DYNAMIC OPTIMIZATION OF WATERING FOR QUALITATIVE IMPROVEMENT OF SATSUMA MANDARIN USING INTELLIGENT CONTROL TECHNIQUES

T. Morimoto, Y. Ouchi*, M.S. Baloch, K. Hatou and Y. Hashimoto

Dept. of Biomechanical Systems, Faculty of Agriculture, Ehime University,
3-5-7 Tarumi, Matsuyama 790-8566, Japan
**Agriculture, Forestry and Fisheries Department, Ehime Prefecture, 4-4-2 Ichiban-cho*
Matsuyama, 790-8570, Japan

Abstract: To improve the quality of Satsuma mandarin during the developing and maturing stages, an optimal watering operation was investigated through identification and optimization using intelligent control techniques. Dynamic changes in the sugar content and the citric acid of Satsuma mandarin, as affected by rainfall and sunshine duration, was first identified using neural networks, and then an optimal operation for watering (rainfall management) that maximizes the sugar content and that minimizes the citric acid of Satsuma mandarin was sought through simulation of the identified neural-network model using genetic algorithms. An optimal solution obtained here was an operation that increases the amount of watering during the first stage and then markedly reduces it during the latter half stage of the maturing stage. From simulation, the maximization of the amount of watering during the first stage resulted in a significant decrease in the citric acid, and the minimization during the latter half stage led to a marked increase in the sugar content. A mulching technique with plastic film and a sprinkling operation allow controlling the amount of rainfall. This operation suggests a better way for supplying the water to Satsuma mandarin and improving the quality.

Keywords: Dynamic optimization, fruit quality, climatic factors, sugar content, citric acid, neural networks, genetic algorithms

1. INTRODUCTION

Mandarin orange, especially Satsuma mandarin, is one of the most important fruits in Japan. Many of the people in Japan like Satsuma mandarin due to its soft texture and sweet taste. Ehime prefecture where our university is located is known as a major source of Satsuma mandarin.

In recent years, however, the production has received large damage by the import of low-cost oranges from other countries. In order to overcome the depression of citrus industry and expand the market in the future, the qualitative improvement of the fruit is highly desired. In this case, it is clear that the physical method (environmental control) is more important than the chemical method (uses of hormone and chemical) in order to improve the quality of the fruit from the viewpoint of food safety.

It is, however, not easy to achieve the qualitative improvement of the fruit by the control of climate factors. Because the physiological responses of the plant are quite complex and uncertain. Non-linearity, time variation, large scale, contaminations of noises and disturbances and son on are typical complexities in the plant control systems.

In recent years, however, many sensors and computers have been rapidly introduced into plant production systems, aiming at their mechanizations and automations. New sensors for measuring plant responses have been also developed. Consequently, many data on climate and plant responses have been stored in the database system. However, there are still some pitfalls, one of which is the severe lack of optimal control techniques for plant production systems.

Intelligent approaches have emerged as promising techniques for dealing well with complex and/or ill-defined processes in biological production processes. An intelligent control technique combining neural networks with genetic algorithms has been developed for realizing the optimization of cultivation and storage processes (Morimoto et al., 1995, 1996, 1997 and 2003). Neural networks are able to identify nonlinear characteristics of a system with their own learning capability (Chen, et al., 1990; Narendra and Parthasarathy, 1990). Elizondo et al. (1994) applied neural networks to make a model which allows to predict the flowering and physiological maturity of soybean from daily maximum and minimum air temperatures, photoperiod, and days after planting. Liu et al. (2001) used neural networks to predict the yield of corn from some fertilizers, rainfall from May to August, planting density and son on. Genetic algorithms have a high ability to search rapidly for a global optimal value of a complex objective function, using a multi-point search procedure involving crossover and mutation (Goldberg, 1989).

The objectives of this study are to identify dynamic changes in the sugar content and citric acid of Satsuma mandarin, as affected by rainfall and sunshine duration and then find an optimal operation of these factors to improve the fruit quality.

