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Design and Modeling of Gripper and Cutting Tool System for Sweet Pepper Harvesting Robot Hand

Shivaji BACHCHE[1], [a], Koichi OKA[1], [b], Hideto SAKAMOTO[1], [c]

This paper presents a new design and modeling fundamentals of gripper and cutting system for 5 degree of freedom robotic arm, designed to harvest sweet peppers in horticultural green house. The design consists of two parallel jaws mounted on gears and operated with the help of servo motor. The same servo motor was used to operate the cutting system which was composed of scissors. The complete system was designed to operate by using one servo motor only. The system model was developed in solidworks and tested for different kinematic and dynamic performances. The performance of gripper and cutting tool system has been evaluated through simulation to determine the parameters to design the practical prototype. Based on the design concept, the practical prototype of the gripper and cutting system was developed by considering the results obtained by model developed in solidworks. The developed prototype was tested to verify the feasibility and reliability of the model developed in solidworks.

Keywords: Gripper, cutting tool, gripper model, sweet pepper harvesting robot, gripper simulation

1. Introduction

The development in technology leads to wide applications of industrial robots in a large number of areas such as assembly, material handling and machine tending, packing, picking, palletizing, gluing and sealing, arc welding, spot welding, painting and coating, foundry applications and water jet cutting. Fruit harvesting is one of the important application in green house horticulture that helps to save the labor cost and input harvesting energy consumption. Robot gripper is the main functional part of robot arm that helps to grasp the fruit and then cut accordingly. It can also be used for pick and place, packing or welding operations. In agricultural harvesting many researchers are engaged to design robotic devices for efficient and delicate agricultural product picking and handling. The agricultural production rates are significantly influenced by utilization of robots and tools and techniques developed for decision support system [1]. The brief review of different types of the fruit harvesting robots and grippers is given by *Y. Sarig* [2] and *A. K. El-Kalay and et al.* [3].

To avoid the physical damage to fruits, manual harvesting is preferred which significantly increases the total cost of fruit production. For the efficient mechanical harvesting, the most important part is to design the proper gripper that can handle soft, delicate objects like fruits, with respect to their various shapes and sizes. The mechanism based on cutting device attached to a tubular arm for picking soft fruits were designed by *Harrell and et al.* [4] which consists of a rotating lip that detaches the fruit already enclosed in the tube; the fruit then rolls down the tube to a container. The use of vacuum grippers in delicate fruit harvesting that avoids high air pressure and physical damage to fruit was tested by *Sarig and et al.* [5], *Hayashi and et al.* [6] and *Monta and et al.* [7] with the help of vacuum technology. This type of grippers shows good results for picking tightly clustered fruits. At the same time, for vacuum grippers, small leakage in the system leads to failure of operation and higher construction and operating cost results in expensive system. In addition with suction cup and gripper, *van Henten et al.*[8] reported use of thermal cutting tool for cucumber harvesting in which cutting was performed by a thermal cutting technique. Though this thermal cutting operation has several advantages over bacterial transfer, it needs precise system control.

Thus, by considering the need of simple and economical gripper, this research was carried out. Sweet pepper is the 4th most important fruit vegetable in Japan grown on approximately 357 hector area of land which needs not only high man power but also high input energy consumption during harvesting operation leading to increase in labor cost and production cost [9]. On the other hand, as both, sweet pepper and leaves has almost same color and due to that it is very difficult to recognize them separately during automatic harvesting. Hence, by considering these issues, a sweet pepper was selected for the study. *Kitamura and Oka* [10] developed sweet pepper picking robot in greenhouse to resolve these issues. This paper presents the further development in sweet pepper gripping and cutting system of old robotic arm. The old model was able to pick and cut sweet peppers by using two different servo motors for gripping and cutting but in proposed design, both operations intended to perform by using only single servo motor. This paper also focuses on modeling of the prototype with various design parameters and different aspects of kinematic and dynamic performances.

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2. Concept of Harvesting Robot

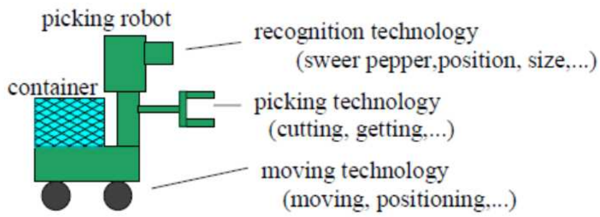

Fig. 1. Concept of sweet pepper harvesting robot.

