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Development of Semi-automatic Cabbage Piling System for Tractor Implemented Chinese Cabbage Hervester

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적 요

배추 생산에 있어서 수확, 운반, 적재 작업은 가장 노동이 집약적으로 요구되는 작업들이다. 최근, 여러 종류의 양배추 수확기가 일본과 유럽에서 개발되었다. 하지만, 국내에서 재배되는 배추는 크기와 형태에 있어 양배추와는 달라 기 개발 기종의 도입이 어렵다. 또한 수확작업의 생력화 효과는 운반, 정선, 적재 작업과 밀접하게 연계되어 있어 출하시의 작업체계를 고려하여 수확에 따른 수집·반출 시스템을 개발하여야 한다. 수확시의 배추는 중량이 25~45 N 정도로 타 작물에 비하여 무겁고 부피가 크기 때문에 수확작업의 기계화를 위해서는 수확장치와 더불어 연속적으로 수확되는 배추를 적절하게 수집하여 적재하고 반출하는 시스템의 개발이 중요하다. 본 연구에서는 수확작업의 생력화 효과를 높이고 생력화 시스템 비용의 절감을 목적으로 작업자 1인에 의해 작업할 수 있는 반자동 형태의 트랙터 부착형 배추 수집, 적재, 반출시스템 시작기를 개발하였다. 시작기는 배추 이송장치, 적재장치, 팔렛 및 반출장치의 3개 부분과 PLC를 이용한 주 제어기로 구성하였다. 배추 수집용기로는 대략 70개의 배추를 담을 수 있는 크기가 1,050 mm×1,050 mm×1,000 mm 인 접이식 메쉬 팔렛을 사용하였으며 하단부에 롤러 안내판을 부착하여 적재한 팔렛의 배출이 용이하도록 하였다. 팔렛을 제외한 전체 시작기의 중량은 235 N 이였으며 크기는 3,940 mm×520 mm×1,630 mm 이었다. 본 연구는 수확장치의 기능 및 생력화 효과를 극대화하고 배추의 손상정도를 최소화하는 시스템을 구성하고자 하였다. 이송장치는 트랙터 부착시 횡공간 점유율을 최소화하도록 하였으며 적재장치는 적재시 배추의 손상을 줄이고 배추가 놓이는 자세를 능동적으로 조절할 수 있도록 주름관을 부착하였다. 시작기의 실내시험 결과 이송장치는 0.18 m/s~0.36 m/s의 범위에서 적재장치는 0.4 m/s~2.4 m/s 범위에서 안정적으로 구동하였으며 두 장치를 동시에 구동하여 시험한 결과 이송장치는 0.26 m/s~0.36 m/s, 그리고 적재장치는 0.9 m/s~2.4 m/s 에서 적정하게 안정적으로 구동하였다. 적재장치의 성능에 있어서 1~3단 적재시에는 주름관을 이용하여 적재하고 4~5단 적재시에는 자유낙하에 의한 적재를 수행할 경우 인력에 의한 적재와 거의 동등한 적재량을 보였으며 손상정도는 거의 무시할 정도였다. 트랙터가 0.3 m/s로 주행하는 경우 노지로부터 배추를 뽑아 이송하는 뽑기벨트의 적정속도가 0.46 m/s인 점을 고려할 때 배추 이송 컨베이어는 0.34 m/s 이상의 속도를 유지할 필요가 있었으며 적재 컨베이어는 2 m/s~2.4 m/s의 속도에서 안정적으로 작동하였다. 배추의 주간 거리가 대략 30~40 cm 인 점을 감안하면 적재장치는 초당 1개의 적재성능을 보였다. 실내에서 수행한 시스템의 성능은 배추에 큰 손상없이 전반적으로 성공적으로 구동하였으나 향후 노면이 고르지 못한 포장에서의 성능 시험이 필요하다.

Keywords : Chinese Cabbage Harvester, Automatic Piling, Mesh Pallet, Tractor Implement.

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1. INTRODUCTION

In Korea, the total cultivation area of Chinese cabbage(C-cabbage) is the largest next to that of pepper among vegetables. However, most processes in cultivating and harvesting C-cabbages depend on human labor. Recently, research on mechanization and automation of C-cabbage production has been started in Korea. Since C-cabbages usually weigh 29 N to 40 N and are big in size at the time of harvest, handling operations such as harvesting, loading and unloading including transportation require the highest labor demand among all other production processes (Song 1999).

