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Determining and Modeling of Static Friction Coefficient of Some Agricultural Seeds

S. M. Shafaei[1✉], A. R. Heydari[2], A. A. Masoumi[2] and M. Sadeghi[2]

ABSTRACT

An automatic control machine was constructed to measure static friction coefficient (SFC). The machine was assembled from the following main parts: movable structural surface, direct current motor (DCM), infrared wave receiver sensor, infrared wave transmitter sensor, control box, liquid-crystal display (LCD), and protractor unit. The SFC of barley, wheat, chickpea, safflower, rye, soybean, and sunflower seeds were measured on different structural surfaces made of wood, galvanized steel, rubber, glass, and aluminum plate using the machine. To reduce error, trails were carried out in five replications. The measured coefficients were modeled using intelligent models by taking in account the seed and surface type. Results of comparison the SFC values indicated that the surface and seed type had significant effects on the SFC ($P<0.01$). The maximum and minimum value of the SFC were obtained in case of rye seed with wood surface (μ_s=0.762) and barley seed with galvanized steel (μ_s=0.318), respectively ($P<0.01$). According to the coefficient of determination (R^2) and the root mean square error (RMSE) values of modeling, prediction of the SFC of experimental seeds based on the adaptive nero-fuzzy inference system (ANFIS) model was more satisfaction rather than the artificial neural network (ANN) model.

Keywords: Artificial neural network, micro controller, nero-fuzzy inference system, structural surfaces.

Abbreviations: ANN: artificial neural network; MLP: multi-layer perceptron; ANFIS: adaptive nero-fuzzy inference system; FIS: fuzzy inference system; R2: coefficient of determination; RMSE: root mean square error; DCM: direct current motor; SFC: static friction coefficient; LCD: liquid-crystal display; DFC: dynamic friction coefficient.

INTRODUCTION

The economical role of agricultural products and the complication of advanced technologies for production (planting, preserving and harvesting), transporting, storing, processing, keeping, quality evaluation, developing, marketing and consumption are increasing in modern societies. Therefore, an accurate and suitable understanding of the physical properties is important (Ganji et al., 2011).

The agricultural products such as grains, fruits, and vegetables during harvesting, transporting, processing and storing apply friction force on machines and they affect machine process and design.

To design equipment, it is important to know the quantity of these friction forces. The total needed power for material conveying were influenced by the amount of

[1] Department of Biosystems Engineering, College of Agriculture, Shiraz University, Shiraz 71441-65186, Iran.
[2] Department of Mechanics of Biosystems Engineering, Faculty of Agriculture, Isfahan University of Technology, Isfahan 84156-83111, Iran.
✉ smshafaei@shirazu.ac.ir
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this friction force. The friction between the solid particle and conveyor belt is the most important factor to determine the maximum angle between the conveyor belt and horizon line in order to transfer solid materials. The forces that the particles imposed on storage places under static and dynamic conditioned depends on the friction between solid particles and surfaces.

The friction force acts as a resistive force against the relative motion of two contacting solid objects. The friction forces are either static or dynamic. The static friction force is a force which exists between two static (no moving) objects while, the dynamic one is between two moving objects. The SFC determines the required force at beginning of object movement and the DFC limits the force required for movement. It was proofed that the DFC is always less than the SFC.

Previous studies have demonstrated that researchers interested to find the SFC for agricultural products. Yalcin et al. (2007) measured the SFC of pea with different moisture contents on four various surfaces. They found that increasing moisture content of seeds resulted in the increment of the SFC. Dursun et al. (2007) measured the SFC of sugarbeet seed on rubber, wood, galvanized steel, and aluminum surfaces. They reported that the coefficients were 0.687, 0.480, 0.392, and 0.279 for studied surfaces, respectively. Kabas and Yilmaz (2006) measured the SFC of cowpea using rubber, wood, and galvanized steel surfaces as 0.4511, 0.3965 and 0.385, respectively.