Figure 1 shows the overview of the concept of sweet pepper harvesting robot. The harvesting robot is composed of three main units; first unit refers to recognition system in which identification and location of the fruit confirmed, second unit refers to picking system in which grasping of fruit and then cutting operation performed; and third unit refers to moving system in which the programmed base sub-unit of the robot moves in the furrows during harvesting operation in greenhouse. In the recognition system, CCD cameras are used to capture the images; binarization of HIS color specification system is used to recognize the fruits and Halcon software utilized for real time image processing. The moving base system includes crawling tracks and wheels controlled by line tracing program and carries the robot arm manipulator on it.

3. Design of New Gripping and Cutting Tool

3.1 System Design

The mechanical system to which this paper represents is a picking system which composed of two parts; the first part is aimed at grasping the sweet pepper and the second part is aimed at cutting the stem of sweet pepper from plant. These both parts have been specifically designed with the purpose of imitating the manual operations by labors.

Figure 2 shows the concept of the new gripping and cutting tool designed to harvest the sweet peppers. In this system, two same size gears and one small size gear was utilized. The same size gears were meshed and installed on supporting plate and power was provided to one of the gear through servo motor. Further, the small gear was meshed with one of the gear installed previously and a circular disc was attached to the top of small gear axis. A sharp scissor was installed on the circular disc by means of link mechanism so that it can operate through the power provided by servo motor at base shaft.

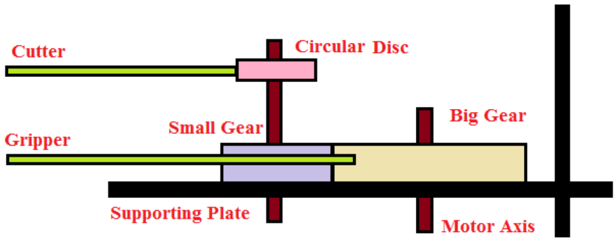

Fig. 2. Concept of picking tool.

The gripper was connected to the big gears of same size and cutter was attached on circular disc. The care was taken that the gripper links should not interfere with small gear rotation. The gripper made from small aluminum plates with internal sponge coating to avoid any physical damage to the sweet pepper and scissor was used as a cutting tool.

3.2 System Operating Mechanism

The rotating power from the servo motor was transferred to the big size gears and then to small gear. The circular disc installed on the axis of small gear rotates with the same speed of small gear while gripper connected to the big gears rotates with the same speed of big gear. The purpose behind using different size gears was to obtain the speed variation in the harvesting operation; that means the gripping speed was slower than the cutting speed but both gripping and cutting operations should perform simultaneously. This offers good advantage of holding the sweet pepper slightly earlier than cutting the stem.

The gripping system and cutting system were controlled by *Kondo KRS 6003 HV* servo motor through computer and whole system was programmed to operate accordingly. The opening- closing of gripper and scissor was controlled by program and developed in VB C++.

When servo motor rotates, the power from motor shaft was transferred to the big gears which also rotate the gripper. At the same time, small gear meshed with one of the big gear rotate the circular disc installed at other end of axis. Further, the scissor attached to the circular disc starts operating with rotation of disc which can be seen in figure 3. Due to variation in size of holding area and cutting area, these big gears and small gears offers speed variation that helps to hold and cut sweet pepper at the same time.

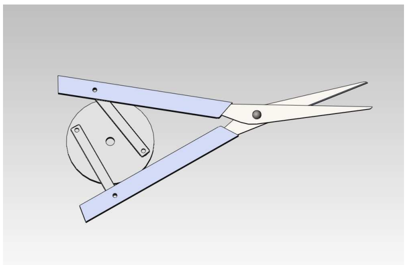

Fig. 3. Attached scissor on circular disc.

3.3 Speed Control of the System

Figure 4 represents the detailed block diagram of the control system used to operate and control the gripping and cutting system in which program was written in *VB C++* to interface between servo motor and computer. The servo controlled *KCB-1* was used to control the Kondo servo motor. The motor rotates by 270^0 without restriction and the program was used to control the rotation of the motor in two patterns, first pattern rotates motor by 173.5^0 in slow speed while second pattern rotates motor up to 202.5^0 in fast speed. The first pattern assists in gripping with slow speed while second pattern facilitates cutting with high speed. Therefore, for complete and successful gripping and cutting of the sweet pepper, motor was programmed to rotate by 202.5^0 with two speed variations.

