Summary

Recently, the 65 or older-year occupied about 50% of all the agricultural labors. The aging of the agricultural labor and labor shortage are serious problems. To solve these problems, more mechanization and labor saving of the cultivation system are needed.

Hokkaido is a big sugar beet production area in Japan. The sugar beet is cultivated by the transplanting in Japan. Compared to England where sugar beet are cultivated by direct sowing; the production cost of transplanting in Japan was three times as expensive as direct sowing in England. Furthermore the working time of the transplanting in Japan was seven times as long as direct sowing in England because weeding is necessary in Japan. The mechanization of the transplanting was achieved, however it is difficult to lower working time of transplanting. This is the reason why direct sowing is now being focused in Japan. But, the weeding thinner tasks that are operated manually are added. And these tasks occupy 60% of all operations of the direct sowing. Therefore, the labor saving in direct sowing will be achieved if the weeding thinner will be mechanized.

The objective of this study is to develop the automatic weeding thinner for the direct sowing of sugar beet. To achieve this objective, first, the recognition between the sugar beet and the weeds was developed; second, computer simulations were implemented to evaluate the correct recognition rate of the sugar beet and the weeds; third And the weeding thinner mechanism, the weeding thinner machine, the weeding thinner system and the control algorithm were designed and developed; fourth, to evaluate the performance of the prototype weeding thinner machine, the indoor and the field tests were performed. The results obtained in this study are summarized as follows:

A. Recognition between Sugar Beets and Weeds Based on Image Processing

For the automatic weeding thinner operations, the recognition between the sugar beet and the weeds is required. The recognition method that can work under the actual agricultural field condition was developed.

The static images of the sugar beet and the weeds taken by the digital camera were used to investigate the segmentation method (the separation between the plants the soil) and the shape characteristics that were effective in the recognizing the sugar beet and the weeds. The plane, which separates the plant cluster and the soil cluster, was determined by the principal component analysis. The plant cluster and the soil cluster were separated by the vice-axis in this plane. The thresholding for the segmentation images were determined by the discriminant analysis. The objects of the recognition were the sugar beet and three types of weeds. The linear discriminant function that included six shape characteristics was produced. As a result, the correct recognition rate of the sugar beet was 85.7%. To increase this correct recognition, another linear discriminant function that included the same six shape characteristics plus a new shape characteristic “leaf angle” was applied. As a result, the correct recognition rate of the sugar beet and the weeds were 87.2% and 94.4%, respective-

ly.

Next, recognition was performed using the images taken by the CCD camera that was mounted in front of a moving tractor. The recognition rate of the sugar beet was about 60% when the linear discriminant function that was produced by using the static images was applied. This decrease was caused by the linear dicriminant function that included the area as a parameter. Therefore, the color information (the Q value of the YIQ color coordinate system) was applied. The thresholding of the Q value was determined as -6. Under the -6, the recognition based on a new discrimant function that included eight parameters was performed. As a result, the correct recognition rate of the sugar beet and the weeds were 89.7% and 91.0%, respectively. This correct recognition rate was equal to that of the static images taken by the digital camera.

Last, the image processing time that was important for the real time processing was measured. The maximum image processing speed was 3Hz when Intel Celeron professor 440MHz was used. In this case, the maximum speed of the tractor was 0.9m/s.

By these results, it is clear that the recognition method developed by this study was the practical method.

B. Evaluation of Correct Recognition Rate by Weeding Thinner Simulations

The weeding thinner algorithm and two computer-simulations were developed. The relationship between the correct recognition rate and the loss rate of the sugar beet was clarified.

The simulation1 was developed using the obtained correct recognition rate of the sugar beet and the weeds (89.7%, 91.0%) to understand the relationship among the forcible thinning distance (the minimum distance that should be vacated), the weeds rate and the weeding thinner accuracy. As a result, when the forcible thinning distance and the weeds rate increased, the weeding thinner accuracy decreased. So, it was concluded that suitable forcible thinning distance was 100mm (The average intrarow spacing was 120mm, Set intrarow spacing after weeding thinner was 240mm). When forcible thinning distance was 100mm and the weeds rate was 400%, the loss rate of the sugar was 90.6%. This result meant that if the weeds rate was less than 400%, the weeding thinner accuracy was more than the correct recognition rate of the sugar beet.

The simulation2 was developed using the various correct recognition rates of the sugar beet and the weeds to understand the relationship between the correct recognition rate and the weeding thinner accuracy. As a result, the weeding thinner accuracy was affected by the correct recognition rate of the weeds rather than the recognition rate of the sugar beet.

C. Development of the Weeding Thinner System

In the case of the automatic weeding thinner operation, the weeding thinner edges should always be operated on the subsurface for the weeding and if the weeding thinner edges reach the sugar beet which should be left, the edges should not touch them. Therefore, a weeding thinner mechanism that can open and close by hydraulic force was developed. The opening clearance of the designed weeding thinner edges was 120mm.

The prototype weeding thinner machine was composed of the weeding thinner mechanism, the hydraulic solenoid valve, the gauge whole, the rotary encoder and the whole for mounting the rotary encoder. The weeding thinner system was composed of the CCD camera for the image acquisition, the PC for the recognition, the PIC for the control, the image acquisition device, the weeding thinner machine and control box. The PIC was used to control the weeding thinner edges. The algorithm for the control of the weeding thinner, the electronic and the hydraulic circuit was designed and developed.