The effect of different surface materials such as concrete, plywood, rubber, mild steel, aluminum, stainless steel, and glass on the SFC was also studied by several researchers (Coskoner and Karababa, 2006; Ghasemi Varnamkhasti et al., 2007; Kashaninejad and Rezaghah, 2007; Abano and Amoah, 2011; Tarighi et al., 2011). Taser et al. (2005) informed that measured values of the SFC against hard-wood sheet, galvanized steel, mild steel, chipboard and rubber surfaces were 0.35, 0.36, 0.39, 0.43, and 0.45, respectively for Hungarian vetch seed and were 0.32, 0.34, 0.39, 0.45, and 0.48, respectively for common vetch seed. Other investigators found that the SFC varied for chickpea on three different surfaces from 0.30 on galvanized steel sheet, 0.43 on plywood to 0.45 on glass (Ghadge et al, 2008). Similar results have been reported by researchers for apricot fruits. They found that the SFC varied for apricot fruits on four different surfaces from 0.62 on galvanized steel sheet, 0.51 on wood, 0.55 on fiberglass sheet, to 0.49 on glass (Ahmadi et al., 2008). Frictional properties of granular materials were also determined in the previous researches (Afzalinia and Roberge, 2007; Altuntas and Demirtola, 2007; Ibrahim, 2008; Rusinek and Molenda, 2007; Sharobeem, 2007).

Intelligent prediction methods use information of the obtained data to extract the best correlation between them and apply this relationship for other situations. The ANNs are one of the most important intelligent approaches of modeling. The ANNs save the information of the data as the weight of network during the network training process by inspiration of human brain (Dayhoff, 1990). New approaches based on the FIS replaced the ANN approach as an alternative to specialized knowledge. These approaches are more flexible and accurately estimate unknown values and they have high ability to express outcomes close to the facts (Karatalopoulos, 2000).

The ANFIS combines neural network learning ability with fuzzy inference rules. The fuzzy systems are suitable for representing uncertain knowledge while the ANNs have special architecture that is useful to learn by example. Therefore, the ANFIS apply both the ANN and the FIS benefits. The ANFIS like other intelligent models behaves data in black box form. It means that the ANFIS using the data input and output to adjust your parameters in the training phase to produce outputs for various inputs, similar to the actual values.

The scope of this study was to determine the SFC of some agricultural seeds on different structural surfaces in account of modeling the SFC based on seed and surface type using the ANN and ANFIS model.

MATERIALS AND METHODS

Theoretical background

In the threshold of movement, the minimum force required to move an object is equal to the maximum static friction force that is obtained from equation (1):

$$f = \mu_s \times N \qquad (1)$$

Where (f) is the static friction force, (μ_s) is the SFC and (N) is the perpendicular force on the surface. If the fixed object is set on sloping surface absence of motion (Figure 1), the coefficient can be calculated by the following equation (2):

$$\mu_s = (f/N) = (m\times g\times \sin\theta \,/\, m\times g\times \cos\theta) = \tan\theta \qquad (2)$$

Where (m) is the mass of the object; (g) is the gravity acceleration and (θ_s) is the angle slope.

Machine design

Mechanical parts

To assemble the various designed parts of instrument, the iron chassis was designed as one opened side compartment in rectangular form. Vertical cube that contain the DCM and LCD were mounted on the chassis. One wood plate with ability to change angle was hinged to the chassis from one end and the other end of plate was connected to the electric motor, was located at the highest point of vertical cube by cable. All parts dimensions were designed according to the requires and engineering principles. The places of electrical parts were considered in main appliance frame based on their application.

Electrical parts

The following electrical circuits were designed for the instrument:

1- Power circuit: was designed to provide the required voltage of electrical parts for each operation.

2- The transmitter circuit: this circuit received voltage from the power circuit in order to generate a square wave output with constant rate on infrared wave transmitter sensor. The infrared wave transmitter and receiver sensor were installed on proper place on the movable plate.

3- Receiver circuit: the circuit consisted mainly of an infrared wave sensor. When the connection between the infrared wave receiver and the transmitter sensor is lost, the circuit will be activated to stop the DCM.

4- Control circuit: it consisted of a main microcontroller to coordinate all circuits in the instrument.

5- Goniometer circuit: it products output voltage from zero to five volts linearly proper to angle of movable plate. The voltage is delivered to the microcontroller and then it is converted to the appropriate angle that is visible on the LCD.

