Springer

Journal of Mechanical Science and Technology 23 (2009) 3366~3373

Journal of Mechanical Science and Technology

www.springerlink.com/content/1738-494x
DOI 10.1007/s12206-009-0923-1

# Development of an automatic vegetable bundling machine using thermal bonding †

Yong-Seok Kim and Soon-Yong Yang*

*Department of Mechanical and Automotive Engineering, Ulsan University, Ulsan, 680-749, Korea*

(Manuscript Received May 6, 2009; Revised July 22, 2009; Accepted September 4, 2009)

**Abstract**

An automatic vegetable bundling mechanism that uses thermal bonding is proposed. The proposed mechanism consists of three modules for reasonable manufacturing. The design specifications were determined by a bundling mechanism that was mechanically optimized, and a prototype of the automatic bundling machine was manufactured. A field test was carried out to verify the performance of the prototype on a vegetable farm. The machine showed an efficiency of about 3.6 times that by manual work. This automatic vegetable bundling machine has already been approved as an agricultural machine and will be commercialized soon.

***Keywords***: Thermal bonding; Bundling machine; Bundling mechanism; Vegetable bundle; Packing

## 1. Introduction

Nowadays, various vegetables are grown and sold regardless of the season. With the marked changes in diet standards and trends, the demand for healthy vegetables, including Chinese leek, dropwort, and spinach, is increasing. Accordingly, vegetable-growing areas and their production are also increasing year by year [1].

Vegetables are distributed in ellipse or rectangular bundles to prevent the occurrence of vegetable waste problems in consumption areas and to improve their merchantability. Therefore, vegetable-producing farms make every effort to improve their selective packing. Vegetables must be packed and shipped fast because they have a high moisture content of 90% or more and their metabolism, which is active even after they are harvested, leads to marked changes in their volume and quality. With the aging of farm populations, however, vegetable-growing farm households are experiencing difficulties. Most work processes for growing vegetables depend on manpower, except for compost spraying and cultivation, and gathering and selective packing especially require 30-76% manpower [2]. Much of the selection and packing processes depend on manual work, so packing mechanization is very much required. Farm households manufacture and use their own tools to improve work efficiency and convenience, but these have no noticeable effect. Several vegetable bundling machines have been developed and are being used to bundle specific vegetables. They involve a band with a metal wire inside and its twisting or tape (for flowers) [3]. Vegetable bundling machines that involve twisting of bands have many bundling errors due to diverse bundle sizes, and may damage vegetables. Vegetable bundling machines with tape are not appropriate for bundling of high-moisture vegetables.

In this study, a bundling method that uses thermal bonding (bonding of the contact surface of the band with heat) is proposed for an automatic vegetable bundling machine that can bundle vegetables regardless of their type and bundle size [4-6]. Therefore, an automatic vegetable bundling mechanism that uses thermal bonding was designed and a prototype was manufactured to verify the performance of

† This paper was recommended for publication in revised form by Associate Editor Yong Tae Kim

*Corresponding author. Tel.: +82 52 259 2820, Fax.: +82 52 259 2820
E-mail address: soonyy@ulsan.ac.kr

the said mechanism.

## 2. Design and modeling of the mechanism

### *2.1 Design parameters*

Vegetables are harvested by gathering, cleaning, selecting, bundling, box-packing, and shipping them, in that order. Fig. 1 shows the harvest processes. This study aimed to automate the bundling process that is indicated by the dashed line.

The packing for shipping of vegetables complies with the Agricultural Product Shipping Standards [7]. Vegetables are generally packed in corrugated cardboard boxes or PE bags by specific weight. Long-stemmed vegetables or leafy vegetables are especially bundled in small weights and packed in corrugated cardboard boxes or PE bags for shipping. The bundling volume varies with the type of vegetable, although even the same vegetables are packed in diverse sizes. This causes difficulty in bundling automation. Bundling is currently being performed by twisting the PP band with a metal wire inside.

