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Optimization Parameters Selection in Beltline Moulding Manufacturing

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Abstract: Optimization is necessary for the control of any manufacturing process to achieve better product quality, high productivity with low cost. The beltline moulding process is difficult task due to its low defects, making the material sensitive to reject. The efficient beltline moulding process involves the optimal selection of operating parameters to maximize the number of production while maintaining the required quality limiting beltline surface damage. In this research, objective is to obtain optimum process parameters which satisfies given limit, minimizes number of defects and maximizes the productivity at the same time. A recently developed optimization algorithm called particle swarm optimization is used to find optimum process parameters. Accordingly, the results indicate that a system where multilayer perceptron is used to model and predict process outputs and particle swarm optimization is used to obtain optimum process parameters can be successfully applied to beltline moulding process through Particle Swarm Optimization (PSO). Results obtained are superior in comparison with Genetic Algorithm (GA) approach.

Key words: Beltline moulding, parameters, Particle Swarm Optimization, Genetic algorithm, material sensitive

INTRODUCTION

Many are the difficulties encountered by companies when choosing to undertake business process analysis on automotive industry in Malaysia and many are the reasons for failure. At the analysis stage when the current processes need to be understood and assessed there are inherent difficulties in capturing their interdependencies in a way that is structured yet representative. One of the key difficulties in the structured representation of business processes is the choice of the level of detail that is appropriate and relevant for the analysis. Among the many tools available to support business process analysis on automotive manufacturing, simulation offers the great advantage of capturing both the dynamic and the statistics aspects of the processes. For instance the frequency of incoming orders the different ways of servicing different types of customers or the dependency of downstream processes on the outcome of upstream ones, can easily be incorporated into a simulation model. The concept of combining Genetic Algorithms (GA) and Particle Swarm Optimization (PSO) simulation is presented in the context of this research. Based on these considerations, conclusions on the current and future role of simulation in business process modelling are presented. Although, different resercher have formalised different definitions of business processes an overview of which may be found by Hlupic *et al*. (2005) there is a general consensus on some common elements: the process itself whether it is referred to as a transformation of input as a work flow or as a set of activities its input and its output, often referred to as value to the customer or business goal (Hlupic *et al*., 2005, 1998).

Particle Swarm Optimization (PSO) is a recently proposed algorithm by Eberhart and Kennedy (1995) motivated by social behaviour of organisms such as bird flocking and fish schooling. PSO algorithm is not only a tool for optimization but also a tool for representing socio cognition of human and artificial agents, based on principles of social psychology. PSO as an optimization tool provides a population-based search procedure in which individuals called particles change their position or state with time. In a PSO system, particles fly around in a multidimensional search space. During flight each particle adjusts its position according to its own experience and according to the experience of a neighbouring particle, making use of the best position encountered by itself and its neighbour. Thus, as in modern gas and memetic algorithms, a PSO system combines local search methods with global search methods, attempting to balance exploration and exploitation.

The PSO algorithm shares similar characteristics to Genetic algorithm, however the manner in which the two algorithms traverse the search space is fundamentally different. Both Genetic algorithms and Particle Swarm Optimizers share common elements:

- Both initialize a population in a similar manner
- Both use an evaluation function to determine how fit (good) a potential solution is
- Both are generational that is both repeat the same set of processes for a predetermined amount of time

Particle Swarm has two primary operators: velocity update and Position update. During each generation each particle is accelerated toward the particles previous best position and the global best position. At each iteration, a new velocity value for each particle is calculated based on its current velocity the distance from its previous best position and the distance from the global best position. The new velocity value is then used to calculate the next position of the particle in the search space. This process is then iterated a set number of times or until a minimum error is achieved.

This study has presented beltline moulding process by using multilayer perceptron modelling and particle swarm optimization. A multilayer perceptron model of beltline moulding was used to determine the optimal number of hidden units to represent the model and particle swarm optimization was used to minimize the Mean Square Error (MSE) between the actual output and the modelled output. Two different test cases illustrated that the combined multilayer perceptron and particle swarm optimization system is capable of generating optimal process parameters and can be used successfully in the parameters selection optimization of beltline moulding. Particle swarm optimization is also proved to be an efficient optimization algorithm. For the test cases, it yielded optimal parameter around 100 iterations which take only a little time with today's computers.