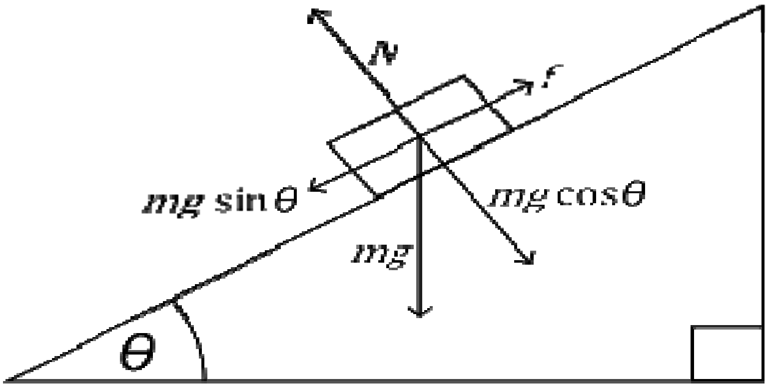

Figure 1. Free body diagram of stillness object setting on the sloping surface

Machine procedure

The machine is ready to use to measure the SFC of desired product using selected surfaces on the movable plate. Seeds were placed on specific location on surface exactly before infrared wave sensors. Infrared wave transmitter and receiver sensor were placed in the opposite side of seeds on the movable plate. The normal connection was established between them. When the machine starts to move, the DCM pulls the plate. The result of this action is plate angle increment. In account of reading angle in the exact form by goniometer part, the slow DCM was used (5 rpm). With increasing plate angle, in the moment of seed moving, connection between infrared wave transmitter and receiver sensor was lost and control unit stop the DCM as the same time. Consequently, the LCD shows the plate angle (±1°). Whole parts of machine can be seen in Figure (2).

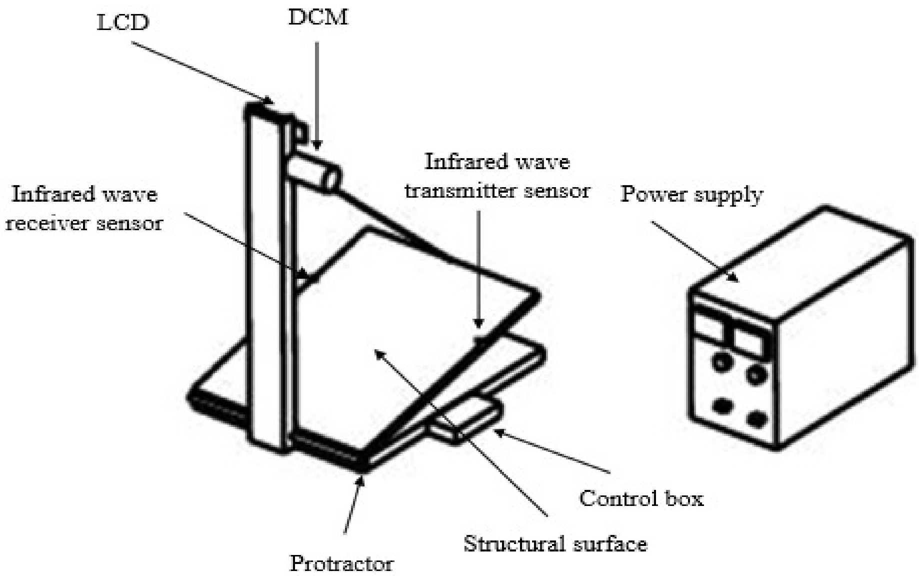

Figure 2. Constructed machine schema

Sample preparation

Seven cultivars, namely 'Fajr', 'Tajan', 'Chico', 'Tomjic', 'Rosen', 'Sahar' and 'Euroflor' were used in the experiments for barley, wheat, chickpea, safflower, rye, soybean and sunflower seed, respectively. The cultivars were supplied from Isfahan Agricultural Research Institute. The seeds were cleaned by hands to eliminate foreign materials such as stones, dirt, broken seeds and foreign grains. The moisture content of seeds was determined by the standard oven drying method at 105±1°C for 24 h (Suthar and Das, 1996). The moisture content values of the varieties were less than 10% on a dry weight basis and they were not significantly different (*P>0.01*). In order to create more contact between seeds and structural surface in the test, seeds were randomly stuck to the sample box as formed with square weightless cardboard.

