifi (DELL Vesto) *8GBDDR4 PC is required for MATLAB installation and project*	1	20 %	**75,000**
Power supply o/p: 24V, 0-7 A, Nos: 2 (Meanwel) *Power supply: Make Meanwel, o/p: 24V, 0-7 A, Nos: 2*	2	0 %	**5,000**
Variable frequency drive Variable frequency drive, 0.75kW, 1ph, i/p: 230V, o/p: 3ph with v/f control, Nos.: 2 (ACE- Meanwel) *Variable frequency drive, 0.75kW, 1ph, i/p: 230V, o/p: 3ph with v/f control, Nos.: 2*	1	0 %	**30,000**

Contingency Budget Detail (Amount in INR) :

Justification	Year-1	Year-2	Year-3	Total
Contingencies are kept for installation of MIMO plant, buying the books (if necessary) etc.	30,000	30,000	30,000	**90,000**

Overhead Budget Detail (Amount in INR) :

Justification	Year-1	Year-2	Year-3	Total
10% amount will be paid by SERB to an Institution	50,000	50,000	50,000	**1,50,000**

Other Budget Detail (Amount in INR) :

Description/Justification	Year-1	Year-2	Year-3	Total
installation of MIMO plant, temporary worker pay Are kept for installation of MIMO plant, worker pay or fitter apy etc.	8,000	15,000	10,000	**33,000**

PROFORMA FOR BIO-DATA (to be uploaded)

1. Name and full correspondence address:

   Dr. Laware Ajit Rambhau

   Department of Electrical Engineering, Dr. Vithalrao Vikhe Patil College of Engineering, P.O. MIDC Area, Vilad Ghat, Ahmednagar-414111

2. Email(s) and contact number(s):
   Email ID: ajitlaware2003@gmail.com
   Contact No.: +917420932662

3. Institution: Dr. Vithalrao Vikhe Patil Foundation's, Dr. Vithalrao Vikhe Patil College of Engineering, Ahmednagar.

4. Date of Birth: 1st June 1977

5. Gender (M/F/T): Male

6. Category Gen/SC/ST/OBC: General

7. Whether differently abled (Yes/No): NO

8. Academic Qualification (Undergraduate Onwards)

	Degree	Year	Subject	University/Institution	% of marks
1.	B.E. Instrumentation and Control Engineering	2000	Process Control, Sensors and Transducers, Applied Instrumentation	North Maharashtra University, Jalgaon. Government College of Engineering, Jalgaon	74.13
2.	M.E. Instrumentation and Control Engineering	2007	Process Control Systems, Controller Synthesis	Savitribai Phule Pune University, Pune (formerly Pune University)	61.4
3.	Ph.D. in Electrical Engineering	2020	Sliding Mode Control, Process Plant Instrumentation	Savitribai Phule Pune University, Pune (formerly Pune University)	Completed

9. Ph.D thesis title, Guide's Name, Institute/Organization/University, Year of Award.
   Ph.D. Thesis: Parametric Analysis and It's Optimization for Process Plant Based on Sliding Mode Control Strategies.
   Guide's Name: Research Guide: Dr. D.B. Talange and Research co-guide: Dr. V.S. Bandal
   Institute/Organization/University: College of Engineering, Pune, India. Savitribai Phule Pune University, Pune (formerly Pune University)
   Year of Award: 25th February 2020.

10. Work experience (in chronological order).

S.No.	Positions held	Name of the Institute	From	To	Pay Scale
1	Lecturer	Dr. Vithalrao Vikhe Patil College of Engineering, Ahmednagar.	16/07/2001	30/09/2007	8275-13500
2	Assistant Professor	Dr. Vithalrao Vikhe Patil College of Engineering, Ahmednagar.	01/10/2007	30/09/2011	12420-18300
3	Associate Professor	Dr. Vithalrao Vikhe Patil College of Engineering, Ahmednagar.	01/10/2011	31/08/2021	37400-67000 (AGP 9000)
4	Professor	Dr. Vithalrao Vikhe Patil College of Engineering, Ahmednagar.	01/09/2021	Till date	37400-67000 (AGP 10000)