In Japan, experimental feeding and piling devices for the cabbage harvester were developed and tested from 1985 to 1988 at the BRAIN(Bio-oriented Technology Research Advancement Institution). A prototype feeding and piling device was composed of a steep cabbage feeding device, folding type two channel cabbage unloading guide, turning shooter with variable slope angle, and a burlap bag with elastic holding strip, whose position varies as amount of loaded cabbages increases. It was reported that further research should be done to reduce the damage on the cabbage and to improve the piling capacity and state. Recently, several commercial cabbage harvesters are available in Japan and Europe. Those harvesters, however, are not suitable for C-cabbages. C-cabbages cultivated in Korea are bigger in size and have a cylindrical shape with spread leaves. And since they were not equipped with the proper mechanism for piling and unloading, three or four people should work to clean and pile the cabbages in a box or pallet.

In 1993 and 1994, Kanamitsu et al. developed a prototype of tractor implement type C-cabbage harvester. Research was focused on the development of the mechanism to pull up and cut the C-cabbage root for harvesting. Here, it should be emphasized that the cabbage or C-cabbage harvester without the proper automatic piling and pallet unloading mechanism is almost meaningless in the viewpoint of labor reduction and job efficiency. In general, performance and efficiency of harvesting operation are determined from the function of the successive cabbage piling and pallet unloading processes. Since a pallet or box is usually used as truck transporting medium, mechanisms of cabbage piling into pallet with loading and unloading pallet are closely related to harvesting, transportation, and distribution.

In most cabbage harvesters, belt or chain conveyor was used to feed cabbages from the cabbage pull-up and cutting device. Most harvesters available so far adopted a sort of sliding device and free falling way in collecting cabbages into the pallet. And three or four labors are usually required for cleaning incoming cabbages, piling those into the pallet, unloading the filled pallet and reloading the empty one. Time required for piling cabbages into the pallet determines the ground speed of the harvester. And the carrying capacity of the empty and loaded pallets of the harvester determines the harvesting performance without intermission.

Up to now, any automatic or semi-automatic collecting and unloading device is not available to pile cabbages by layers into the pallet with little damage and to unload pallet from the harvester continuously during the harvesting process. In this paper, semi-automatic cabbage piling and pallet unloading system was developed based on the pre-specified functional requirements of harvesting process while considering physical properties of C-cabbage and the overall harvesting efficiency. And the performance of the system including each component was tested and presented.

2. MATERIALS AND METHODS

Geometrical properties of C-cabbages are crucial in mechanizing harvesting process and are closely related to the design specification of the mechanism. And the amount of the damage, which could occur according to various ways of feeding and piling cabbages including free falling into the pallet were measured and analyzed. When cabbage falls down on the pallet floor, outer leaves can have damage. Damage caused by free fall was measured with the number of damaged(torn off) outer leaves and decrease of weight after removing leaves with damage.

Foldable mesh type pallet (1,050 mm × 1,050 mm × 1,000 mm) made with 5 mm diameter wire shown in Fig. 1 was chosen to reduce the space of harvester to carry the residual empty pallets. Two guide plates were attached at the bottom of the pallet so that the pallet may easily slide over the pairs of roller mounted on the floor frame. The pallet could hold around 70 cabbages of an average size. Once a pallet was filled with cabbages, the pallet was discharged to the ground by sliding over the inclined plate. And an empty pallet was unfolded and mounted.

Prior to specify the functional specification in designing semi-automatic cabbage piling and pallet unloading system, three prototype automatic piling system have been developed and tested. Those showed some deficiencies such as small piling capacity because of improper piling methods and mechanism, moving interference of the piling guide inside the pallet during the piling process, high cost for the full automatic function, and too much weight of the system for the 30 PS tractor and etc. The final prototype was newly designed and built in compromising system cost and function.

Since it was economically meaningless and technically very difficult to fully automate loading and unloading the mesh pallet, the final prototype was developed in a semi-automatic manner with one operator. Functions of the prototype were selected to utilize operator's capability in a sense of the optimum collaboration and interface between man and system. This concept could reduce the system complexity and high cost caused by the sophisticated automatic mechanism to realize the desired handling job. Furthermore, it could improve the whole performance of the system with relatively low-level automatic devices due to the flexibility of human handling. Meanwhile, the low level automatic device could reduce simple but repetitive hard works.