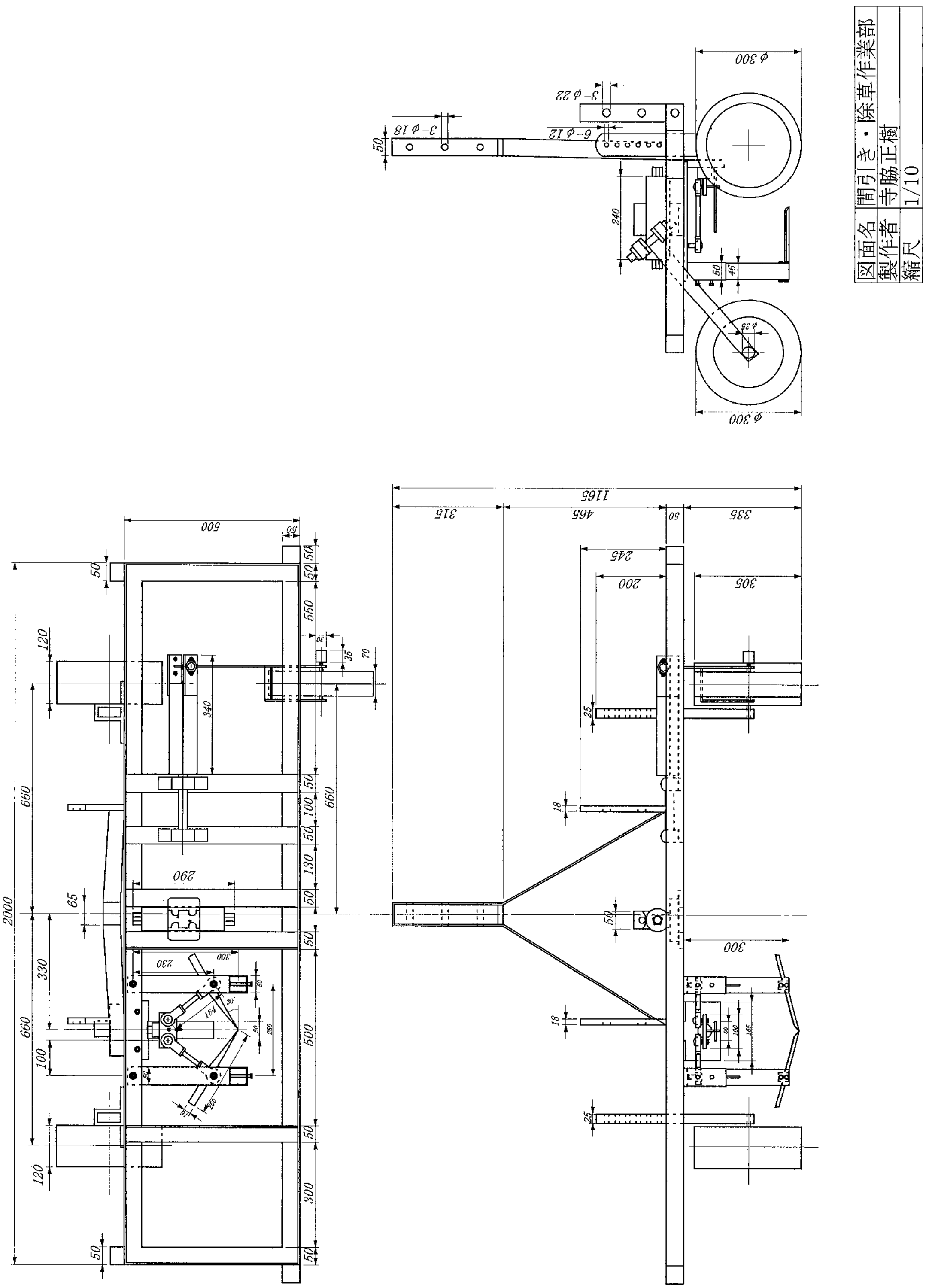
D. Performance Test of Weeding Thinner Machine

The indoor and the field test were tried to evaluate the performance of the weeding thinner machine.

First, to understand the basic performance of the weeding thinner, the open and the close time and the reaction time were measured. The open and the close time was measured by the potentiometer that was mounted on the weeding thinner mechanism; the reaction time was measured by the proximity sensor. As a result of the open and the close time measurement, if the cone index of the soil was less than 0.19MPa, the open and the close time was not affected by the cone index of the soil. If the flow rate was more than 15L/min, the open and the close time did not change. The open and close time was about 80ms and 100ms, respectively. It was concluded that this open and close time was practical. The measurement result of the reaction time was 128ms.

Next, the indoor test was tried to determine the position where the CCD camera would be mounted on the tractor and to calculate the control accuracy of the weeding thinner edges. The control accuracy of the weeding thinner edges was not affected when the distance between the CCD camera and the weeding thinner edges was 1000mm to 3780mm and the tractor speed was 0.1m/s to 0.3m/s. As a result of the indoor test using the dummy sugar beet, the maximum error of the weeding thinner edges was 43mm.

Last, the field test was tried to evaluate the weeding thinner machine. The tractor speed was 0.1m/s. The total number of the sugar beet used in the field test was 185. If the ideal weeding thinner was performed, 144 sugar beets were left in stand. As a result of the weeding thinner machine, 127 sugar beets were left in stand. The accuracy of the automatic weeding thinner operation was 88.2%. This result was lower than the result of the simulation. The main reason of this result was the lack of the measurement accuracy of the intrarow spacing. But, the weeding rate was 94.8% and the sugar beets that was damaged by the weeding thinner edges were 5.5%. It was clear that the developed weeding thinner system was enough in conducting on automatic weeding thinner operation.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