11. Professional Recognition/ Award/ Prize/ Certificate, Fellowship received by the applicant.

S.No	Name of Award	Awarding Agency	Year
1	Co-chairman of technical session, 23rd national Convention of Agriculture Mechanization through Entrepreneurial Development	Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, India	6-7 February 2010
2	Department Prize for Outstanding Student Performance.	Department of Instrumentation and Control Engineering, North Maharashtra University, Jalgaon, Maharashtra, India..	2000
3	Department Prize for University Second Rank.	Department of Instrumentation and Control Engineering, North Maharashtra University, Jalgaon, Maharashtra, India..	2000
4	Reviewer	Elsevier's ISA Transactions, SN Applied Science, Transactions of the Institute of Measurement and Control and	2020-till date

12. Publications *(List of papers published in SCI Journals, in year wise descending order).*

S.No.	Author(s)	Title	Name of Journal	Volume	Page	Year
Journal Publications						
1	Laware Ajit R., Joshi Sanjay B., Bandal Vitthal S. and Talange Dhananjay B.	Design and experimental Validation of Normal Terminal Sliding Mode Control for Level Tank System	International Journal of Industrial and System Engineering (IJISE) **(Accepted on 2/7/2023)**	Under Publication schedule (2023)		
2	A.R. Laware, B.J. Parvat and R.R. Navthar	An Integral Augmented Sliding Mode Controller: The Experimental Application to Level Control Plant	International Journal of Automation and Control (IJAAC) **(Accepted on 27/2/2023)**	Under Publication schedule (2023)		
3	Laware Ajit R., Awaze Sneha K., Bandal Vitthal S., and Talange Dhananjay B.	Experimental Evaluation of Non-Singular Terminal Sliding Mode Controller for Process Control System	ECTI Transactions on Electrical Engineering, Electronics and Communications	Vol. 21, No. 1	1-11	2023
4	Laware Ajit R., Bandal Vitthal S., and Talange Dhananjay B	On the Optimization of Robust Smith Predictor Control Strategy for Integrating Processes with Dead Time	ECTI Transactions on Electrical Engineering, Electronics and Communications	Vol. 21, No. 2	1-11	2023
5	Laware Ajit R., Bandal Vitthal S., Patil Anita K. and Talange Dhananjay B.	Design and Experimental Evaluation of Non-Singular Terminal Sliding Mode Controller Using Modified Sliding Surface Variables	International Journal of Systems, Communication and Control (IJSCC) https://doi.org/10.1504/IJSCC.2022.10048704	Vol. 14, No. 1	40-59	2023
6	A.R. Laware, R.R. Navthar, V.S. Bandal and D.B. Talange	Global optimization of second-order sliding mode controller parameters with new sliding surface: An application to process control systems	Elsevier's ISA Transactions https://doi.org/10.1016.2021.08.013	126	498-512	2022
7	M.G. Ghogare, A.R. Laware, S.L. Patil, and C.Y. Patil	Design and Analysis of Decentralized Dynamic Slding Mode Controller for TITO Process	International Journal of Robotics and Control Systems https://dx.doi.org/10.31763/ijrcs.v2i2.648	Vol. 2, Issue 2	277-296	2022
8	Patil Anita K. and Laware Ajit R.	Application of Big Data and IOT protected mode in Agriculture	International Journal for Engineering Applied Science and Technology ISSN: 2455-2143	Vol. 5, Issue 12	1-9	2021
9	Laware A. R., Talange D. B. and Bandal V. S.	Experimental realization of constrained optimization of sliding mode controller parameters with modified objective functions	International Journal of Software Computing and Testing. https://doi.org/10.37628/ijosct.v6i1.594.	Vol.6, No.1	8-25	2020
10	A. R. Laware, V. S. Bandal, M. G. Ghogare and D. B. Talange	Design of LMI-based finite-time sliding mode controller: The convex optimization problem	Journal of Engineering Sciences, UGC Care Approved Group II Multidisciplinary Journal https://doi.org/10.15433.JES.2020.V11I5.43P.87	Vol. 11, Issue 05	542-549	2020
11	A. R. Laware, D. B. Talange and V. S. Bandal	Evolutionary optimization of sliding mode controller for level control system	Elsevier's ISA Transactions https://doi.org/10.1016/j.isatra.2018.08.011	83	199-213	2018
12	A. R. Laware, D. B. Talange and V. S. Bandal	Temperature Control of Heat Exchanger using Sliding Mode Control Law	Journal of Control and Instrumentation (JoCI) ISSN: 2229-6972	Vol. 6, Issue 1	14-27	2015
13	A. R. Laware, D. B. Talange and V. S. Bandal	Real-Time Temperature Control System using PID Controller and Supervisory Control and Data Acquisition System (SCADA)	International Journal of Application or Innovation in Engineering and Management (IJAIEM)	Vol. 2 Issue 2	88-94	2013