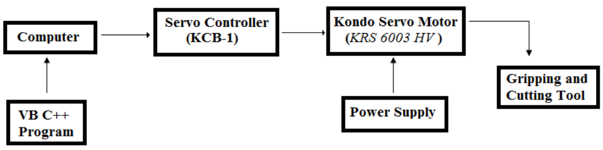

Fig. 4. Block diagram of speed control of the system.

4. Modeling of New Gripping and Cutting Tool

The designed gripping and cutting system was simulated and validated in *SolidWorks 2011* to observe the system behavior with real parameter environment and to test the system against different kinematic and dynamic performances. The modeling of the system provides all the optimal parameters which were used to build the prototype and improve the system performance. Figure 5 shows different views of the gripping and cutting system model developed in *SolidWorks*.

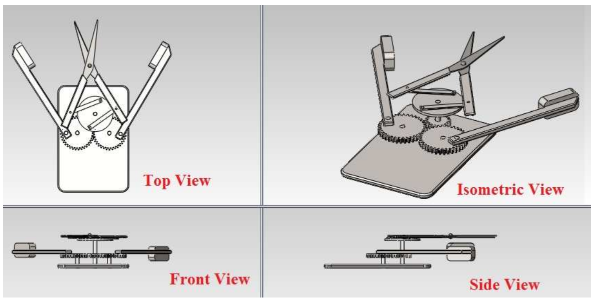

Fig. 5. Gripping and cutting model developed in *SolidWorks* with different views.

The gripping and cutting model developed in software was tested by means of high quality solid mesh with 4 point Jacobian having 1.06 mm tolerance and total 16626 nodes. After successful meshing of the model, it was tested against stress, strain, factor of safety, displacement of the components in model and fatigue properties of the model.

5. Experimental Device and Experiments

Based on the results obtained from model, the gripping and cutting prototype was constructed. Figure 6 illustrates built prototype with set of components used in model.

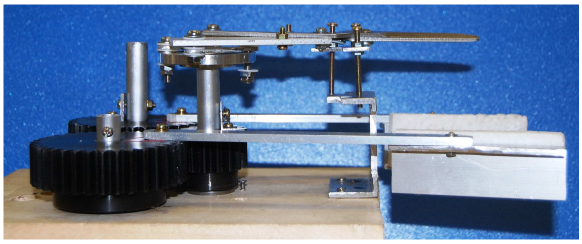

Fig. 6. Experimental prototype.

The plain carbon gears; two of module 2.5 with 36 teeth and one of same module and 18 teeth were used to drive the system. A 50 mm circular disc was installed on the top of small gear shaft along with scissor as shown in figure 3. Further, Table 1 represents the characteristics and properties of the experimental prototype.

Table 1 Details of experimental prototype.

	Property	Value
Gripper	Degree of Freedom	1 / 2
	Grasp type	Compliant, parallel grasp, force closure
	Maximum opening	150 mm
	Grasping force	1.603 N
	Grasping surface	80 X 45 mm
Cutter	Cutting type	Slicing horizontal cut, force closure
	Maximum opening	45 mm
	Cutting tool	Scissor
Motor		DC servo, brushless, 5W
Torque	Motor torque	6.57 N-m
	Required torque	1.32 N-m
Gears	Plain carbon (2)	2.5M 36T 20PA 10FW 10NSD
	Plain carbon (1)	2.5M 18T 20PA 10FW 10NSD
	Average time to grasp and cut	1.10 sec

The performance of the developed experimental device was tested by means of adopting the device to grasp and cut the sweet peppers. For the experiments, four different patterns were selected as;

1. Sweet pepper without leaves
2. Sweet peppers with leaves
3. Partially overlapping sweet peppers
4. Overlapping sweet peppers with leaves

These four conditions were used during the experiments so that the reliability and functionality can be determined easily. During each grasping and cutting, the time required to perform the grasping and cutting operation was recorded. The depth of stem cut from sweet pepper was supposed to deep so the distance of cutter was adjusted to 40 mm from the gripper. This distance can be increased or decreased by adjusting the shaft of cutter installed on circular disc. To check the practical feasibility of the tool, different size and shapes of sweet peppers were used for experiments.

6. Results and Discussion

6.1 Simulation Results of model

The gripping and cutting model developed in Solidworks helps to determine the reliability, flexibility and effectiveness of the system. The model was simulated to obtain the data for static and buckling study; that means to check the model for its physical properties and performance.

