DEVELOPMENT OF ELECTRICAL CONTROL DEVICE FOR AUTONOMOUS TRACTOR

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1. INTRODUCTION

The Higher industerialization, The shorter labor for farming with not also reduction of quantity like as agricultural population but also deterioration of quality like as old age or womon in Korea.
Most of Farmers magnified their farm land for increasing income, but they have been in difficulties because of employment of skillful driver of farm machinery and ensurance farm labor which need finishing seasonable works.
To solve above problem, It is widely proceeding to robotization throughout all the field of agriculture. Robotization of farm works must be premise of moving of robot in land-dependant-agriculture and performance of farming robot is depend on autonomous travelling technology which can trace our desired path with small tracking error.
For autonomous travelling, It must be controlled electrically that operating device of tractor which has been handled by human and cope with variable environment detecting interference on the path.
Recently technologies of robot and autonomous traveling for labor-saving in farm work have been widely developed with sensor and navigation algorithm.
Yukumoto et al.(1997) tested to cultivate by unmanned tractor on which electro – hydraulic actuator, IMU and laser distance meter mounted, he reported tracking error is less than 10cm.
Parkinson et al.(1997) tried that tractor travel autonomously on desired path with a few cm by using CDGPS which modified landing control system for air vehicle.
Most study on autonomous tractor has paid no attention to set up design data of actuator with sensor relatively, because being given much weight in navigation algorithm.
In this study, a compatible actuator for unmanned tractor was developed and evaluated it's performance. Details are as follows.

1. Investigation of design factor for electronic steering control of tractor
2. Development of actuator and system controller
3. Evaluation of tractor control system through traveling test

2. PROCEDURES AND METHODS

2.1 Design of steering controller

2.1.1 Steering model of wheel type tractor

We assumed as follows to make decision of steering rate in 2D geometry model of steering system

□ Differential gear act ideally to turning radius.

□ Slip toward travelling and lateral direction to be ignored

□ Dynamic limitation of tractor to be ±35degree as maximum steering angle and 23km as maximum speed.

When tractor traveled to z(m) with steering rate α, moving distance of center of front wheel toward x, y axle is,

$$x = z\cos(0.5\alpha z + \delta_i + \theta_i)$$
$$y = z\sin(0.5\alpha z + \delta_i + \theta_i) \tag{1}$$

Coordination of modeled tractor on x, y plane is,

$$\begin{bmatrix} X_{i+1} \\ Y_{i+1} \end{bmatrix} = \begin{bmatrix} 1 & 0 & X_i \\ 0 & 1 & Y_i \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \tag{2}$$

Yaw angle from center line on tractor is,

$$\theta_{i+1} = z(0.5\alpha z + \delta_i)/L + \theta_i \tag{3}$$

The rotated angle of x, y plane about z axis is,

$$R_\theta = \begin{bmatrix} \cos\theta & \sin\theta & 0 & 0 \\ -\sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}$$

where

z: traveling distance of tractor during steering(m)
δ : steer angle of front wheel about center line on tractor(rad)
θ : yaw angle about center line on tractor (rad)
α : steering rate(rad /m)
L: distance between center of front wheel and center of rear wheel(m)

Maximum steering angle which tractor can keep stabile turning is,

$$\frac{Wv^2 y_s}{gr} \geq Wx_g, \qquad r = \frac{L}{\sin\theta} \tag{5}$$

where

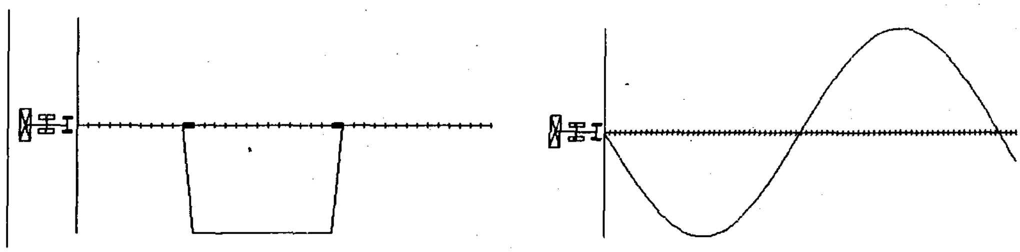
W : weight of tractor(N), g: acceleration of gravity(m/s2)
v : speed of tractor(m/s), *r*: turning radus (m)
ys : vertical distance between ground and weight center of tractor (m)
xg : **horizontal distance between grounding surface of wheel and weight center of tractor (m)**
L : distance between front and rear axle(m)