2. MATERIALS AND METHODS

*2.1 Plant materials and measuring instrument*s

Satsuma mandarins (*Citrus Unshu* Marcorv.) grown in simple greenhouses at the sloping land in the mountain were used for the experiment. The simple greenhouses are made by vinyl sheets. The reason that we used them is to limit the rainfall and control the water supply to the plants. The time-series of fruit responses such as the sugar content and the citric acid of the fruit were measured as the output variables, and the time-series of climate factors such as rainfall, sunshine duration and air temperature were measured as the input variables every month from July to December (developing and maturing stages of the fruit) over 2002 since 1996. The sugar content and the citric acid of the intact fruit during cultivation were nondestructively measured using a newly developed near-infrared saccharimeter (Kubota, K-BA100). This is a portable typed measuring instrument.

2.2 Optimization problem

In general, the quality of the fruit is determined from many factors such as sugar content, acidity, firmness, and so on. Here, it was supposed that the fruit quality increases with increasing the sugar content and decreasing the citric acid, keeping the sweetness taste of consumers in view. Therefore, the aim for optimization is to maximize the sugar content and minimize the citric acid of Satsuma mandarin at the last time point of the maturing stage.

Let $y_1(k)$ and $y_2(k)$ (k=1, 2, ..., N) be time series of the sugar content and the citric acid of the fruit, respectively. Let $u_1(k)$ and $u_2(k)$ be time series of rainfall and the sunshine duration, respectively. An objective function, F(T), is given by the difference of two factors, values of both the sugar content and the citric acid at their last time points, N, in their dynamic responses obtained from simulation.

$$F(T) = a \times y_1(N) - b \times y_2(N) + c \qquad (1)$$

For realizing optimization, the control process was divided into *l* steps. Therefore, the optimization problem here is to determine the *l*-step set points of the amount of watering and sunshine duration, which maximize the objective function F(T).

$$\text{maximize } F(T) \qquad (2)$$
$$\text{subject to } 50 \le u_1(k) \le 300 \text{ mm},$$
$$50 \le u_2(k) \le 300 \text{ hours}$$

2.3 Identification and optimization techniques

Optimal operations of both the amount of watering (rainfall management) and sunshine duration that maximizes the sugar content and that minimizes the citric acid of Satsuma mandarin were investigated. The procedure is as follows.

(1) Collect many real data (data sets) on the input and output of a system, which are here the time-series of rainfall and sunshine duration as the input variables and the sugar content and the citric acid of the fruit as the output variables, for system identification.
(2) Identify the sugar content and the citric acid of the fruit as affected by rainfall and sunshine duration using neural networks and then make a black-box model for simulation.

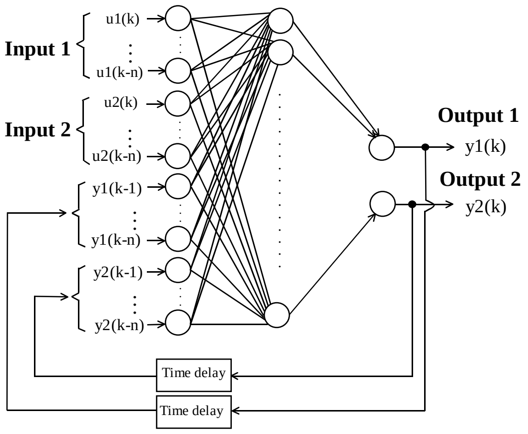

Fig. 1 Structure of a three-layer neural network for dynamic identification

(3) Calculate numerous responses of the sugar content and the citric acid of the fruit as affected by various types of l-step set points of rainfall and sunshine duration, generated by genetic algorithms, using the identified neural-network model (black-box model).

(4) Search for the optimal values (l-step set points of rainfall and sunshine duration) that maximize the objective function (=fitness) effectively from among numerous responses of the sugar content and the citric acid, obtained from simulation, according to the guide of genetic algorithms.

2.4 Neural network for dynamic identification

Neural networks were used for identifying the dynamic responses of the sugar content and the citric acid of the fruit as affected by the sunshine duration and rainfall, and then making a black-box model for simulation. Figure 1 shows a time-delay neural network for dynamic identification. It consists of three layers and has arbitrary feedback loops that produce time histories of the data for dynamic identification. The input variable is rainfall and sunshine duration, and the output variable is the sugar content and the citric acid of the fruit during the developing and maturing stages.