Vegetables are difficult to handle because they are very moist and soft. Their mechanical properties are greatly influenced by their temperature and moisture content. The mechanical properties of some vegetables according to the studies of Bong [8] and Jun [9] are shown in Table 1

Table 1. Mechanical properties of vegetables.

| Material | Rupture Load(N) | Rupture Stress(kPa) | Cutting Force (N/10Stems) |
|---|---|---|---|
| Chinese leek | 92.4 | 20.5 | 93.1 |
| Crown daisy | 91.2 | 19.8 | 145.2 |
| Chamnamul | 91.9 | 18.4 | 63.4 |
| Leek | - | 40.8 | - |
| Spinach | - | 31.0 | - |

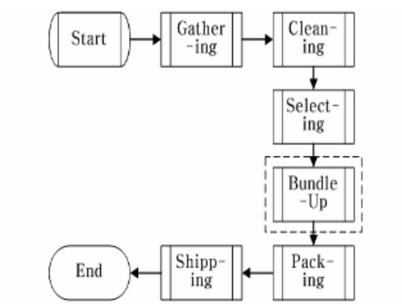


Fig. 1. Vegetable harvesting process.

The selected bundling band was manufactured by adding natural fiber to the EVA (Ethylene Vinyl Acetate) that is biodegradable (can be decomposed by microorganisms, including bacteria) and photodegradable (can be decomposed by the ultraviolet ray energy of sunlight). This material is appropriate for vegetable packing because it is very flexible even as its tensile strength is similar to that of the current vegetable bundling band. It is also sanitary, non-toxic, and eco-friendly, and has a high thermal bonding characteristic even in humid conditions.

To verify the thermal bonding characteristic of this bundling band, a 16 mm-wide, 1.2 mm-thick EVA band was used at a bonding temperature of 200°C and an applied bonding force of 70 N. Fig. 2 shows the resulting thermal bonding characteristic of the bundling band.

The cross-section of the vegetable bundle is typically ellipse or rectangular. Given the same volume of bundled vegetables, consumer preferences depend on the shape of the bundle. The bundling band must not only not damage the vegetables, but must also maintain the shape of the bundle during transport.

The end of the vegetable bundle must also be neatly trimmed. A rotating cutter is typically used for this. Srivastava and Goering [10] stated that a speed of 50-75 m/s is required to ensure the cutter's cutting reliability, while considering various other factors, including the cutter's sharpness and the vegetable stems' rigidity. The condition wherein the entire cutter blade can be used for cutting, with the blade fixed and with the vegetable moving, is expressed in Eq. (1), for which the linear velocity of the rotating blade must be 30 m/s [11]:

$$\frac{V_v}{V_m} \le \frac{2\pi R_c}{NL\cos\alpha} \tag{1}$$

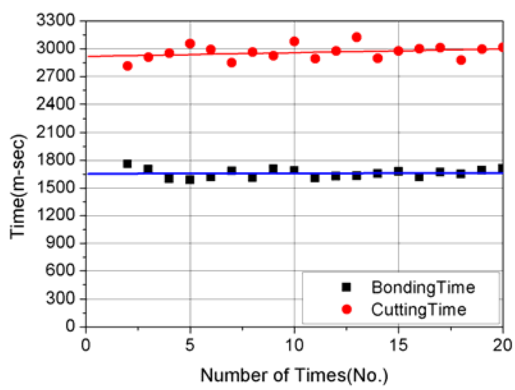


Fig. 2. Property of bundling band.

Table 2. Specifications of the design concept.

| Items | Concept Specification |
|---|---|
| Bundle object | Long stemmed or leaf vegetables |
| Binding method | Thermal bonding method |
| Bundle section shape | Ellipse or rectangular |
| Joining position | Short radius position |
| Practicable bundle size | Free size(diameter: 30~200 mm) |
| Band feeder method | Continual feed by roll type band |
| Band cutting method | Scissors mechanism |
| Binding tension adjust | Spring force and band friction |
| Vegetable root trimming | Rotational cutter |

Wherein $V_v$ is the linear velocity (m/s), $V_m$ is the forward velocity of the machine (m/s), L is the effective length of the blade (m), $R_c$ is the gyration radius of the disk blade (m), α is the inclination angle (°), and N is the number of disk blades.

Table 2 shows the conceptual design specifications according to the design parameters.