Literature review: PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles.

Each particle keeps track of its coordinates in the problem space which are associated with the best solution (fitness) it has achieved so far. The fitness value is also stored. This value is called pbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the neighbours of the particle. This location is called lbest. When a particle takes all the population as its topological neighbours the best value is a global best and is called gbest.

The particle swarm optimization concept consists of at each time step, changing the velocity of (accelerating) each particle toward its pbest and lbest locations (local version of PSO). Acceleration is weighted by a random term with separate random numbers being generated for acceleration toward pbest and lbest locations. In past several years, PSO has been successfully applied in many research and application areas. It is demonstrated that PSO gets better results in a faster, cheaper way compared with other methods. Another reason that PSO is attractive is that there are few parameters to adjust. One version with slight variations, works well in a wide variety of applications. Particle swarm optimization has been used for approaches that can be used across a wide range of applications as well as for specific applications focused on a specific requirement.

Multilayer perceptron models which are developed for a better understanding of the effects of beltline moulding process and the resultant quality of beltline can be combined with optimization methods in order to determine optimum control parameters for different objectives such as minimizing manufacturing cost or maximizing productivity. Evolutionary computation algorithms such genetic algorithms and particle swarm optimization are usually utilized for optimization of multilayer perceptron based models. Tandon *et al.* (2002) optimized machining parameters in end milling to minimize machining time by combining a feed forward neural network force model with particle swarm optimization.

MATERIALS AND METHODS

Instead of mutation PSO relies on the exchange of information between individuals, called particles of the population, called swarm. In effect, each particle adjusts its trajectory towards its own previous best position and towards the best previous position attained by any member of its neighbourhood (Kennedy, 1998).

The particles evaluate their positions relative to a goal (fitness) at every iteration and particles in a local neighbourhood share memories of their "best" positions then use those memories to adjust their own velocities and thus subsequent positions. The original formula developed by Kennedy and Eberhart was improved by (Shi, 1998) with the introduction of an inertia parameter, w that increases the overall performance of PSO. The best previous position (i.e., the position corresponding to the best function value) of the ith particle is recorded and represented as $P_i = (p_{i1}, p_{i2}, ..., p_{iD})$ and the position change (velocity) of the ith particle is $V_i = (v_{i1}, v_{i2}, ..., v_{iD})$. The particles are manipulated according to the following equations (the superscripts denote the iteration):

$$V_i^{k+1} = \chi\left(\omega V_i^k + c_1 r_{i1}^k \left(P_i^k - X_i^k\right) + c_2 r_{i2}^k \left(P_g^k - X_i^k\right)\right) \quad (1)$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (2)$$

$$i = 1, 2, ..., N$$

Where:

N	=	The size of the population
χ	=	A constriction factor which is used to control and constrict velocities
ω	=	The inertia weight
c_1 and c_2	=	Two positive constants called the cognitive and social parameter, respectively
r_{i1} and r_{i2}	=	Random numbers uniformly distributed within the range 0, 1 equation

Eberhart and Kennedy (1995) is used to determine the ith particle's new velocity at each iteration while Eq. 2 provides the new position of the ith particle, adding its new velocity to its current position. The performance of each particle is measured according to a fitness function which is problem dependent. In optimization problems, the fitness function is usually identical with the objective function under consideration.

The first term on the right hand side of Eq. 1 is the previous velocity of the particle which enables it to fly in search space. The second and third terms are used to change the velocity of the agent according to pbest and gbest. The iterative approach of PSO can be described as follows.

Step 1: Initial position and velocities of agent are generated. The current position of each particle is set as pbest. The pbest with best value is set as gbest and this value is stored. The next position is evaluated for each particle by using Eq. 1 and 2.

Step 2: The objective function value is calculated for new positions of each particle. If a better position is achieved by an agent, the pbest value is replaced by the current value. As in step 1, gbest value is selected among pbest values. If the new gbest value is better than previous gbest value, the gbest value is replaced by the current gbest value and stored.