Figure 7 represents the component contact and applied torque acting on the gripping system along with center of gravity force acting centrally downward.

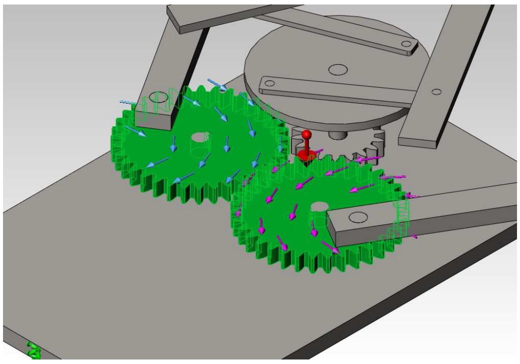

Fig. 7. Gripper components with acting torque.

The simulation results for stress on the system were illustrated in figure 8 and indicates clearly that the system support the stresses developed internally. This also means that the model can tolerate the stresses generated after application of torque and during the operation. Only some part of gripper bar that connects to the gears were observed more stressed than other components. The minimum stress and maximum stresses were recorded as 1.1749 N/m^2 and 1.6821 N/m^2 respectively.

The simulation results for equivalent strain on the system were shown in figure 9 in which it was observed that the gripper bar that connects to the gears were slightly exposed to the strain. The minimum strain and maximum strain were observed as 5.62 and 5.92 respectively. It means overall system has almost inferior deformation when the external forces applied or during the operation.

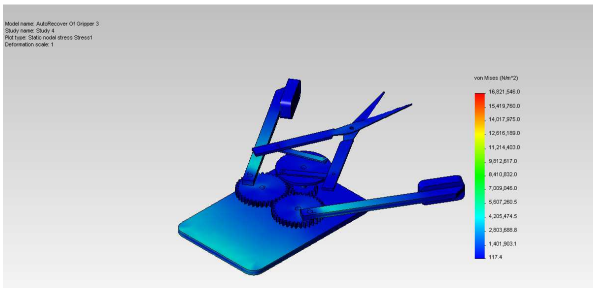

Fig. 8. Stresses acting on the model.

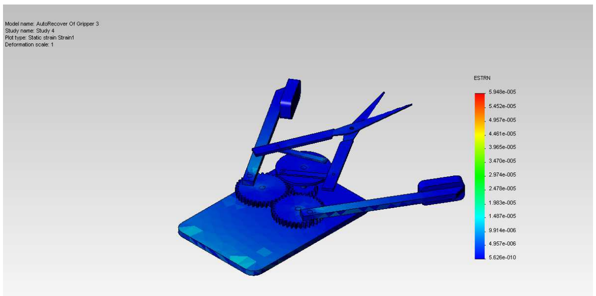

Fig. 9. Strains acting on the model.

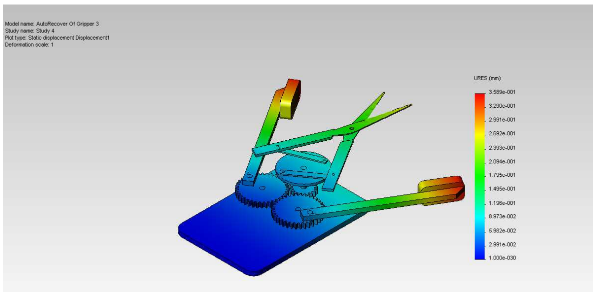

Fig. 10. Overall displacement of the model.

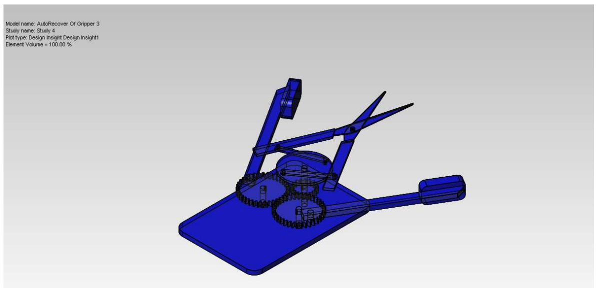

Fig. 11. Design insight view of the model.

The figure 10 shows the overall displacement of the model in which maximum displacement was found at gripper bars and then at scissor tips. This clearly indicates that the gripper bars and scissor tips has supplementary movement in association with the gears. Also the distinction in the displacement confirms that the speed variations of the large and small gears that responsible for movement of the gripper bars and scissor tips at different speed.