### *2.2 Design and modeling of the mechanism*

The bundling mechanism consists of the table that supports the entire system, the conveyer that transports the vegetables, the hopper that maintains the shape of the bundle, the vegetable pressing part that applies binding tension to the vegetables, the arm part that moves the bundling band around the vegetable bundle, the thermal binding part that binds the bundling band using thermal bonding, the cutter that cuts the bundling band after the bundling, and the bundling band feeding part that continuously supplies the bundling band. The main parts and their names are shown in Fig. 3. The bundling machine is divided into Module Ⅰ (the table, conveyer, and hopper), Module Ⅱ (the arm drive, vegetable pressing device, and conveyer drive), and Module Ⅲ (the thermal bonding device, band cutter, and band feeding device). CATIA V5 was used as the modeling tool for the design of each part. Interferences and conflicts were avoided by virtually assembling the parts, and the mechanical operation was reviewed through a simulation using the SMO (SimDesigner Motion) module of MSC [12]. Parts processing and manufacturing convenience were taken into account in the design to facilitate laser processing and banding processing.

The composition and function of each module are described below.

Fig. 4 shows the composition of Module Ⅰ and the results of its modeling. The table consisted of an aluminum profile support and a stainless table plate. The conveyer consisted of a drive chain and a sprocket, and was driven by a vehicle window lift motor. The hopper consisted of a cup that held the vegetable, and a guide roller, and it was fixed on the conveyer chain. The hopper was manufactured in such a way that it could be replaced according to the size and shape of the bundle, and the guide roller can move along the rail and support the vegetable.

Fig. 5 shows the composition of Module Ⅱ and the results of its modeling. The arm drive consisted of the

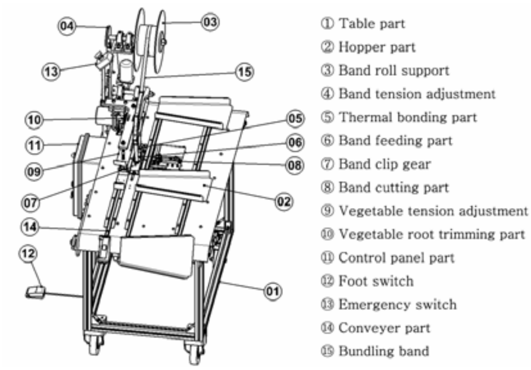


Fig. 3. Parts name of principal device.

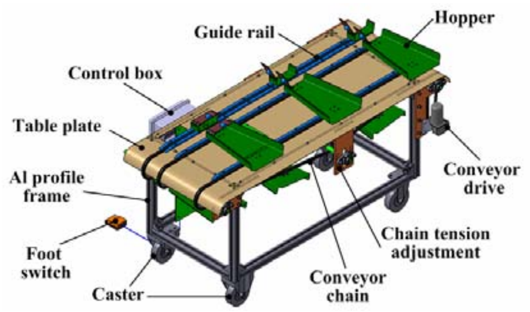


Fig. 4. Composition and 3D-CAD model of Module Ⅰ.

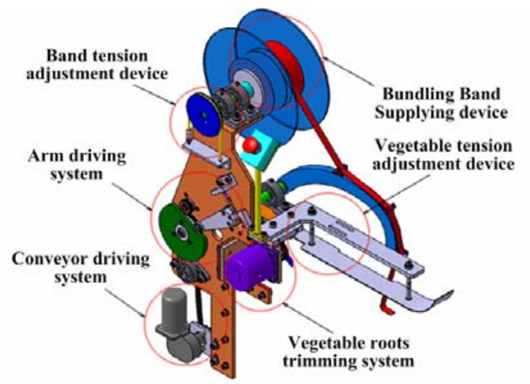


Fig. 5. Composition and 3D-CAD model of Module Ⅱ.

arm, drive motor gear, cam gear, cam, and push rod. The arm moved the bundling band around the vegetable on the hopper and pressed the bundling band to bond it. The trajectory height at the arm end could be changed by adjusting the push rod angle, and the time in which the arm end reaches the lowest point could be determined by adjusting the cam gear angle. The concentric circle size of the cam determined the bonding time (the pressurizing time) of the band.