Frictional trails

The angles of external friction were determined with the use of a constructed machine (Figure 2). Seeds were placed on a horizontally inclined plate with desired surface that hinged to the frame, the motor was activated, and the angle of inclination of the adjustable arm and the friction plate was increased until seed box tends to move. When connection between infrared wave transmitter and receiver sensor was destroyed by the seed box, the DCM was stopped and the angle was seen in the LCD. The SFC for every analyzed friction surface was determined using equation (2). To reduce error, the experiments were conducted in five replications in each case of wood, galvanized steel, rubber, glass, and aluminum plate for studied seeds.

Statistical analysis

The measured data were analyzed using a randomized complete factorial test to study the effect of seed type and different structural surfaces on the SFC. The two factors had five measurements per experimental unit. A total of 175 measurements were taken for seeds. The obtained data were subjected to analysis of variance (ANOVA) to detect treatment effects and linear regression analysis.

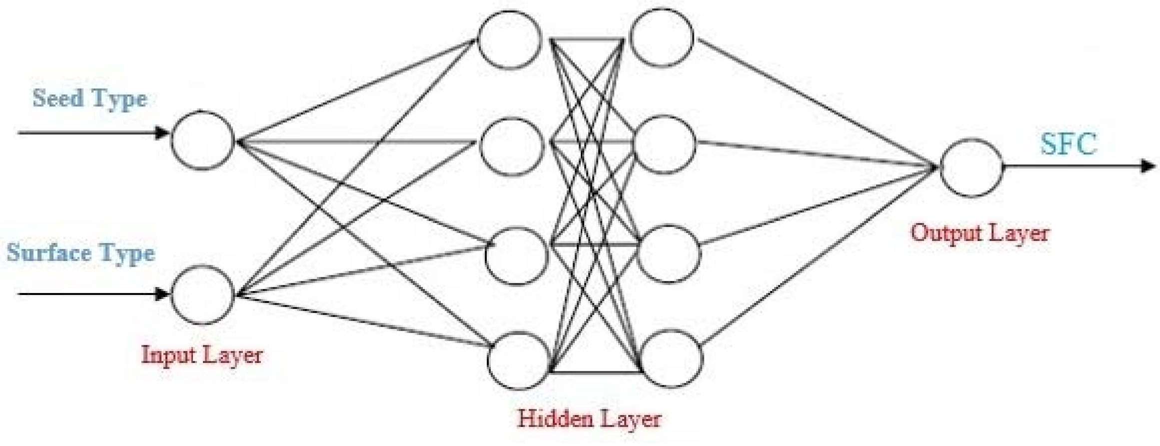

Figure 3. Schema of designed ANN

Intelligent model development

The ANN model

The MLP method via three layers of neurons was used in order to design the ANN model. The first layer was the input layer for seed and structural surface type, the second layer was the hidden one and the third one was the output layer for the SFC as the target variable. Seventy percent of obtained data from frictional trails were used for training, 15% for evaluating, and 15% for testing the designed ANN model. The composite parameters such as type of learning cycles, number of the hidden layers and neurons, and the learning algorithm were defined during the ANN learning by trying and testing method in order to increase the model precision and prevent data over fitting (Fletcher, 1987).

In account of large number of algorithms and training functions to train, evaluation and test the ANN, the non-linear algorithms with reduced slope, coupled slope, Broyden- Fletcher- Goldfarb- Shanno, radial basis function technic and trigonometric, logarithmic, linear, logical Gaussian functions were applied using MATLAB software. Schema architecture of the ANNs can be observed in Figure (3). To evaluate the model, two parameters (R^2 and RMSE) were determined based on equations (3) and (4), respectively (Garcia-Pascual et al., 2006; Giner and Mascheroni, 2002).

$$R^2 = \frac{\sum_{i=1}^{N}(SFC_{exp,i} - SFC_{expave})^2 - \sum_{i=1}^{N}(SFC_{exp,i} - SFC_{pre,i})^2}{\sum_{i=1}^{N}(SFC_{exp,i} - SFC_{exp\,ave})^2} \quad (3)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(SFC_{pre,i} - SFC_{exp,i})^2\right]^{1/2} \quad (4)$$

Where, $SFC_{exp,i}$ is the ith experimentally observed SFC, $SFC_{pre,i}$ is the ith predicted SFC, $SFC_{exp\ ave}$ is average of observed SFC and N is the number of data.