For the learning of the neural network, two (n+1)th historical input data $\{u_1(k), ..., u_1(k-n)\}$ and $\{u_2(k), ..., u_2(k-n)\}$ and two nth historical output data $\{y_1(k-1), ..., y_1(k-n)\}$ and $\{y_2(k-1), ..., y_2(k-n)\}$are applied to the input layer, and two current outputs $y_1(k)$ and $y_2(k)$ are applied to the output layer as training signals (k=0, 1, .., N-n, N: data number) (Chen et al., 1990; Isermann et al., 1997). The learning (training) method is error back-propagation (Rumelhart et al., 1986; Hint, 1992)

The data were divided into two data sets, a training data set and a testing data set. The former is used for training the neural network, and the latter for evaluating the accuracy of the identified model. Here, the system order and the hidden-neuron number of the neural-network were determined based on the cross-validation.

2.4 Genetic algorithm for finding an optimal solution

Genetic algorithms are used for finding the optimal l-step set points of the amount of watering and the sunshine duration that maximizes the sugar content and that minimize the citric acid of the fruit.

Definition of individual. Since an optimal value to be obtained here is the l-step set points of the amount of watering and sunshine duration, an individual can be given by the l-step set points of the amount of watering $\{u_1(1), u_1(2), ... u_1(l)\}$ and $\{u_2(1), u_2(2), ... u_2(l)\}$. They were all coded as 8-bit binary strings.

$$\text{Individual } i = \{u_1(1), u_1(2), ... u_1(l), u_2(1), u_2(2), ... u_2(l)\}$$

Definition of fitness. Fitness is an indicator for measuring an individual's survival quality. All individuals are evaluated in terms of their performances, which are based on their fitness values. During the evolution process, therefore, individuals having higher fitness reproduce, and individuals with lower fitness die in each generation. An individual having the maximum fitness is regarded as an optimal solution. Fitness is similar to the objective function in conventional optimization problems. So, fitness can be represented by Eq. (1)**.**

$$\text{Fitness} = F(T) \qquad (3)$$

Genetic operations. A single crossover was used. Two individuals (e.g., 00000110 and 01011011) are first mated at random. Next, these binary strings are cut at the 4-bit position along the strings and then two new individuals (00001011 and 01010110) are obtained by swapping all binary characters from the 1-bit to the 4-bit position. The mutation inverts one or more components of the binary strings from 0 to 1 or vice versa. Here, a two point mutation was used. One individual (e.g., 10011101) is first selected at random, and then a new individual (00010101) is created by inverting two characters (genes), selected at random, from 0 to 1 or 1 to 0. The mutation operation increases the variability of the population and helps to avoid the possibility of falling into local optima in the evolution process (Krishnakumar and Goldberg, 1992). The number of the mutation depends on the mutation rate. The selection of individuals was carried out based on the elitist strategy by which an individual with maximum fitness is compulsorily remained for next generation. However, the searching performance can easily fall into a local optimum because only the superior individuals with higher fitness are picked in each generation. In this study, therefore, quite different

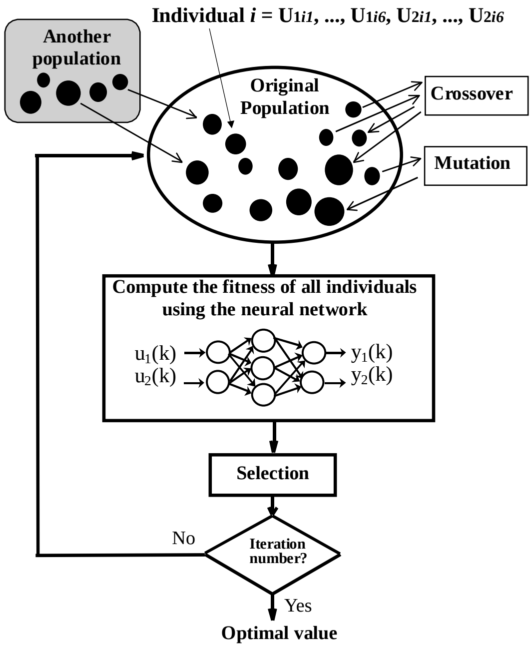

Fig. 2 The flow chart of the genetic algorithms.

individuals (=100) in another population were added into the original population in order to maintain the diversity and obtain a global optimal value.