Three major parts with functional specifications were set in developing semi-automatic cabbage piling and pallet unloading system.

a) Automatic C-cabbage feeding device

– Secure and variable rate feeding of cabbage to the automatic piling device considering the speed of pull up belt

– Compact and steep feeding mechanism to meet the spatial restriction

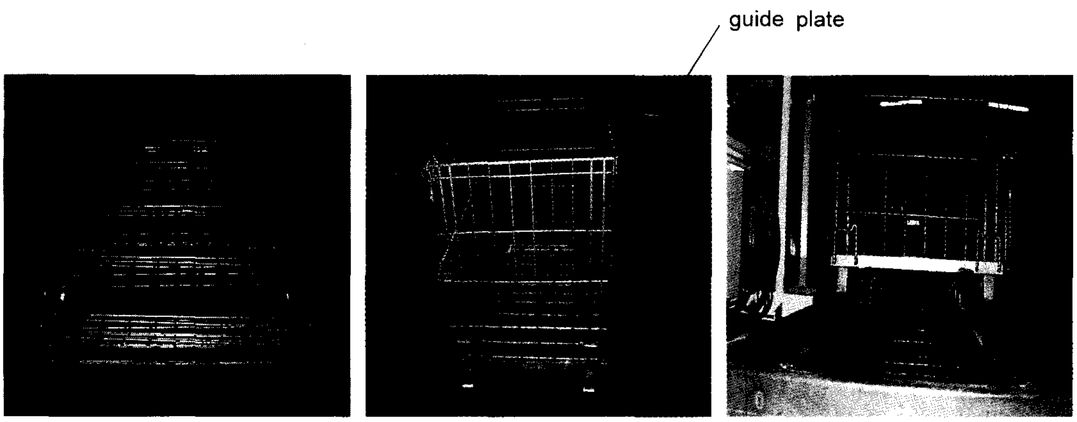
b) Semi-automatic piling device

– Automatic sequential positioning of the end of the piling belt conveyor

Speed control of piling belt to feed cabbage securely

– Sensor to check incoming cabbage

– Secure feed and piling of cabbage into the pallet with flexible positioning



(a) folded state (b) unfolded state (c) pallet on the roller

Fig. 1 Pallet used for the prototype.

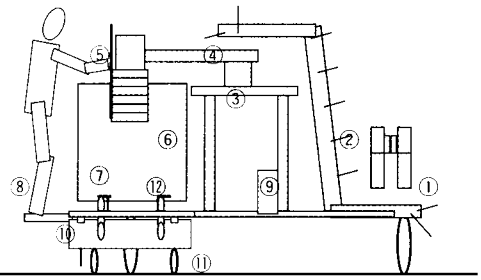
c) Pallet loading and unloading device

– Folding and unfolding type mesh pallet with guide plate

– Roller attached floor with hook joint

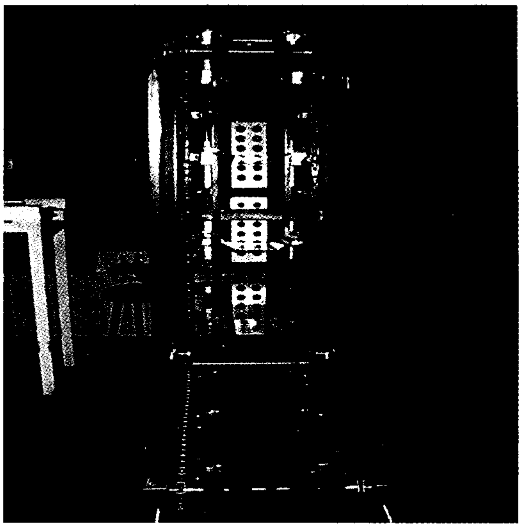
– Pallet holder and release pedal

The prototype was composed of main PLC system controller and three parts such as cabbage feeding device, automatic piling device with retractable bellows, and pallet unloading device. Fig. 2 shows the overall schematic figure of the prototype. Cabbage feeding device was built with a chain conveyor and a series of stainless steel cabbage carrying plates. Chain conveyor was composed of lower horizontal feeding part, middle 85° steep up-moving part, and upper horizontal feeding part. Carrying plates were attached to the chain and devised to be folded and unfolded using roller and guide attachment(Fig. 3). Various speeds of the feeding chain belt and piling belt conveyors were tested to ensure the proper attitudes of cabbages while being fed.