The ANFIS model

The Sugeno method in five layers was hired in order to design the ANFIS model. The first layer was the input layer for seed and structural surface type; the second layer was the input member functions; the third one was the rules layer; the fourth one was output member functions; and the last one was output layer for the SFC as the target variable. Similar to the ANN model, 70% of the obtained data from frictional trails were used for training, 15% for evaluating, and 15% for testing the designed ANFIS model. Schema architecture of the ANFIS model was shown in Figure (4).

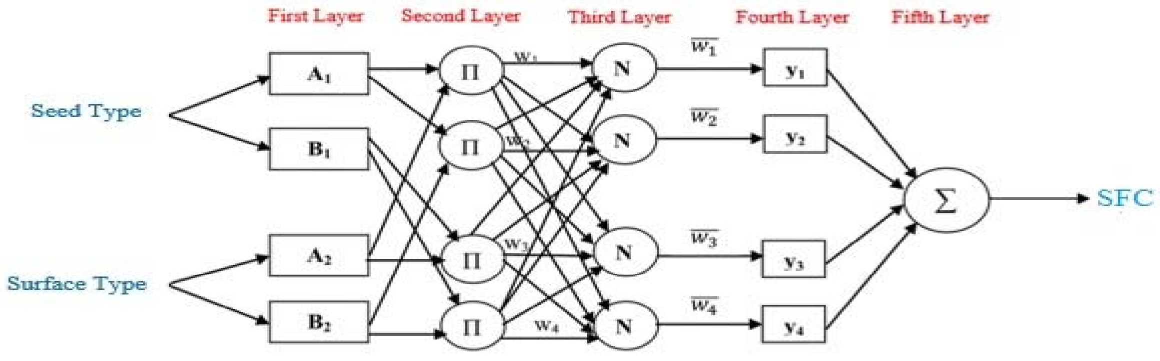

Figure 4. Schema of designed ANFIS

To design the ANFIS model, hybrid learning algorithm was applied to determine member function parameters in Sugeno approach. To learning model, the combination of a least squares method and the back-propagation with descended slope were used. In the other words, to obtain best structure of model, different models with Pi-shaped, triangular, trapezium, generalized bell-shaped, Gaussian, Gaussian combination, two sigmoids, product of two sigmoids, constant and liner member function for input and output function were test. To evaluate the model, R^2 and RMSE values were employed based on equations (3) and (4), respectively.

Table 1. Variance of analysis for the SFC of seed and surface type

Source of Variation	Degree of Freedom	Sum of Squares	Mean Squares	F value
Seed	6	0.015	0.003	0.065**
surface	4	0.009	0.002	0.043**
Seed×Surface	24	0.044	0.002	0.043**
Error	140	6.435	0.046	
Total	174	6.503		

**Significant at less than 1% probability level

RESULTS AND DISCUSSION

Measured values of SFC

The results of structural surface and seed type effect on the SFC were reported in Table (1). Structural surface and seed type significantly affected the SFC (*P<0.01*). Maximum and minimum value of the SFC were obtained in case of rye seed with wood surface (μ_s=0.762) and barley seed with galvanized steel (μ_s=0.318), respectively (*P<0.01*). All measured values of the SFC were shown in Table (2). The variations in values of the SFC of wheat and barley seeds on a galvanized steel surface are similar to the range of values given by Boac et al. (2010). In case of seed and surface type effect on the SFC for agricultural product, similar results were found by Ozarslan (2002), Singh and Goswami (1996), Carman (1996) and Yalcın and Ozarslan (2004) for cotton, cumin, lentil and vetch seeds, respectively. The trend observed was in agreement with the studies made for sorghum (Mahapatra et al., 2002), chickpea seeds (Konak et al., 2002), and okra seeds (Sahoo and Srivastava, 2002).