Figure 2 shows the flow chart of the genetic algorithm. The procedure is as follows:

Step 1: An initial population consisting of several individuals is generated at random.

Step 2: New individuals in another population are added to the original population to maintain the diversity of the original population. Here, the other population is independent of the original population.

Step 3: Crossover and mutation operations are applied to the individuals selected at random.

Step 4: The fitness values of all individuals are calculated using the neural-network model, and their performances are evaluated.

Step 5: Superior individuals are selected and retained for the next generation based on elitist strategy selection.

Step 6: Steps 2 to 5 are repeated until the fitness continues to keep the same minimum value with increasing generation number. An optimal value is given by an individual with minimum fitness.

3. RESULTS AND DISCUSSIONS

3.1 Dynamic changes in the sugar content and the citric acid of the fruit

First, the data for identification were obtained. Figure 3 shows seven types of time course changes in the sugar content and the citric acid of Satsuma

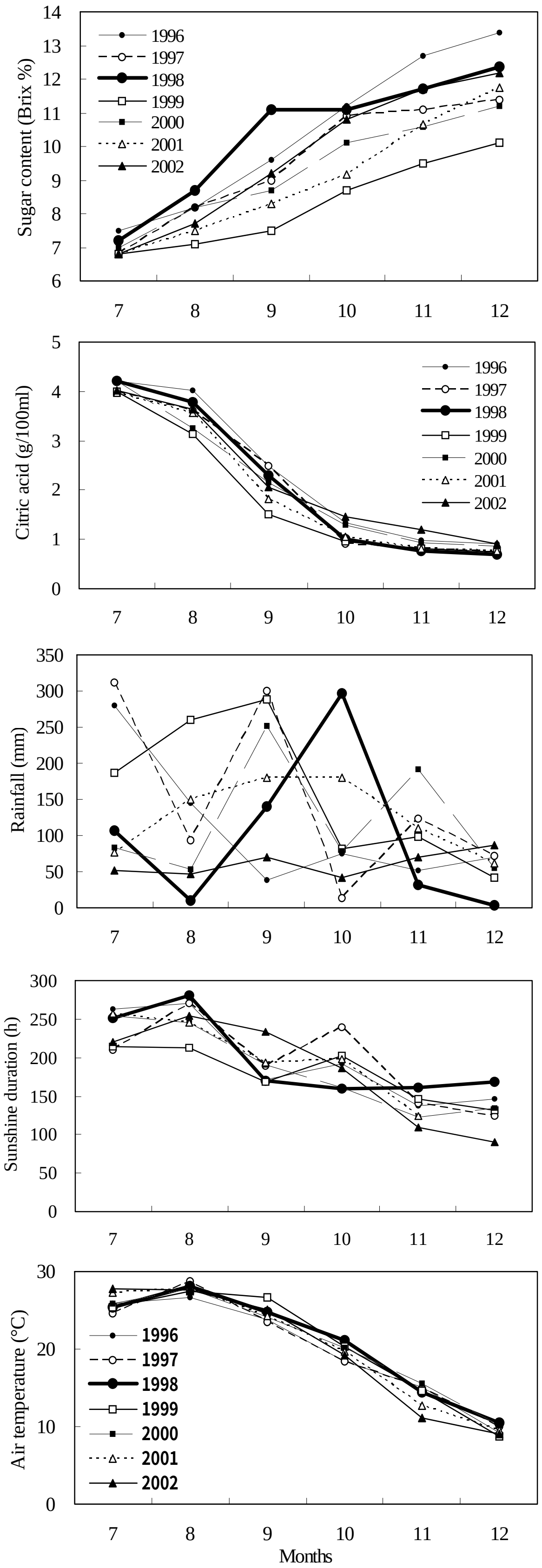

Fig.3 Time course changes in the sugar content and the citric acid of Satsuma mandarin as affected by amount of rainfall, sunshine duration and air temperature, measured from July to December over 2002 since 1996

mandarin as affected by rainfall, sunshine duration and air temperature. They were respectively measured from July to December over 2002 since 1996. The period, from July to December, corresponds to the maturing stage of the fruit.