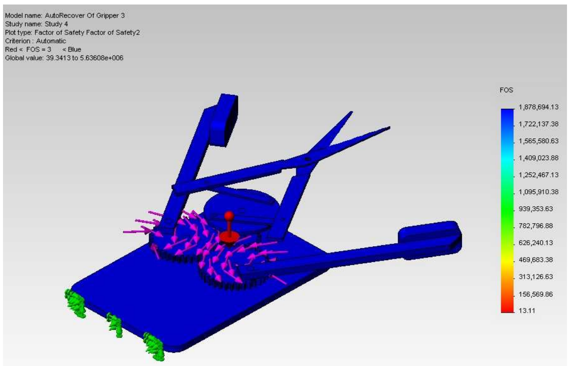

Fig. 12. Factor of safety plot.

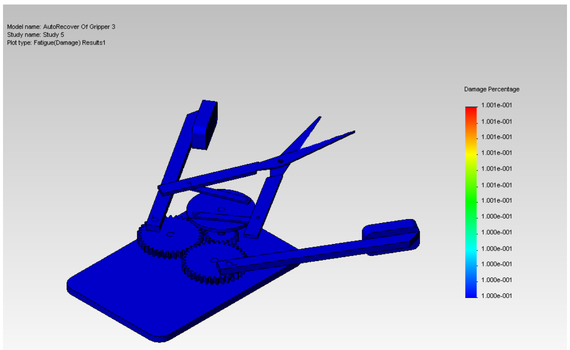

Fig. 13. Fatigue - damage plot.

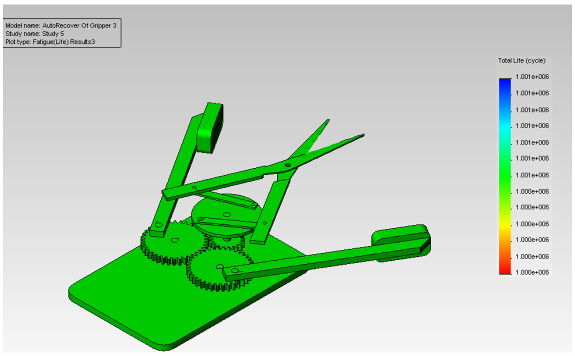

Fig. 14. Fatigue – life cycle plot.

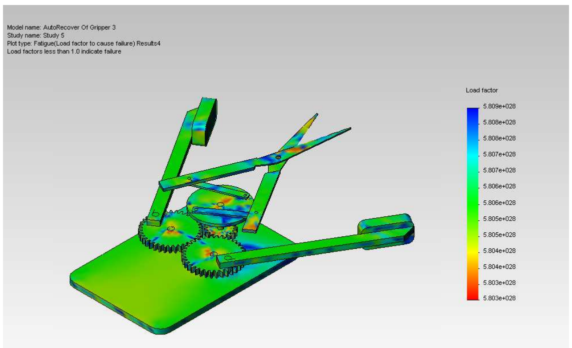

Fig. 15. Fatigue – load factor plot.

A Design Insight plot shows the regions of the model that carry the loads most efficiently with a continuous path between the various forces acting on model as shown in figure 11. The model was found significantly strong to carry all the forces acting on it without any modification.

Figure 12 represents the factor of safety plot for the model in which the model was found significantly safe against deformation and buckling effects. It also demonstrates that the structural capacity of a system beyond the expected loads was enormously higher.

The percentage of the life of the structure consumed by the defined fatigue events can be seen in figure 13 in which the percentage damage was found very less for model. This property of the model was found significantly affected by life cycle and can be seen in figure 14. The biaxial ratio was found as 1 which clearly indicates that the life cycle of the model affected moderately by the performance of the system. The load factor of safety for fatigue failure at each location was demonstrated by figure 15 in which all the system was exposed to the factor of safety as 3. The load factor less than 1 indicates the failure of the system and in developed model it was found as 5 which confirms the minimum fatigue failure of the model.

The simulation results of the model validate the physical characteristics and properties of the system and confirm its reliability, flexibility and significant effectiveness of the system.

6.2 Experimental Results

The constructed prototype was tested for the practical application for grasping and cutting the sweet peppers. The performance of prototype was found significantly reliable during the experiments. Figure 16 to 19 represents the performance of the prototype during the experiments.