The band bundling device consisted of the fraction drum, the fraction band, and the tension adjustment spring. The bundling band was adjustable according to the size of the bundle. By adjusting the fraction between the fraction drum and the fraction band, the tension of the bundling band and thus of the vegetable bundle, could be adjusted.

The vegetable tension adjustment device (the pressing device) consisted of the guide rail, the tension adjustment bar, and the tension absorption spring. It firmly bundled the vegetables and prevented the loosening of the bundle due to the expansion force via its adjustment according to the bundle size.

The vegetable root trimming device consisted of the motor, the disk rotor, and the blade. It trimmed the vegetable roots after the vegetable bundling.

Fig. 6 shows the composition of Module Ⅲ and the results of its modeling.

The thermal bonding device consisted of the heater core, the cartridge heater, the temperature sensor, and the heater controller. The heater core was manufactured with copper.

Fig. 7 shows the bundling mechanism by thermal bonding and the continuous feeding mechanism of the bundling band.

The bonding of the bundling band was performed by momentarily melting the band between the heater core base and the silicon base and pressurizing it using the arm and the heater. The shape of the heater core base was the irregular grill type, considering the contact property. To prevent the fixing of the bundling band to the heater core base after the bonding, the heater core base was coated with teflon.

The bundling band cutter consisted of the scissors, the link, the sliding bar, the pressure spring, the push lever, and the drive motor. The scissors mechanism was applied to the cutter. The band was cut by the turning of the push lever assembled at the drive motor and the extension of the scissors attached to the sliding bar.

The bundling band feeding device consisted of the clip gear, the band pusher, the sliding bar, the compression spring, the push cam, the clutch pin, and the drive motor.

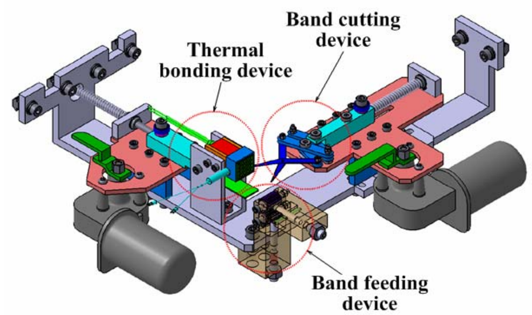


Fig. 6. Composition and 3D-CAD model of Module Ⅲ.

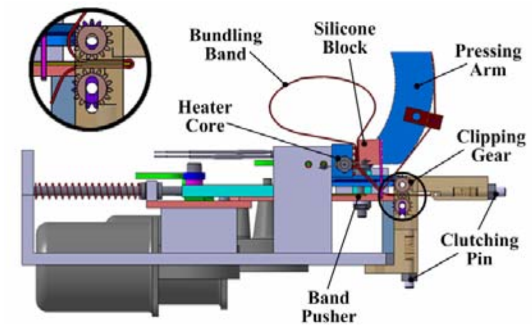


Fig. 7. Schematic of mechanism of thermal bonding and band feeding.

The bundling band was fed by the turning of the push lever attached to the drive motor and the pusher attached to the sliding bar. The push lever pushed the band that was suspended in front of the clip gear into a pair of clip gears. The band that was pushed between the clip gears was not pulled out because the clip gears did not inversely rotate due to the anti-inverse rotation clutch pin.

A new band was fed 0.6 s after the band was cut. This corresponded to an initial band feeding lever angle of 114°, with an initial band cutting lever angle of 0° during the initialization of the system.

The cycle times of this bundling mechanism were 4.5 s for the conveyer moving time, 4.5 s for the arm driving time (including the 3.0 s bonding time), 1.5 s for the band feeding/cutting time, and 2.0 s for the loss time, with a 40-rpm drive motor rotation. The work cycle time, or the duration of one bundling, was 12.5 s. Assuming an eight-hour workday, as many as 2,300 sheaves could be bundled.

Fig. 8 shows the virtual prototype, for which 3D modeling and virtual assembly of parts were used according to the design specifications of the bundling mechanism that used thermal bonding.