			ISSN: 2319-4847			
Conference Publications						
14	Mukesh Ghogare, SanjayKumar Patil, ChetanKumar Patil, Ajit Lawar and Lalit Chaudhari	Design and Experimental Validation of Non-singular Terminal Sliding Mode Control for Level Control System, 2021 IEEE 18th India Council International Conference (IDICON) organized by I.I.T. Guwahati.	2021 IEEE 18th India Council International Conference (IDICON) https://doi.org/10.1109/INDICON52576.2021.9691606.	--	1-6	2021
15	A. R. Laware, D. B. Talange and V. S. Bandal	Design of Predictive Sliding Mode Controller for Cascade Control System	2016 IEEE First International Conference on Control, Measurement and Instrumentation (CMI) https://doi.org/10.1109/CMI.2016.7413756.	--	284-289	2016
16	D. B. Talange, A. R. Laware, and V. S. Bandal	Development of an Internal Model Sliding Mode Controller for Cascade Control System	2015 International Conference on Energy Systems and Applications (ICESA 2015) https://doi.org/10.1109/ICESA.2015.7503312.	--	51-56	2015
17	A.R. Laware and V. S. Bandal	PIC Micro Controller based Micro Irrigation System	23rd National Convention of Agricultural Engineering, Mahatma Phule Krishi Vidyapeeth, Rahuri.	--	15-21	2010
Communicated Paper (s)						
18	Laware A.R., Nerkar M.H. and Bandal V.S.	An Execution of Dynamic Sliding Mode Control with Dynamic Sliding Manifold to Control Systems	Journal of Control and Decision, Taylor and Francis Group	Under Review (First Revision Completed)		

13. Detail of patents.

S.No	Patent Title	Name of Applicant(s)	Patent No.	Award Date	Agency/Country	Status
NIL						

14. Books/Reports/Chapters/General articles etc.

S.No	Title	Author's Name	Publisher	Year of Publication
1	Optimization of Fast Terminal Sliding Mode Controller	Dr. Laware A.R. and Dr. Navthar R.R.	Weser Books, Germany	10/06/2022 https://doi.org/10.33545/wb.book.274

15. Any other Information (maximum 500 words)

1. PI attended 11 workshops/ FDPs/STTPs.

2. PI attended 6 seminars and 6 training programs while following are the responsibilities handled
   a. Nodal Officer: Pradhan Mantri Kaushal Vikas Yogena (PMKVY-TI) , AICTE Scheme for 2017-18 and 2018-19.
   b. Research coordinator of college from year 2020.
   c. Coordinator of National Conference, RTIC 2010 held at Dr. Vithalrao Vikhe Patil College of Engineering, Ahmednagar.
   d. Nodal officer: DDU-GKY(AICTE) scheme.
   e. Nominated faculty: NISP (AICTE) scheme.
   f. Head of Electrical Department.