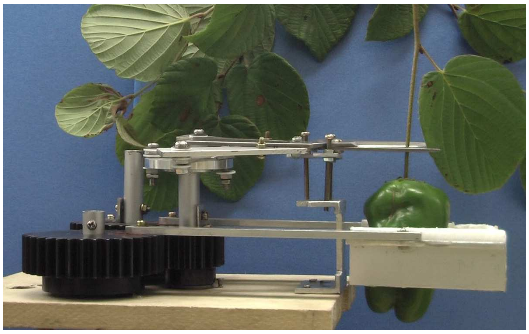

Fig. 16. Performance of prototype with pattern 1.

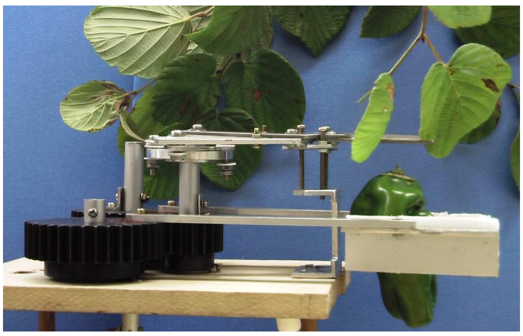

Fig. 17. Performance of prototype with pattern 2.

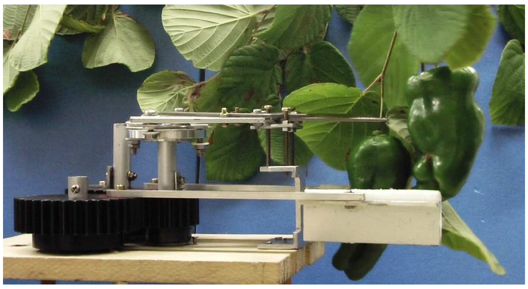

Fig. 18. Performance of prototype with pattern 3.

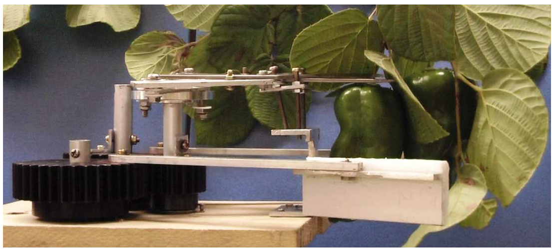

Fig. 19. Performance of prototype with pattern 4.

In the 1st and 2nd patterns of experiments, the significant performance of the prototype was observed. The grasping and cutting actions were smooth and easy. There were no judgment errors found during the harvesting operation and all the samples were harvested successfully. While in the 3rd and 4th patterns, the slight judgment error was observed but still the prototype was able to perform harvesting. In the 4th pattern, the observation were recorded that the two overlapped sweet peppers were grasped but only the first one was exposed to cut by scissor. Also, even the stem was covered with leaves; the cutter cut the stem through the leaves. The performance of the prototype was found satisfactory in 3rd and 4th pattern. As per the results obtained in simulation, none of the system component exposed to deformation and fatigue.

7. Conclusions

The gripping and cutting tool was modeled, simulated and validated in *Solidworks* successfully. The performance of the system was observed significantly reliable and effective. The static and fatigue studies of the system confirms the consistency and effectiveness with maximum factor of functionality. Thus, the physical characteristics and properties of the system were verified.

The system was constructed and tested successfully based on the simulation results. The experiments with four different patterns confirm the performance of the system. The 1st and 2nd patterns were observed significant successful rate of harvesting than the 3rd and 4th patterns. Finally, the developed gripper and cutting system tool for sweet pepper harvesting robot hand confirmed its successful performance. Further, optimization of the physical parameters and properties with different material can be considered as further research.

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2A33

Evaluation of Equal Error Rate in Document Authentication System Using Magnetically Labeled Pattern

Takayuki Yajima*, Syunji Sonoda, Tsutomu Yamada and Yasushi Takemura

Artifact-metric system using magnetic fibers can be applied for authentication system of stock certificate, bill, passport, plastic cards and other documents. The security of this system is guaranteed by its feature of difficulty in copy or reproduction. The security documents with randomly printed magnetic pattern based on artifact-metric system using magnetic fibers is studied. In this study we focused on the equal error rate (EER). It is the error rate at which false match rate is equal to false non-match rate. According to our evaluation for the accuracy of authentication of the system, EER is 5.6×10^{-5} % by comparing the waveform calculated from the pattern with the pseudo waveform obtained by MR sensor in the simulation. It is found that the authentication accuracy of the authentication system using magnetically labeled pattern can be higher than that of artifact-metric system using magnetic fiber.