Table 2. The SFC values for different seeds and contact surfaces

Seed Type	Contact Surface				
	Wood	Galvanized Steel	Rubber	Glass	Aluminum
Barley	0.326±0.003	0.318±0.013	0.511±0.004	0.415±0.011	0.545±0.014
Wheat	0.561±0.007	0.389±0.002	0.571±0.010	0.326±0.010	0.487±0.002
Chickpea	0.592±0.002	0.382±0.001	0.481±0.011	0.497±0.001	0.322±0.003
Safflower	0.611±0.005	0.556±0.009	0.486±0.007	0.385±0.002	0.489±0.010
Rye	0.762±0.010	0.545±0.004	0.482±0.002	0.556±0.007	0.455±0.008
Soybean	0.395±0.008	0.324±0.005	0.458±0.003	0.546±0.011	0.356±0.005
Sunflower	0.458±0.002	0.548±0.011	0.451±0.009	0.456±0.010	0.378±0.005

The ANN model performance

Predicted values against measured values of the SFC that depict predicting precision were shown in Figure (5) for the appropriate ANN model based on the MLP method. Results of the ANN modeling indicated that, the ANN precision in estimating the SFC was not acceptable. The proper ANN model to describe the SFC was achieved with R^2 = 0.601 and RMSE = 0.00112 in the test stage and 13 neurons in hidden layer via exponential and Sine function in hidden and output layer, respectively (Table 3). The maximum and minimum error of predicting the SFC were found for soybean seeds on glass surface (0.263) and 0.094 in case of rye seeds with wood surface, respectively. Table (3) reported five appropriate eminent network structures of the developed ANNs to predict the SFC of studied seeds associated with R^2 and RMSE in the three development stages. Although some researchers reported that the MLP approach of the ANN model was suitable method in agricultural engineering modeling (Kashaninejad et al., 2009; Aghajani et al., 2012; Kashiri et al., 2012; Dayhoff, 1990) but, in this study it was discovered that the model had no satisfaction prediction. This might due to the low number of input data or irregular changes trend of data.

Table 3. The ANN model structures to predict the SFC of experimental seeds

Network structure	R^2			RMSE			Function	
	Training	Evaluation	Test	Training	Evaluation	Test	Hidden layer	Output layer
2-13-1	0.578	0.466	0.601	0.00361	0.00404	0.00112	Exponential	Sine
2-15-1	0.433	0.473	0.553	0.00526	0.00874	0.00211	Identity	Exponential
2-21-1	0.412	0.597	0.512	0.00520	0.00262	0.00388	Exponential	Logistic
2-25-1	0.551	0.494	0.542	0.00501	0.00244	0.00246	Exponential	Sine
2-29-1	0.585	0.465	0.455	0.00362	0.00246	0.00314	Logistic	Identity

Table 4. The ANFIS model structures to predict the SFC of experimental seeds

Used technicin structure	R^2			RMSE			Member function	
	Training	Evaluation	Test	Training	Evaluation	Test	Input layer	Output layer
Sub. clustering	0.989	0.985	0.999	0.00046	0.00064	0.00008	Triangular	Linear
Sub. clustering	0.986	0.945	0.988	0.00058	0.00091	0.00011	Trapezium	Constant
Sub. clustering	0.972	0.997	0.982	0.00052	0.00062	0.00088	Gaussian	Linear
Grid partition	0.991	0.994	0.962	0.00058	0.00044	0.00046	Pi-Shaped	Linear
Grid partition	0.985	0.965	0.944	0.00062	0.00046	0.00014	Gaussian	Constant

The ANFIS model operation

Modeled values versus observed values of the SFC that showed predicting precision were shown in Figure (6) for the five top ANFIS models based on Sugeno method. Results of the ANFIS modeling indicated that it has an acceptance precision to estimate the SFC of samples. According to Table (4), the best ANFIS model to describe the SFC was achieved with R^2 = 0.999 and RMSE = 0.00008 in test stage and 12 rules in hidden layer via triangular and linear member function in input and output layer, respectively. The maximum and minimum error of predicting the SFC were found that in account of rye seeds in aluminum surface (0.011) and 0.002 in case of wheat seeds with rubber surface, respectively. Five appropriate eminent structures of the ANFIS model to predict the SFC of studied seeds supplemented with R^2 and RMSE in the three development stages were reported in Table (4). Used structure of the ANFIS model was depicted in Figure (6). The ANFIS model was commonly used for non-uniformity data, especially when there was no understanding of the physical relations and fundamental about system (Jang, 1993). Some researchers employed the ANFIS model to predict some engineering parameters related to agricultural sciences (Nasiri et al., 2013; Ganjeh et al., 2013; Dastorani et al., 2011)