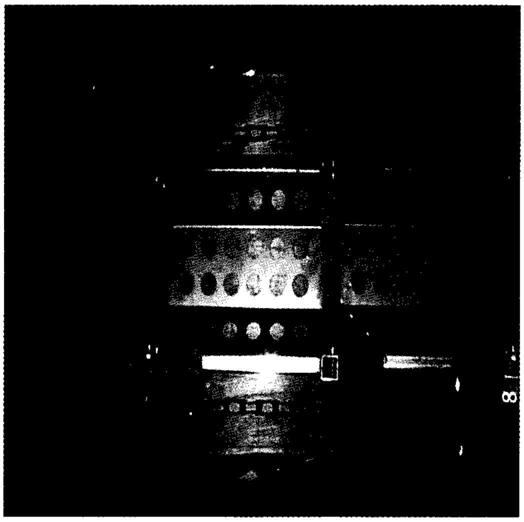


① Pull up and cutting device and feeder
② Steep feeding conveyor
③ R-θ positioning device
④ Piling feeder
⑤ Handling rod with switch box
⑥ Retractable bellows
⑦ Mesh type pallet
⑧ Operator
⑨ System controller
⑩ Foot plate with pallet fixing device
⑪ Detachable discharging plate with hook
⑫ Roller guide of pallet

Fig. 2 Overall schematic diagram of the prototype.



(a) feeding conveyor



(b) carrying plate with roller attachment

Fig. 3 Cabbage feeding conveyor and a series of cabbage carrying plates.

To pile cabbages being fed into the pallet in an order, mesh pallet or piling conveyor should have three degrees of freedom such as x, y, and z directions. Since automatic positioning of a pallet to pre-specified x, y, and z locations requires a complex mechanism, piling conveyor was chosen to have planar two degrees of freedom. And moving a piling conveyor up and downward was substituted with a guided retractable round bellows(250 mm contraction and 1,000 mm expansion). Bellows of 300 mm inner and 340 mm outer diameters was mounted at the end of piling conveyor to reduce the damage of cabbage caused by free falling from the piling conveyor. Circular brush plates were mounted inside the bellows to reduce the passing speed of cabbages through the bellows. The role of the brush was to reduce the freefall impact when cabbage fell down through the bellows. Outside the bellows, two sets of springs were mounted to adjust the extraction force of the bellows. The operator could expand and contract the spring-mounted bellows by handling the attached aluminum rod. Piling conveyor was driven in two different modes, manual and automatic modes and was controlled sequentially using PLC to position the end of piling conveyor within the pallet. Each layer had 20 pre-specified piling positions, 5 stages in radial(R) and 4 stages in transverse(θ) directions as shown in Fig. 4. Two hydraulic cylinders with rotary encoders were used for activating piling belt conveyor. Piling conveyor was controlled to position sequentially in response to the sensor signal of incoming cabbage. An extra portable control box was mounted to the end of piling conveyor. A portable control box had functions manual and automatic operations, reset and emergency stop buttons. 25Ø×300 mm hydraulic cylinder was used to activate the piling conveyor in radial direction in the range of 600 mm. Double sliding mechanism was adopted to move lower part 300 mm and upper part 300 mm as shown in fig. 5a. Details of mechanism and drawings refer to Song(1999). 25Ø×150 mm hydraulic cylinder was also used to rotate the piling conveyor in the range of 30°, 15° in each direction(clockwise and counter clockwise) as shown in fig. 5b. Size of the piling conveyor was designed to be 200 mm × 300 mm × 770mm.

Once pallet was filled with cabbages, pallet-holding device was released by pressing pedal to release the pallet fixture. And an operator pushed pallet to slide down to the ground. Height of the base of the prototype was designed to be 500 mm above the ground. Unloading plate was mounted with a series of caster for the pallet to slide easily. And a wheel were attached at the end of unloading plate. Since the ground may not be flat always, a hinge joint was selected to connect the base frame and unloading plate.