Step 3: Steps 1 and 2 are repeated until the iteration number reaches a predetermined iteration number. Success of PSO depends on the selection of parameters given in Eq. 1 (Shi *et al*., 1998) studied the effects of parameters and concluded that c1 and c2 can be taken around the value of 2 independent from problem. Weighting function w is usually utilized according to the following equation:

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} x_{iter} \quad (3)$$

Equation 3 decreases the effect of velocity towards the end of search algorithm which confines the search in a small area to find optima accurately. The velocity update step in PSO is stochastic due to random numbers generated which may cause an uncontrolled increase in velocity and therefore instability in search algorithm. In order to prevent this usually a maximum and a minimum allowable velocity is selected and implemented in the algorithm. In practice these velocities are taken as [-4.0, +4.0].

The role of the inertia weight, w is considered important for the PSO's convergence behaviour. The inertia weight is employed to control the impact of the previous history of velocities on the current velocity. Thus, the parameter w regulates the trade-off between the global (wide-ranging) and the local (nearby) exploration abilities of the swarm. A large inertia weight facilitates exploration (searching new areas) while a small one tends to facilitate exploitation, i.e., fine tuning the current search area. A proper value for the inertia weight, w provides balance between the global and local exploration ability of the swarm and thus results in better solutions.

RESULTS AND DISCUSSION

Modelling the data using MLP: This section shows the details of the MLP modelling process of defects models. 43 data points were collected from the experiments. Initially, the dataset consisted 14 variables but parameters cutter and looper were removed because it carries no informational value. Therefore, inputs for the MLP consisted of 12 variables.

For the defects model, the output is the Mean Square Error (MSE) of actual versus modelled defects. MLP uses tangent-sigmoid activation function in the hidden layer and linear activation function in output layer. This combination of activation functions can approximate any function (with a finite number of discontinuities) with arbitrary accuracy, provided that the hidden layer has enough units (Demuth and Beale, 2005).

Regularization was used to avoid over-fitting, since data points are not enough to use Early Stopping method. The MLP weights initialization was performed using the NW algorithm to improve convergence speed. To implement regularization, training was performed using "trainbr". It is important to note that the performance function for the "trainbr" algorithm was the Sum Square Error (SSE) performance function but MSE was used to guide the PSO optimization.

Both input and output data were preprocessed prior to training so that the model is numerically robust and rapidly converge (Norgaard *et al*., 2000). The normalization is transformed so that the mean is removed ($\mu = 0$) and the standard deviation is 1 ($\sigma^2 = 1$). The rescaling is done so that inputs and outputs reside between -1 and 1. This step is important so that the inputs are properly scaled for the transfer function used in the hidden and output layers.

Table 1: MLP structure results for defects

Training SSE	Squared weights	Effective number of parameters
5.617000	74.1111	8.40997
2.922560	22.1726	15.80150
0.335414	56.3065	24.08720
0.347128	43.4658	24.63590
0.295796	37.9359	25.92430
0.273642	40.4999	27.44300
0.275927	39.8439	27.36630
0.275453	43.1597	27.18740
35.20390	163.2850	127.00000
0.277340	41.9922	27.03220
0.280599	38.9334	27.07540
0.274520	42.8866	27.19950

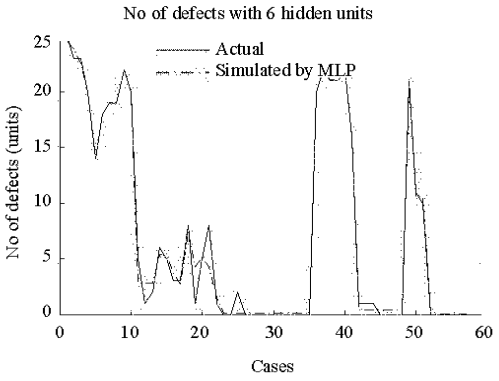

Fig. 1: Modelling results for defects model with 12 variables

The tests were performed to determine the optimal number of hidden units to represent both the defects and "time" models. The results are presented in section 0.

MLP modelling results: This study describes the experiments performed to determine the optimal number of hidden units to represent the model. For this purpose, the number of hidden units is varied from 1-20 and the model was evaluated each time the number of hidden units is changed.

The MLP training was performed for 500 epochs (cycles) while the SSE performance function was used to evaluate the convergence of the MLP each time a hidden unit is added or removed. The optimal hidden layer size was found to be 6 for both defects model. The MLP training results for the defects model is shown in Table 1. The SSE comparisons for different hidden layers and the optimal MLP structures were found. The modelling results for defects are shown in Fig. 1.