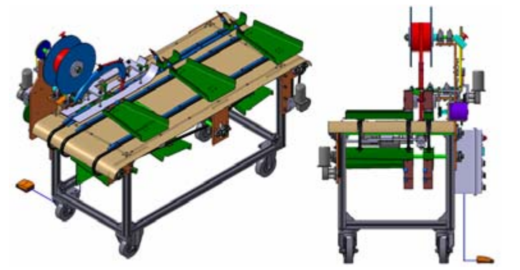

Fig. 8. Design result of the vegetable bundling mechanism.

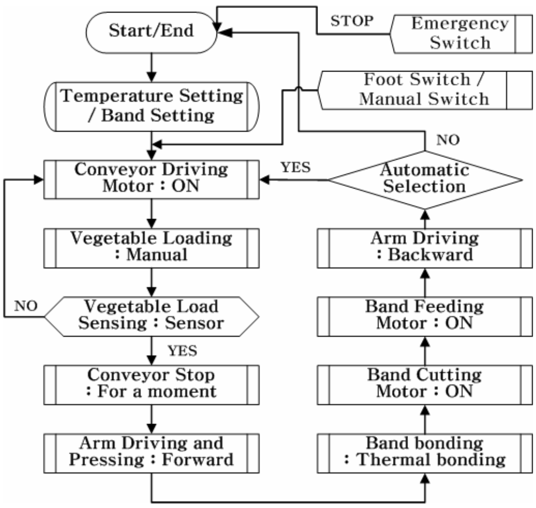


Fig. 9. Diagram of the bundling system control.

### *2.3 Design of the control system*

The PICBASIC module was selected for the control system. It uses PLC (programmable logic control). In PICBASIC, programming is easy because the microcontroller has a basic interpreter inside, and the main operations for the automatic control can be carried out with a single instruction. The controller can be manufactured at a low cost because its downloading and debugging functions can be done merely with a PC and cables, without the need for expensive MDS (Microprocessor Developer System) equipment [13]. Fig. 9 shows the control diagram of the bundling system. The heater for the bonding of the bundling band was selected by the bonding characteristic test of the EVA band that was applied to this bundling system. A heater was installed with the temperature controller because the bonding condition varied according to the band thickness, the bonding pressure, the surrounding environment (humidity and temperature), and the season. A DC motor for the vehicle window was used as the drive device. The vehicle window lift motor is cheaper than general motors. It is tight against moisture, which makes it appropriate for this bundling system. And it is also easy to control because it rotates at least once by current application. Table 3 shows the hardware specifications of the control system selected for this bundling system.

Table 3. Specifications of the control part.

| Part | Model | Specifications | Remarks |
|---|---|---|---|
| PLC Controller | PICBASIC-2000 Model:PB-2H Main:PIC16F74B | 27 I/O, 16K EEPROM, 96 RAM | Input: DC24V |
| Motor | FPC3 | 40 rpm, 28 N.m | Input: DC12V |
| Heater | Cartridge Heater | Size:8φ 5~15(W/cm²) | Max: 500℃ |
| Temp' Sensor | R.T.D | Size:8φ PT 100 Ω | Max: 1500℃ |
| Temp' Controller | T3S SERIES | Method: Digital Level:F.S±1% | Output: DC4V |
| Trimming motor | K6D(DC) | 3000 rpm, 20W, 6.5 kg-cm | Input DC24V |

## 3. Prototype manufacture, performance test and review

The performance test was conducted according to the test standard of the National Institute of Agriculture Engineering (NIAE), NAMRI T 6050 [14], and its inspection standard, NAMRI S 6050 [15], with respect to the bundling capacity (bundles/hour), imperfect bundling rate (%), bundling strength (N), and damage rate (%).

A manufacturing drawing was made with the drawn 3D-CAD model, and a prototype was manufactured according to the design specifications. Fig. 10 shows the manufactured prototype.

The performance test was carried out twice in a dropwort farm at ambient temperature about 5~10℃, and performed by setting about 180~200℃ of the bonding temperature. Dropwort was chosen as the test vegetable because its mechanical properties are worse than those of other vegetables. Thus, if it passed the test, other vegetables would surely pass it as well. Fig. 11 shows the test being performed and the bundles of dropwort, and Table 4 shows the test results.