It is found that the time course changes in the rainfall are quite different each other, while the changes in the air temperature were almost same every year. This means that the differences of the sugar content and the citric acid at the last stage mainly arise from the differences of the time course changes in the rainfall and the sunshine duration. It seems, especially, that the time-course change in the rainfall gives the large effect on the sugar content. In this study, therefore, two climate factors, rainfall and sunshine duration, were selected as input variables for identification. It is found that the sugar content has a tendency to increase with decreasing rainfall.

3.2 Identification of sugar content and citric acid

Next, seven types of data sets on the input and output in Fig.3 were divided into the training data set and the testing data set, and then identified using the neural network shown in Fig.1. Here, six data sets were selected as the training data set, and one data set was chosen as the testing data set.

The model was validated through cross-validation. Based on cross validation, the number of system parameters and the number of hidden-neurons of the neural network were determined to be 3 and 5, respectively. Figure 4 shows the comparison of the estimated responses, calculated from the neural network model, and the observed responses for the sugar content and the citric acid of the fruit. This testing data set is quite different from the training data sets. It was found that the two estimated responses were closely related to their observed responses in both cases. This means that a simulation model could be obtained to predict these two responses in the future. Thus, through identification procedure, a two-input two-output simulation model (black-box model) was built to obtain the responses of the sugar content and the citric acid of the fruit.

3.3 Optimization result

Here, the optimal 6-step set points of rainfall (amount of watering) that maximizes the sugar content and that minimize the citric acid of the fruit was obtained from simulation.

The optimal solution of rainfall was the combination of the maximum and minimum values, {300, 300, 300, 50, 50, 50 mm}. The value of rainfall can be easily converted into the amount of the water supply to oranges. Uses of plastic-film mulching and sprinkling allow to control rainfall. Figure 5 shows

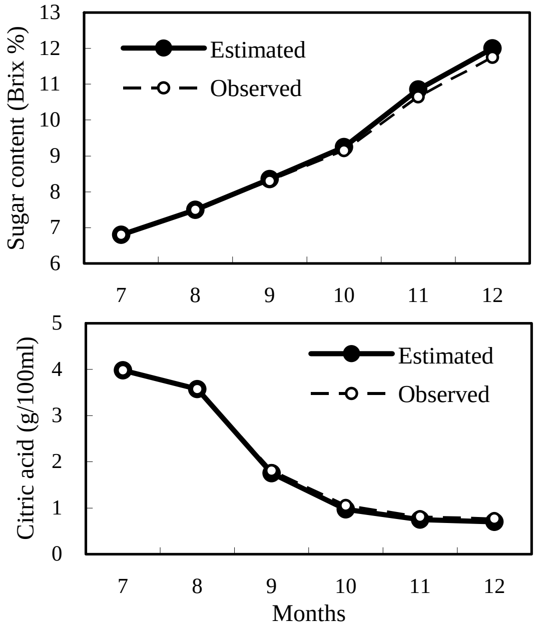

Fig. 4 Comparisons of the estimated responses, calculated from the neural network model, and the observed responses.

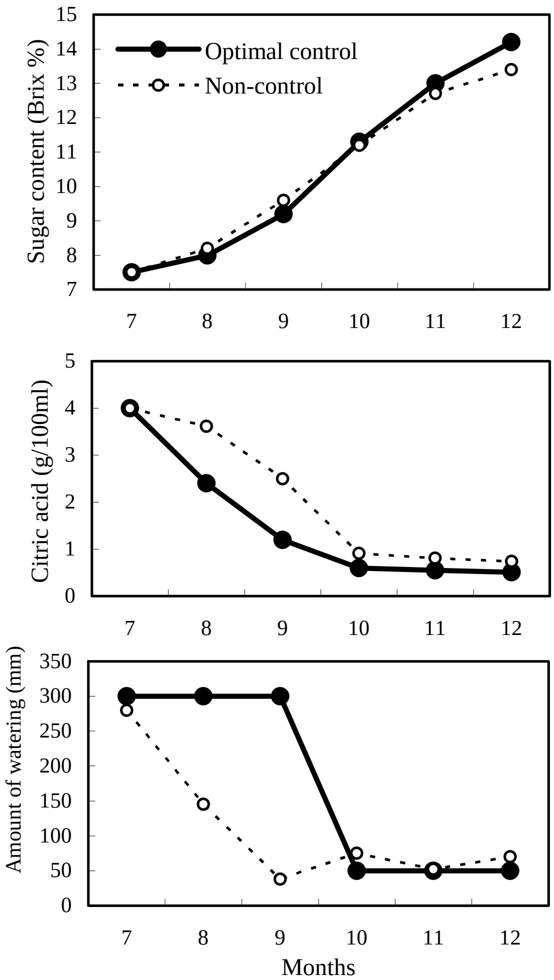

Fig. 5 Optimization results of the sugar content and the citric acid of the fruit by the control of the amount of watering.