Feature selection using Particle Swarm Optimization (PSO): The PSO was used to select the three best inputs to explain the input-output relationship of defects model. A ranking-based system was used to select the best features. Using this system, the value of each particle in the swarm represents the importance of each feature. During optimization, the three best-ranked features were used to train the MLP.

The objective of the PSO is to minimize the MSE fitting error between the actual output and the modelled

Table 2: Summary of results for population size for defects model

Population size	Fitness (MSE)	Features selected		
		Feature 1	Feature 2	Feature 3
5	0.9461	1	11	12
10	0.9587	1	8	11
15	1.0314	1	11	12
20	0.9855	1	6	11

Table 3: Optimization results (defects model)

Particles	Screw	Pulling	Line speed	MSE
5	34.1610	5.6179	5.0299	0.0349
10	28.5224	4.7581	4.9684	0.0649
15	34.6320	4.8848	5.1947	0.0396
20	32.3356	6.2272	5.0496	0.0311

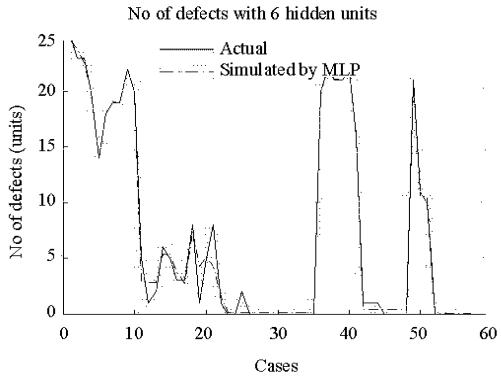

Fig. 2: Best fitting model for defects

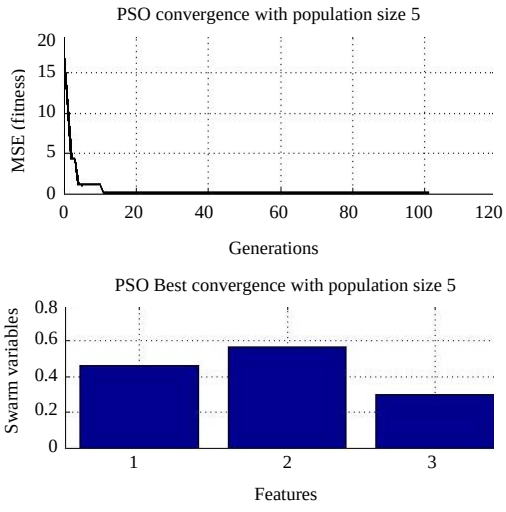

Fig. 3: The defects optimization results using 5 particles

output. If the features are discriminative the generalization error should be small since the MLP approximation is close to the actual output. If the features are not discriminative, the model approximation should be poor (indicated by high MSE values). Three experiments were performed to:

- Determine the swarm (population) size required for PSO to converge
- Determine the best combination of features to minimize production defects
- Determine the best combination of features to minimize the machine adjustment time

The minimum population size required to converge is 5 for defects. Therefore, the population of 10 was chosen to sufficiently model both problems (Table 2 and 3, Fig. 2 and 3).

CONCLUSION

We can conclude for population has 5 individuals convergence from generation number Zero-20 and best fitting on generation number 9 with best fitting value is 6.268. Meanwhile, population has 10 individuals convergence from generation number 13-20 and best fitting on generation number 20 with best fitting value is 1.314.

Furthermore, GA gave improvement when population has 15 individuals convergence from generation number 5-20 and best fitting on generation number 15 and 18 with best fitting value is 1.31. But population has 20 individuals gave the better on best fitting value to 1.309 on generation number 16. The fitting value much better compare to others number of population.

The PSO was used to optimize the input values for the MLP. 6 units were used in the hidden layer. Both the defects and time models were tested. The objective of the PSO is to minimize either the number of defects or the manufacturing time. The fitness is calculated as number of defects or manufacturing time:

- Function defects and time were used as fitness functions
- Both should yield 0 as best values

Since the input should be within certain bounds, any value outside the range of [+1, -1] was clamped during preprocessing. The optimization was performed for 100 generations with 10 particles for each population. Linearly decreasing inertia weight was used to ensure good convergence. The inertia weight starts with 1 and was decreased after each iterating until it reaches zero. The population test for the defects model.

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