While 60-70 vegetable sheaves per hour can be manually bundled, with this bundling machine, 235 sheaves per hour could be bundled. Therefore, bundling machine could bundle about 3.6 times more than manual bundling.

The number of incidences of imperfect bundling and the damage rates were slightly higher than those in manual bundling, though. The imperfect bundling rate was 2% and the damage rate was 3%, which are lower than

Table 4. Performance test results.

| Test Item | Bundling Capacity (sheaf/h) | Rate of Imperfect Bundling (%) | Strength of Bundling (N) | Rate of Damage (%) |
|---|---|---|---|---|
| Standard | Design Max 288 | Less than 5% | More than 20 | Less than 5% |
| 1st | 215 | 2.5 | 20.6 | 2.4 |
| 2nd | 254 | 1.5 | 23.0 | 3.6 |
| Average | 235 | 2.0 | 21.8 | 3.0 |

Fig. 10. Picture of the prototype of the automatic bundling machine.

Fig. 11. Pictures of the field test and the bundle shape.

the test standards of 5% for each. It seems that these rates can be improved by adjusting the bundling conditions.

The bundling strength, which was similar to that by manual bundling, must be optimized because it is connected to the vegetable damage rate.

A 300 mm-long bundling band is required for the manual twisting method, but only 180 mm for this bundling machine, about 40% shorter.

In addition, the following problems were solved through the performance test.

A soft wire brush was attached at the arm end to prevent the band bonding errors caused by foreign matter between the bundling band and the heater.

The bundling strength fell because the bonding part of the bundling band was opened due to the residual heat and expansion force of the vegetable bundle. To address this problem, the bonding part of the bundling band was sprayed with water during the bonding. The water spray quantity was controlled by the spraying time of the spray pump. The water spraying time is very important because too much water will decrease the temperature of the heater.

The pressure and temperature for the bonding of the bundling band can slightly vary according to the work conditions. The proper sticking pressure and temperature must be determined through many tests and through actual experience prior to the commercialization of the machine.

The vegetable bundling machine that is currently being used in farms does not work or errs when the bundle size is large or small. With this bundling machine, bundling was possible regardless of the bundle size, and the shape of the bundles was elliptical and uniform.

The Korea Agricultural Machinery Industry Cooperative (KAMICO) has approved the use of this bundling machine as an agricultural machine. This technology has been patented in Korea [16], and its international patent (under PCT or the Patent Cooperation Treaty) is pending [17]. Its commercialization is also underway.

## 4. Conclusions

A vegetable bundling mechanism was designed with the thermal bonding method that momentarily melts the bundling band and pressurizes it for bonding. Its prototype was manufactured and its performance tested. This bundling machine has already been approved as an agricultural machine; and based on the results of the performance test conducted in this study, it will be commercialized after it is supplemented, modified, and retested. This is the first time that the thermal bonding method has been applied to vegetable bundling, and it shows many advantages. It seems that it can even be applied to many bundling systems. The following conclusions were arrived at.

(1) The thermal bonding method, which momentarily melts the bundling band and pressurizes it for bonding, was applied to an automatic vegetable bundling

machine that bundled sheaves with diameters of 30-200 mm, regardless of the bundle size.

(2) The gear clip mechanism and the scissors mechanism were used to continuously supply the bundling band and to cut it, respectively. The cam mechanism was applied to the application of pressure on the bundling band and to the bonding time.

(3) When the performance test specimen was limited to dropwort, the imperfect bundling rate and the damage rate were 2% and 3%, respectively, higher than those by manual work but lower than the standards of 5% for each.

(4) The required band length was 180 mm, which is about 40% shorter than that for general manual work.

(5) This automatic vegetable bundling machine was designed to bundle about 288 sheaves per hour; but in the bundling performance test, only 235 sheaves per hour could be bundled, which is about 3.6 times that by manual work.

## Reference

[1] NAQMS(National Agricultural Products Quality Management Service), *The Cultivation Trends for Main Crops Classified by Local Area*, Registration No. 11-1380729-000017-10, Korea (2006), 14-15.

[2] RDA(The Room for the Management of Agriculture), *Labor Input Times by Classification of Work Steps and Main Crops*, Rural Development Administration Registration No. 31200-51710-57-9962, Research Report on the Management of Agriculture No. 84, Korea (1999. 12), 31-35 and 59.