For the sequential control of the system, PLC (MASTER-K50, LG Industrial Systems Co. Ltd.) was used. And details of PLC sequence program refers to Song(1999). Fig. 6 shows the flow diagram of the motion block diagram of PLC.

The overall system performance of the prototype was evaluated through testing each unit such as collecting and feeding unit from pull-up-device, piling unit, and unloading unit. One hundred cabbages harvested at Hwasung, Korea were used without being treated for the experiment.

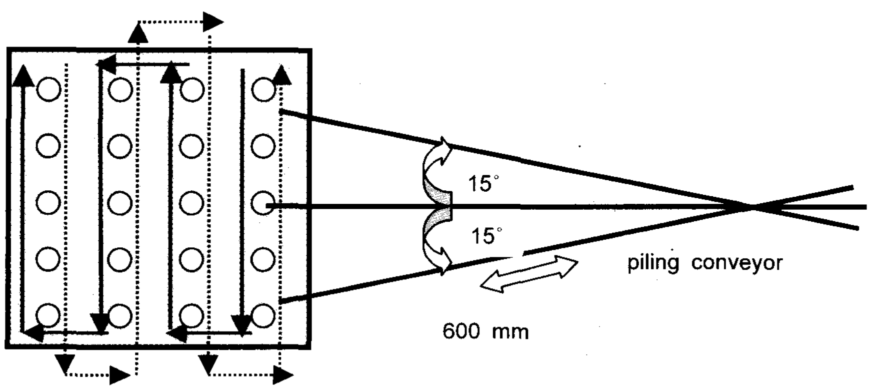
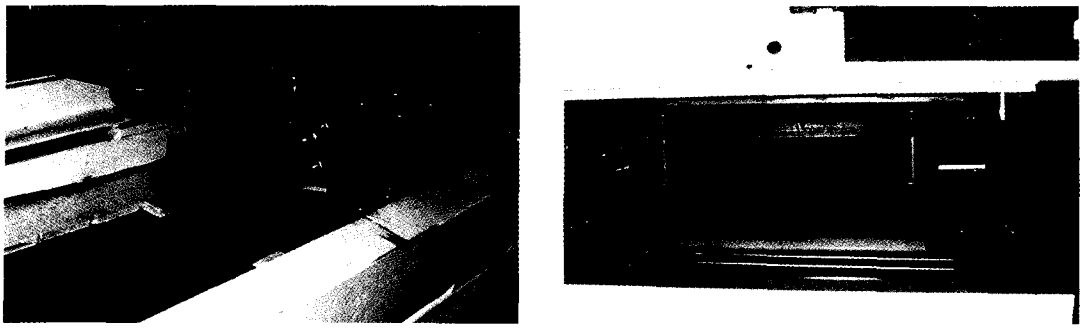


Fig. 4 Pre-specified path sequence of bellows mounted at the end of piling conveyor.



(a) double sliding linear mechanism (b) rotating unit

Fig. 5 Linear and rotating units of the piling device.