the optimal control results of the sugar content and the citric acid of the fruit. Increasing the amount of watering to the maximum value during the first stage significantly reduced the citric acid of the fruit, and lowering it to the minimum value during the latter half stage markedly increased the sugar content. A sprinkling operation allows to increase rainfall during the first stage, and a mulching technique with plastic film sheets permits to decrease rainfall (amount of watering) during the latter half stage. Therefore, the optimal operation obtained here suggests a better way for supplying the water to oranges and then improving the quality of Satsuma mandarin grown at the sloping land.

4. CONCLUSIONS

In this study, the identification and the optimal control of the sugar content and the citric acid of Satsuma mandarin during cultivation were carried out using intelligent approaches such as neural networks and genetic algorithms. On the basis of present findings, it is concluded that a three-layer neural network with time-delay operators was useful to identify the dynamic change in the sugar content and the citric acid of the fruit, as affected by rainfall and sunshine duration. It allows predicting the two responses in the future with high accuracies. An optimal solution obtained here was an operation that increases the amount of the water supply during the first stage and then markedly reduces it during the latter half stage of the maturing stage. Increasing the amount of the water supply to the maximum value during the first stage significantly reduced the citric acid, and lowering it to the minimum value during the latter half stage markedly increased the sugar content. A mulching technique with plastic film sheets allows the amount of rainfall (water supply) to be roughly controlled. This operation suggests a better way for supplying water and improving the quality of Satsuma mandarin.

REFERENCES

Chen, S., Billings, S.A. and Grant, P.M. (1990). Non-linear system identification using neural network. *Int. J. Control*, 51(6),1191-1214.

Elizondo, D.A., McClendon, R.W., Hoogenboom, G. 1994. Neural network models for predicting flowering and physiological maturity of soybean. *Transactions of the ASAE*, 37(3), 981-988.

Goldberg, D.E. 1989. Genetic algorithms in search, optimization and machine learning, Addison-Wesley, Reading, Massachusetts.

Hint, G.E. (1992). How neural networks learn from experience. *Scientific Amer.*, 12: 105-109.

Isermann R., S. Ernst, and O. Nelles. 1997. Identification with dynamic neural. *Preprints of 11th IFAC Symposium on System Identification*. Vol.3: 997-1022, Fukuoka, Japan.

Krishnakumar, K., and D.E. Goldberg. 1992. Control system optimization using genetic algorithms. *Journal of Guidance, Control, and Dynamics*, 15(3), 735-740.

Liu, J., Georing, C.E. and Tian, L. 2001. A neural network for setting target corn yields. *Transactions of the ASAE*, 44(3), 705-713.

Morimoto, T., Torii, T. and Hashimoto, Y. (1995) Optimal control of physiological processes of plants in a green plant factory. *Control Engineering Practice*, 3(4), 505-511.

Morimoto, T., Hatou, K., and Hashimoto, Y. (1996). Intelligent control for plant production system. *Control Engineering Practice*, 4(6): 773-784.

Morimoto, T., Purwanto, W., Suzuki, J. and Hashimoto, Y. (1997). Optimization of heat treatment for fruit during storage using neural networks and genetic algorithms. *Comput. Electron. Agric*., 19, 87-101.

Morimoto, T., Tu, K., Hatou, K. and Hashimoto, Y. (2003). Dynamic optimization using neural networks and genetic algorithms for tomato cool storage to minimize water loss. *Transactions of the ASAE.* 46(4), 1151-1159.

Narendra, K.S., and K. Parthasarathy. 1990. Identification and control of dynamical systems using neural networks. *IEEE Trans. Syst., Man, and Cybern.*, 1(1), 4-27.

Rumelhart, D.E., Hinton, G.E. and Williams, R.J. (1986). Learning representation by back-propagation error. *Nature*, 323(9), 533-536.

.