Undertaking by the Principal Investigator

To

The Secretary
SERB, New Delhi

Respected Sir,

I, Dr. Laware Ajit Rambhau_ hereby certify that the research proposal titled **Modeling and Control of Non-linear Multivariable System with Delay, Parametric Uncertainty & External Disturbances: An Experimental Validation with Soft Computing Approaches**

submitted for possible funding by SERB, New Delhi is my original idea and has not been copied/taken verbatim from anyone or from any other sources. I further certify that this proposal has been checked for plagiarism through a plagiarism detection tool i.e. **turnitin** approved by the Institute and the contents are original and not copied/taken from any one or many other sources. I am aware of the UGCs Regulations on prevention of Plagiarism i.e. University Grant Commission (Promotion of Academic Integrity and Prevention of Plagiarism in Higher Educational Institutions) Regulation 2018. I also declare that there are no plagiarism charges established or pending against me in the last five years. If the funding agency notices any plagiarism or any other discrepancies in the above proposal of mine, I would abide by whatsoever action taken against me by SERB, as deemed necessary.

29.11.2023

Signature of PI with date

Name / designation

Dr. Laware Ajit Rambhau

Head of Department
Dept. of Electrical Engg.
Dr.V.V.P.College of Engg.
Ahmednagar

Certificate from the Investigator

Project Title: Modeling and Control of Non-linear Multivariable System with Delay, Parametric Uncertainty & External Disturbances: An Experimental Validation with Soft Computing Approaches

It is certified that

1. The same project proposal has not been submitted elsewhere for financial support.

2. We/I undertake that spare time on equipment procured in the project will be made available to other users.

3. We/I agree to submit a certificate from Institutional Bio safety Committee, if the project involves the utilization of genetically engineered organisms. We/I also declare that while conducting experiments, the Bio safety Guidelines of Department of Biotechnology, Department of Health Research, GOI would be followed in to.

4. We/I agree to submit ethical clearance certificate from the concerned ethical committee, if the project involves field trails/experiments/exchange of specimens, human & animal materials etc.

5. The research work proposed in the scheme/project does not in any way duplicate the work already done or being carried out elsewhere on the subject.

6. We/I agree to abide by the terms and conditions of SERB grant.

AR Laware · Dr. Laware Ajit Rambhau

Name and signature of Principal Investigator:
Date: 27/11/2023
Place: Ahmednagar

Head of Department
Dept. of Electrical Engg.
Dr.V.V.P.College of Engg.
Ahmednagar

Name and signature of Co-PI (s) (if any):
Date: 27/11/2023
Place: Ahmednagar

Dr Ramdas Rambhau Nalthar

HOD & Professor
Dept. of Mechanical Engg
Dr. V. V.P. College of Engg
Ahmednagar-414

CEA/Elect/2023/3150 Date 27/11/2023

Endorsement from the Head of the Institution of PI

This is to certify that:

1. Institute welcomes participation of Name: Dr. Laware Ajit Rambhau Designation: Professor as the Principal Investigator and Dr. Navthar Ravindra Rambhau as the Co-Investigator/s for the project titled **Modeling and Control of Non-Linear Multivariable System with Delay, Parametric Uncertainty & External Disturbances: An Experimental Validation with Soft Computing Approaches** and that in the unforeseen event of discontinuance by the Principal Investigator, the Co-Investigator will assume the responsibility of the fruitful completion of the project with the approval of SERB.
2. The PI, Dr. Laware Ajit Rambhau is a permanent or regular employee of this Institution.
3. The project starts from the date on which the Institution receives the grant from SCIENCE & ENGINEERING RESEARCH BOARD (SERB), New Delhi.
4. The investigator will be governed by the rules and regulations of the Institution and will be under administrative control of the Institution for the duration of the project.
5. The grant-in-aid by the SCIENCE & ENGINEERING RESEARCH BOARD (SERB), New Delhi will be used to meet the expenditure on the project and for the period for which the project has been sanctioned as mentioned in the sanction order.
6. No administrative or other liability will be attached to SCIENCE & ENGINEERING RESEARCH BOARD (SERB), New Delhi at the end of the project.
7. The Institution will provide basic infrastructure and other required facilities to the investigator for undertaking the research project.
8. The Institution will take into its books all assets created in the above project and its disposal would be at the discretion of SCIENCE & ENGINEERING RESEARCH BOARD (SERB), New Delhi.
9. The Institution assumes to undertake the financial and other management responsibilities of the project.