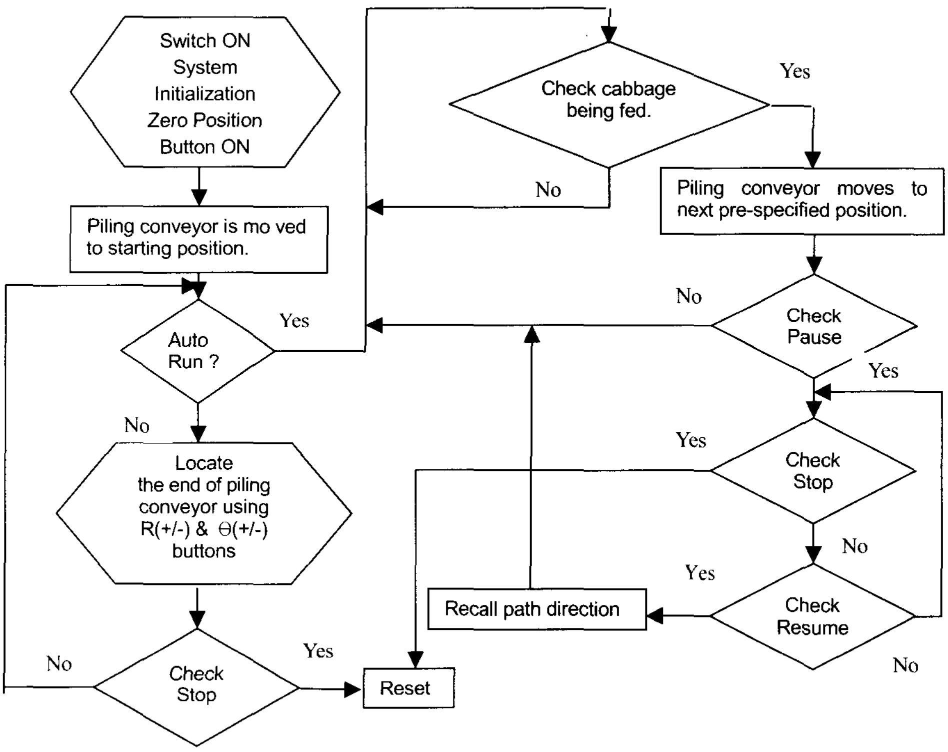


Fig. 6 Flow diagram of PLC control of piling system.

3. RESULTS AND DISCUSSION

Geometric properties of six varieties of C-cabbage were measured. The overall width and height ranged from 460 mm to 760 mm and from 330 mm to 440 mm respectively. Width and height of the head ranged from 190 mm to 240 mm and from 260 mm to 360 mm respectively. Weight ranged from 25 N to 45 N. The number of outer leaves was 10 to 15.

Table 1 shows the damage of C-cabbage from free falling. Damage caused by free fall was measured with the number of damaged(torn off)

Table 1 Damage of cabbage caused by free falling

Weight (N)		Height(mm)			
		1000		1300	
		WD(N)	LR	WD(N)	LR
2.5-3.0	Range	0.00-0.13	0-2	0.00-0.27	1-6
	Avg	0.06	0.8	0.11	2.8
3.0-3.5	Range	0.00-0.04	0-1	0.10-0.34	2-4
	Avg	0.03	0.2	0.19	3.6

Avg : average WD : weight decrease.
LR : number of leaves removed.

outer leaves and weight decrease after removing damaged leaves. Free falling at the height of 500 mm caused little damage to the outer leaves. If cabbage falls down at the height over 1,000 mm, some kind of a buffer device to reduce the impact is necessary. A rubber pad was placed at the bottom of a mesh pallet. Once bottom layer is filled with cabbages, bottom layer works as a buffer. From the second layer, impact damage caused by free fall is not that serious. However, piling in an order increases the holding capacity of the pallet and reduces damage caused by contact friction among cabbages.

Fig. 7 showed the overall view of the developed prototype, which was composed of the system controller and three parts such as feeding device, automatic piling device with retractable bellows, and pallet unloading device. Size of cabbage feeding device was 2,012 mm × 520 mm × 1,630 mm and weighed 118kgf and piling system had the size of 1,025 mm × 450 mm × 1,187 mm and weight of 82 kgf. Unloading system was the size of 1,150 mm × 600 mm × 100 mm and weighed 35kgf. Total system size and weight were 3,940 mm × 520 mm × 1,630 mm and 235kgf respectively. Fig. 8a shows the hand controller attached at the front end of the piling conveyor, which can control the motion of the piling conveyor. Fig. 8b shows the overall controller. Fig. 8 shows the flow diagram of controller.

Indoor laboratory experiments showed that the cabbage carrying feed conveyor worked successfully in the range of 0.18 m/s to 0.36 m/s. Piling conveyor

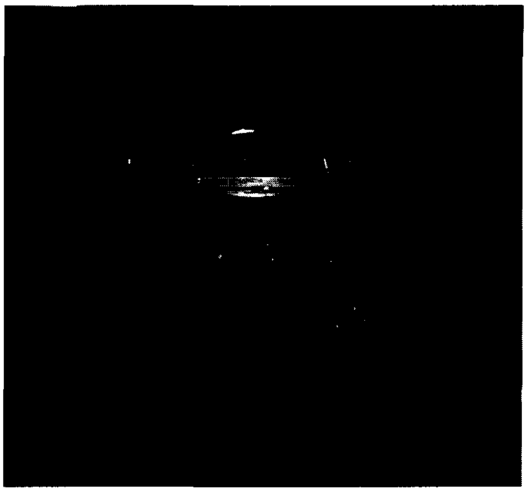
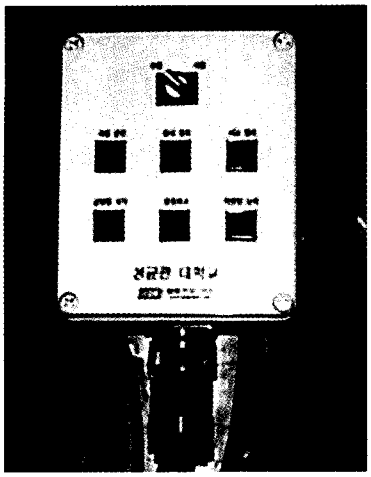