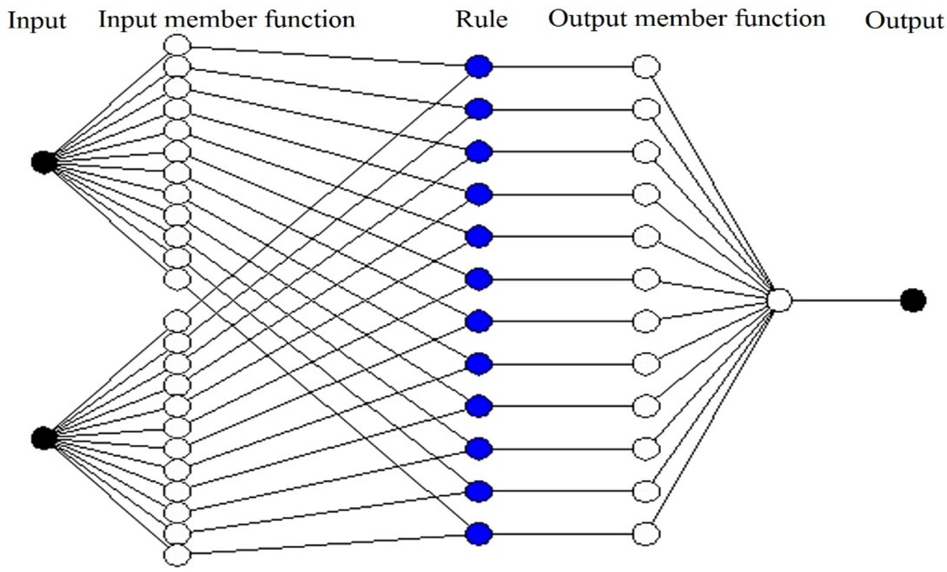

Figure 5. Appropriate structure of the ANFIS model for predicting the SFC of experimental seeds

Comparison between the ANN and ANFIS model in predicting the SFC

The predicted SFC with the ANN model based on the MLP and ANFIS model according to Sugeno was compared to the observed SFC in Figures (5) and (6), respectively. In these figures, the regression lines represented 0.548 and 0.991 measured data for the ANN and ANFIS model, respectively. Comparison of the RMSE of the models indicated that the ANFIS model (RMSE = 0.00039) had less error than the ANN model (RMSE = 0.00292). These results demonstrated that the agreement is very good in the ANFIS model and this model tracks the observed SFC well throughout the considerable conditions. Therefore, the suitable model to describe the SFC of seeds was found to be the ANFIS. Other researchers reported that the ANFIS model was more suitable than the ANN model in agricultural engineering modeling (Dastorani et al., 2011; Ahmadzadeh Gharah Gwizl et al., 2010).

CONCLUSIONS

An automatic development machine was constructed in the present study operated satisfactorily and it can be used in other studies. The results indicated that the seed type and structural surface significantly affected the SFC. The lowest (0.318) and the highest (0.762) values of the SFC were obtained for the rye with wood surface and barley with galvanized steel, respectively. The results also indicated that the ANFIS model was the eminent model to describe the SFC of studied seeds.