Seal of Institution

Date: 27.11.23

Signature

Registrar of University/Head of the Institution

Principal
College of Engineering
Ahmednagar

Contd..2..

NAAC A+ ACCREDITED WITH GRADE
DR. VITHALRAO VIKHE PATIL COLLEGE OF ENGINEERING, AHMEDNAGAR

Endorsement from the Head of the Institution of Co-PI

This is to certify that:

10. Institute welcomes participation of Name (PI): Dr. Laware Ajit Rambhau Institute Name: Dr. Vithalrao Vikhe Patil College of Engineering, Ahmednagar as the Principal Investigator and Name (Co-PI) Dr. Navthar Ravindra Rambhau Designation: Professor as the Co- Investigator/s for the project titled **Modeling and Control of Non-Linear Multivariable System with Delay, Parametric Uncertainty & External Disturbances: An Experimental Validation with Soft Computing Approaches.**

11. The Co-PI, Dr. Navthar Ravindra Rambhau is a permanent or regular employee of this Institution.

12. The Co-PI will be governed by the rules and regulations of the Institution and will be under administrative control of the Institution for the duration of the project.

13. The Institution will provide basic infrastructure and other required facilities to the investigator for undertaking the research project.

14. No administrative or other liability will be attached to SCIENCE & ENGINEERING RESEARCH BOARD (SERB), New Delhi at the end of the project.

Seal of University / Institution

Date: 27.11.23

Signature

Registrar of University/Head of the Institution

Principal
College of Engineering
Ahmednagar

Maharashtra State Board of Secondary and Higher Secondary Education

This is to certify that the withinsigned Adaware

LAWARE AJIT RAMBHAU

DIVISIONAL BOARD	SEAT NO.	CENTRE NO.	SCHOOL NO.	SR. NO. OF CERTIFICATE
PUNE	C093686	0318	12.172	077861

Passed the **SECONDARY SCHOOL CERTIFICATE EXAMINATION** *(10-year Course)*
of MARCH-1992 *in the Grade* DISTINCTION *with subjects shown below :*

CORE SUBJECTS	MARKS OBTAINED / OUT OF	OTHER SUBJECTS	GRADES
MARATHI	79/100	[OPTIONAL SUBJECTS]	
HINDI	79/100	DRAWING & PAINTING	A
ENGLISH	75/100		
MATHEMATICS	132/150	[SCHOOL SUBJECTS]	
SCIENCE	135/150	PHYSICAL EDUCATION	A
SOCIAL SCIENCES	87/100	SCOUTING	A
GRAND TOTAL	587/700	%AGE ON GRAND TOTAL =>	83.85

GRAND TOTAL (IN WORDS)	* FIVE HUNDRED AND EIGHTYSEVEN *
DATE OF BIRTH	01-06-1977

(IN WORDS) (FIRST JUNE NINETEEN HUNDRED SEVENTY SEVEN

12)

HEAD MASTER
Shri. E. K. Ashram Vidyalaya, Malunje BK.
Tal. Sangamner, Dist. Ahmednagar.

Signature of the Head of the School
(School Stamp)

24th June 1992
Pune 411 010

Divisional Secretary

IMPORTANT: No change in this S.S.C. Certificate shall be made except by the authority issuing it. Any infringement of this requirement will result in the cancellation of the certificate in question and may also involve imposition of other appropriate penalty as may be decided by the Board.

NOTES :

(1) The date of birth shown in this certificate is the same as that entered in the candidate's application for admission to the examination.

(2) The Secondary School Certificate is awarded to successful candidates in : **Grade Distinction :** 75% and above.
Grade First : 60% and above & below 75%
Grade Second : 45% and above & below 60%
* Means Grade I given as per regulations.
Grade Pass : To all other successful candidates including the exempted.
# Indicates that the candidate is given the benefit of combined passing in the subjects Mathematics & Science.
Grades shown in Optional and School Subjects are denoted as under :

GRADE	A	B	C	E	H
MARKS OBTAINED	60% & above	45% to 59%	35% to 44%	EXEMPTED	CONCESSION FOR THE PHYSICALLY HANDICAPPED

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