Fig. 7 Developed prototype.

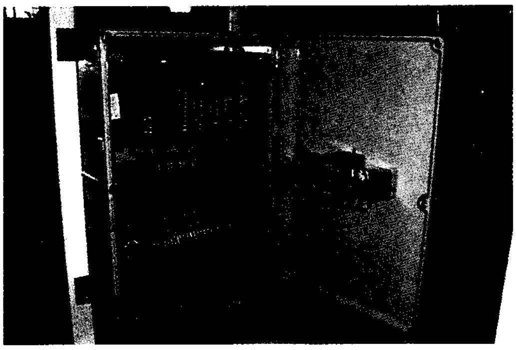
also worked successfully in the speed range of 0.39 m/s to 2.38 m/s. With the conveying speed 0.46 m/s of the pull up belt of the cabbage harvester, simultaneous running of cabbage feeding and piling conveyors showed proper operation in the ranges of 0.26 m/s to 0.36 m/s and 0.9 m/s to 2.4 m/s respectively.

When a tractor moved at the speed of 0.3 m/s, the proper speed of the pull-up belt conveyor of the harvester was 0.46 m/s(Hong, 1999). Considering the feeding speed of the pull up belt, the speed of the cabbage feeding conveyor should be over 0.34 m/s and the proper speed range of the piling conveyor was 2 m/sec to 2.4 m/sec.

Piling experiments have been done with and without bellows five times each. Combined type of handling such as handling with bellows for the 1st, 2nd and 3rd layers and handling without bellows(as it is fully contracted) for the 4th and 5th layers was chosen based on the results of piling experiments. The selected piling scheme showed that cabbages were piled in an order at the 1st, 2nd and 3rd layers without any serious damage because of the bellows. Without bellows operator should bend his body a lot to pile cabbage at the bottom(1st), 2nd, and 3rd layer pilings. For piling at the 4th and 5th layer, bellows was fully contracted to the reset position and operator did not control the bellows. In fact, handling bellows was difficult at the 4th and 5th



(a) hand controller unit



(b) overall PLC system controller

Fig. 8 controllers for the system.

layers because there was not enough free space for bellows to be handled. And it should be avoided that bellows it self became an obstacle to the path of cabbage. Since the piling conveyor automatically moved along specified positions sequentially and the height of falling was less than 500 mm at the 4th layer, cabbage from the piling conveyor did not move much after falling. Since operator did not need to bend his body seriously at the 4th and 5th layers, he could work easily without bellows. Operator only modified the attitude and position of the cabbage slightly without concerning the bellows control. Piling capacity of the proposed system showed about 95.6% of the capacity by manual piling.

4. CONCULSIONS

Since Chinese cabbages weigh 25 to 45 N and are big in size at the time of harvest, handling operations such as harvesting, loading, and unloading including transportation require the highest labor demand among all other cultivation processes. Most harvesters developed so far adopted a sort of slide and free falling way in collecting cabbages into the pallet. Three or four labors are usually required for cleaning incoming cabbages and loading those in the pallet. Because of the required time for piling cabbages without severe damage and the required space capacity to carry empty and loaded pallets, harvesting speed should be adjusted in accordance with time required for consecutive operations.

In this paper, semi-automatic cabbage piling and pallet unloading system, which required one labor, was developed based on the pre-specified functional requirements of harvesting process. The system allowed the operator to modify "the position of cabbage slightly to ensure piling in an order without serious damage. Overall system worked successfully resulting into almost same capacity while improving job productivity and reducing required labor. The prototype could handle around one cabbage/second and showed practical feasibility in the sense of the system cost, labor reduction, and maintenance of the cabbage quality during harvest operation.

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