Keywords: authentication system, artifact-metric system, magnetic pattern, equal error rate

1. Introduction

It has been reported that the documents with randomly dispersed magnetic fibers can be used for authentication classified as artifact-metric system [1]. The advantages of this system can be utilized for the authentication of stock certificate, bill, passport, plastic cards and other documents by supplying randomly determined characteristics which are similarly to biometrics using finger print, iris and others. The security documents with randomly printed magnetic pattern based on artifact-metric system using magnetic fibers is studied.

2. The documents with randomly printed magnetic pattern

In the authentication system studied here, the magnetic pattern consists of randomly dispersed magnetic dots. Figure 1 shows an example of the document with randomly dispersed magnetic dots and its waveform. A differential type magnetoresistance (MR) sensor is scanned along the magnetic pattern. A waveform of the detected signal by the MR sensor is complicated, it is difficult to determine the distribution of the magnetic dots from the waveform. This is a unique feature of the authenticating system. A degree of similarity between a detected waveform and a waveform of a genuine article is calculated in order to evaluate the authentication accuracy. Different from artifact-metric system, the waveform of a genuine article can be calculated from the magnetic dots in our system. Registration of the waveform of a genuine article is not required, its low cost gives an advantage on our authentication system.

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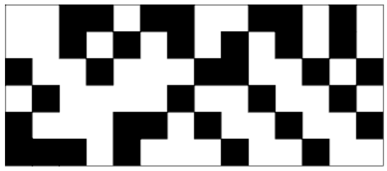
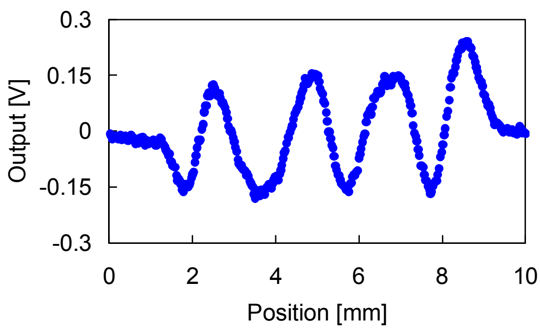


(a) Printed image of random magnetic pattern.



(b) Waveform obtained by MR sensor.

Fig. 1 Magnetically labelled pattern.

3. Evaluation of the authentication system

In the authentication system, two signal waveforms are used. A template pattern is defined as an output waveform recorded from a genuine document. This pattern is used for authentication of documents by comparing the detected waveform from other documents or the same document. These compared waveforms are called sample patterns. At the point of identification, a degree of the similarity between the template pattern and the sample pattern is calculated. A threshold value for the similarity is defined in order to decide if two waveforms were obtained from the same or an equivalent pattern.

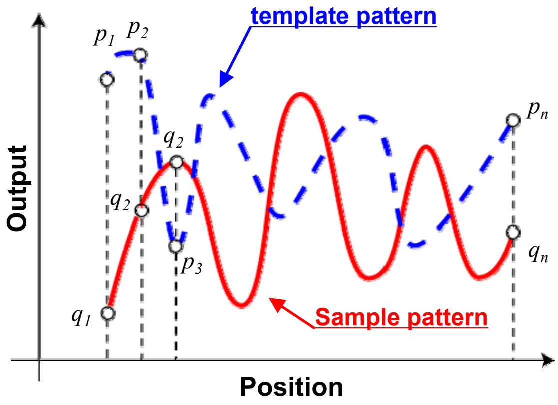


Fig. 2 Calculation of similarity.

3.1 Calculation of similarity

A degree of the similarity between the template pattern and the sample pattern is calculated by the correlation coefficient *S*. Then, the degree of similarity between template (*P*) and sample pattern (*Q*) is defined as *S*(*P*,*Q*), is calculated by the following equation:

$$S = \frac{\sum_{i=1}^{n}(p_i - \bar{p})\cdot(q_i - \bar{q})}{\sqrt{\sum_{i=1}^{n}(p_i - \bar{p})^2 \cdot \sum_{i=1}^{n}(q_i - \bar{q})^2}} \qquad (1)$$

Where $\bar{p}$ and $\bar{q}$ are mean average of all the elements of *P* and *Q*, respectively. The similarity *S* is in the range of $-1 \le S \le 1$. The higher value of *S* is obtained when there is a similar waveform for *P* and *Q*.