[3] K. S. Han, J. Y. Son, W. K. Park and C. H. Kang, Development of Automatic Binding Machine for Vegetables, *Korean Society for Agricultural Machinery Winter Conference*, Korea (1999) 668-674.

[4] S. Y. Yang and Y. S. Kim, *The Development of a Garden Stuff Automatic Bundling System*, Ministry of Commerce; Industry and Energy, Result report of the spread business for the research outcome, Korea (2006) 36-57.

[5] W. G. Lee, S. Y. Yang and Y. S. Kim, *The Development of an Industrial Binding System Using Heat,* Results of the report of the Small and Medium Business Administration on the Consortium of Small and Medium-sized Businesses, Korea (2007. 02) 29-39.

[6] Y. S. Kim, J. J. Kim, T. P. Park and S. Y. Yang, Development of Bundling Machine for Vegetables, *Proceeding of the KSME 2008 Spring Annual Meeting,* Korea (2008, 06) 539-544.

[7] Standard of KMAF, *The Standards Book for Shipments of Farm Produce*, Korean Ministry of Agriculture and Forestry, Korea (1999. 01) 117-123.

[8] J. Y. Bong, Relationship of the Role of Water in Withering and Mechanical Properties of Some Leafy Vegetables: 1. Effect of Withering on Viscoelastic Properties of Spinach and Leek, *Korean Society of Food Nutrition*, 15 (3) (1986) 286-293.

[9] H. J. Jun, *Development of a Stem-cutting-type Harvester for Non-head Leafy Green Vegetables*, Department of Agricultural Engineering, Graduate School, Kangwon National University. Doctorate Dissertation, (2006) 45-47.

[10] A. Srivastava and C. E. Goering, *Engineering Principles of Agricultural Machines: Hay and Forage Harvesting*, American Society of Agricultural Engineers, USA, (1991) 1-19.

[11] C. J. Jung, *The Mechanization of Crop Cultivation*, Seoul University, Korea, (1988) 225-228.

[12] Y. S. Kim, J. J. Kim, C. D. Lee and S. Y. Yang, A Study on the Design of a Bundling Mechanism for Vegetables, *Proceedings of the KSMTE Spring Conference 2008*, Korea, (2008) 159-163.

[13] Comfile Technology, PICBAGIC Module, http://www.comfile.co.kr/product/13_01_01.htm, (2008).

[14] Standard of NIAE, *Experimental Method for Binding Machines for Agricultural Products: NAMRI T 6050*, National Institute of Agriculture Engineering, Korea, (2007. 03).

[15] Standard of NIAE, *Checkup Standards for Binding Machines for Agricultural Products: NAMRI S 6050*, National Institute of Agriculture Engineering, Korea, (2004. 12).

[16] T. P. Park, Y. S. Kim and S. Y. Yang, *Automatic Bundle Packing Apparatus Using Bonding Tape*, Korea Patent No. 10-0726096, (2007).

[17] T. P. Park, Y. S. Kim and S. Y. Yang, *Automatic Bundle Packing Apparatus Using Bonding Tape*, Patent Cooperation Treaty Application No. PCT/KR2007/003443, (2007).

**Yong-Seok Kim** received his B.S. in Mechanical Engineering from Ulsan University, Korea, in 2003. He then received his M.S. and Ph.D. degrees in Mechanical and Automotive Engineering from Ulsan University, Korea, in 2005 and 2009, respectively. Dr. Kim is currently a post doctor at the School of Mechanical and Automotive Engineering at Ulsan University in Ulsan, Korea. His research interests include concurrent engineering, mechanism design, rapid prototyping and CAD.

**Soon-Yong Yang** received his B.S. and M.S. degrees in Mechanical Engineering from Busan University, Korea, in 1979 and 1981, respectively. Also, he then received his M.S. and Ph.D. degrees in Precision Engineering from Tokyo University, Japan, in 1987 and 1997, respectively. Dr. Yang is a professor in the school of Mechanical and Automotive Engineering at Ulsan University in Ulsan, Korea. His research interests include vehicles mechatronics, field robot and hydraulic engineering.