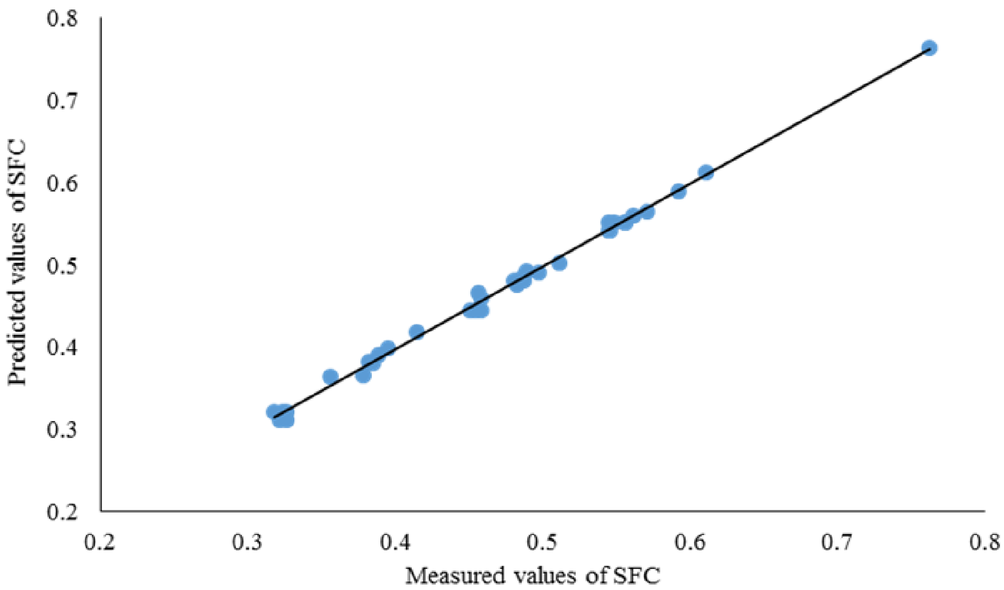

Figure 6. Comparison between measured and predicted values of the SFC by the appropriate ANFIS model

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تحديد ونمذجة ثابت معامل الاحتكاك من بعض البذور الزراعية

شافعي[1]✉، حيدري[2]، ماسومي[2]، صادقي[2]

ملخص

تم صناعة آلة التحكم الآلي لقياس معامل الاحتكاك الساكن(SFC) ، حيث تم تجميع الجهاز من الأجزاء الرئيسية التالية: سطح هيكلي متحرك ، ماتور تيار مباشر(DCM) ، جهاز استشعار لاستقبال الأشعة تحت الحمراء، وجهاز استشعار لارسال امواج الأشعة تحت الحمراء ، صندوق عنصر التحكم، وعرض الكريستال السائل(LCD) ، ووحدة متنقلة. تم قياس(SFC) معامل الاحتكاك الساكن ل الشعير والقمح والحمص، الكركم، الجاودار، فول الصويا، وبذور عباد الشمس على أسطح هيكلية مختلفة مصنوعة من الخشب والفولاذ المجلفن والمطاط والزجاج والواح الألمنيوم باستخدام الجهاز. للحد من الخطأ، تم تنفيذ محاولات في خمسة مكررات. المعاملات التي تم قياسها تم عملها باستخدام نماذج ذكية عن طريق أخذ في الاعتبار نوع البذور سطحها. نتائج مقارنة قيم معامل الاحتكاك الساكن (SFC) أشارت إلى أن سطح ونوع البذور لها تأثيرات مهمة ومعنوية على معامل الاحتكاك الساكن (SF), ($P < 0.01$) . تم الحصول على الحد الأقصى والحد الأدنى لقيمةSFC معامل الاحتكاك الساكن في حالة بذور الجاودار مع سطح الخشب (ميكرو ثانية μ_s = 0.762) وبذور الشعير مع الفولاذ المجلفن (ميكرو ثانيةμ_s = 0.318)، على التوالي($P < 0.05$)، وفقا لمعامل التحديد (R^2) وجذر الوسط الحسابي لقيمة مربع الخطأ (RMSE) في النموذج، كان التنبؤ لمعامل الاحتكاك الساكن SFC للبذور التجريبية القائمة على التكيف مع نموذج نظام الاستدلال- nero-fuzzy , (ANFIS) اكثر راحه من نموذج الشبكة الاصطناعية (ANN) .

الكلمات الدالة: الشبكة الاصطناعية المتعادلة، التحكم المصغر، نظام الاستدلال- nero-fuzzy، الأسطح الهيكلية.

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[1] كلية الزراعة، جامعة شيراز، ايران.

✉ smshafaei@shirazu.ac.ir

[2] كلية الزراعة، جامعة أصفهان، ايران.

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