3.2 Evaluation by equal error rate

In this study we focus on the equal error rate (EER). It is the error rate at which false match rate is equal to false non-match rate. False match rate (FMR) is the probability that the authentication system incorrectly accepts the false documents in an authentication process. And false non-match rate (FNMR) is the probability that the authentication system incorrectly rejects the genuine document during the authentication process.

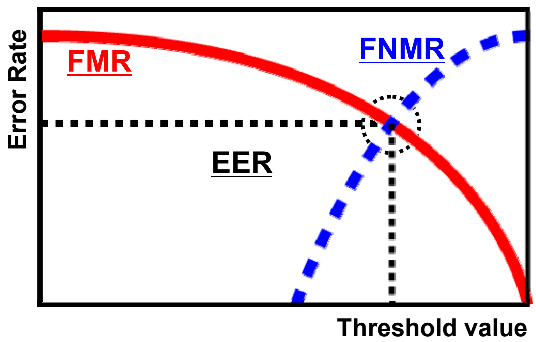
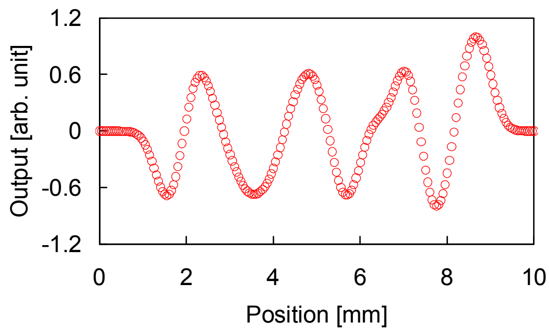
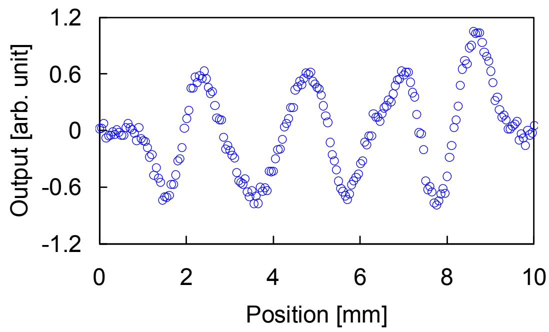


Fig. 3 Evaluation by equal error rate.



(a) The calculated waveform.



(b) The pseudo waveform obtained by MR sensor.

Fig. 4 The waveform in the simulation.

4. Analysis of equal error rate

The EER using the pseudo waveforms obtained by MR sensor as the template pattern is compared with the EER using the calculated waveform as the template pattern. Figure 4 shows the calculated waveform and the pseudo waveform. In the simulation, the dimension of the document is 7.0 mm wide. Scanning range is 12.8 mm by MR sensor. The density of dot is 60 %. The number of documents is hundred thousand copies. Measurement times to each document are 5000 times.

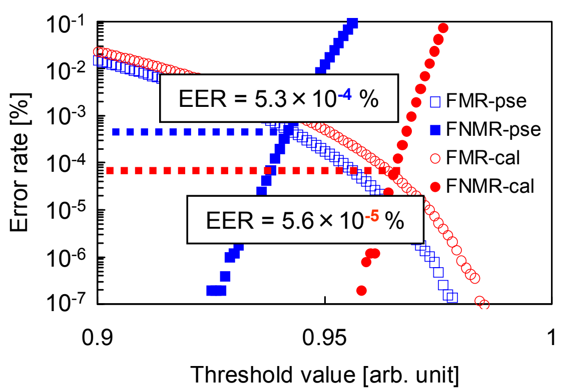


Fig. 5 Analysis of equal error rate.

Figure 5 shows a calculated result of the FMR and FNMR. The EER using calculated waveform is 5.6×10^{-5} % and about ten times lower than the EER using the pseudo measured waveform. In addition, the EER by comparing the calculated waveform is lower than the EER of artifact-metric system using magnetic fibers [1][2].

5. Conclusions

In this paper, the accuracy of document authentication using magnetically labelled pattern is evaluated. In the authentication system studied here, the magnetic pattern consists of randomly dispersed magnetic dots. The authentication system using magnetic pattern don't require registration of the waveform of a genuine article, its low cost gives an advantage on our authentication system. It is found that the accuracy of the authentication system can be higher than that of the artifact-metric system using magnetic fibers.

References

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