Therefore maxium steering angle limited by tractor speed

$$\theta = \arcsin\left(k\frac{L}{v^2}\right) \qquad (6)$$

2.1.2 Steering Simulation

The steering simulation was performed on sinusoidal curve and crank as virtual pathes in personal computer(Pentium II 300Mhz). Variable ranges was listed Table 1



Crank-shaped path Sinusoidal path

Fig. 1. Virtual Path Drawn in Simulation S/W

Table 1 Range of simulated variables

Variable	Range
Target Point	0.5m～4.5m
Steering Rate	0.08～0.20rad./sec
Speed	0.2m/s～6m/s

2.1.3 Design objective

○ resolution of steering : Θ = 0.2deg

○ steering speed : 1.8sec./70°(+35°~ -35°)

2.1.4 Design constant

○ Torque needs

$$T_a = \frac{(Jm+Jl)}{g}\times\omega = \frac{(Jm+Jl)}{g}\times 2\pi \times \frac{(fl\times 1.8)}{360}\times\frac{1}{ta} \qquad (7)$$

$$Jl = Js + Jg_1 + Jg_2 + Ph = 184.8N.cm$$

where

Ta: steering torque (N-cm)

Jm :inertia moment of steering motor (N ·cm²)

Jl: inertia moment of load (N · cm²)
ω :angle acceleration of motor (rad/sec²)

2.2.Design of driving control device

(1) Brake control device

Efficiency braking torque depends on the pressure of hydraulic oil in driving cylinder which can be controlsolenoid valve. We used experimental formula that was proposed by Hedrick in order to control the press force of brake pad

$$T_{br} = K_{br} \cdot P_{break}, (K_{br} = 1.11 N \cdot m / kPa) \quad (8)$$

where

Tbr : brake torque
Kbr : transfer contant
Pbrake: pressed force on brake pad
$P_{brake} = C \cdot P_{input}$
Pinput : input force from outside for driving brake
C: transfer contant

(2) Clutch and transmission control device

○ Characteristic of changing speed of transmission

In most of tractors, the characteristic curve of speed engaged by gear stage can be expressed as follows

$$V_{d1} = (aT_a^3 + bT_a^2 + cT_a + d)\frac{N_a}{N_r} \quad (9)$$

V_{d1} : the speed of tractor
T: Stage of reduction gear
N_a: measured engine rpm
N_r: rated engine rpm
a, b, c, d : constant

○ Structure of controller

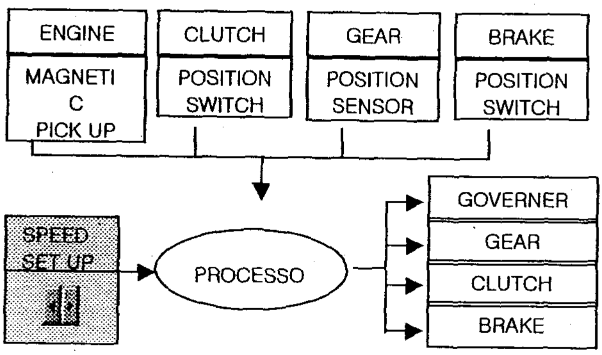


Fig.2. Schematic Block Diagram of Speed Controller

Speed controller was designed to change speed automatically by controlling governer postion, clutch position and gear stage according to the amplitude of voltage as input signal from main processor or operator(Fig.2)

(3) Detection of device position

Position of continuous control device for operating tractor was detected potentiometer which was connected to device with steel wire. Position of stage control device was detected by comparing voltage of potentiometer and voltage of reference that calibrated according to each stage.

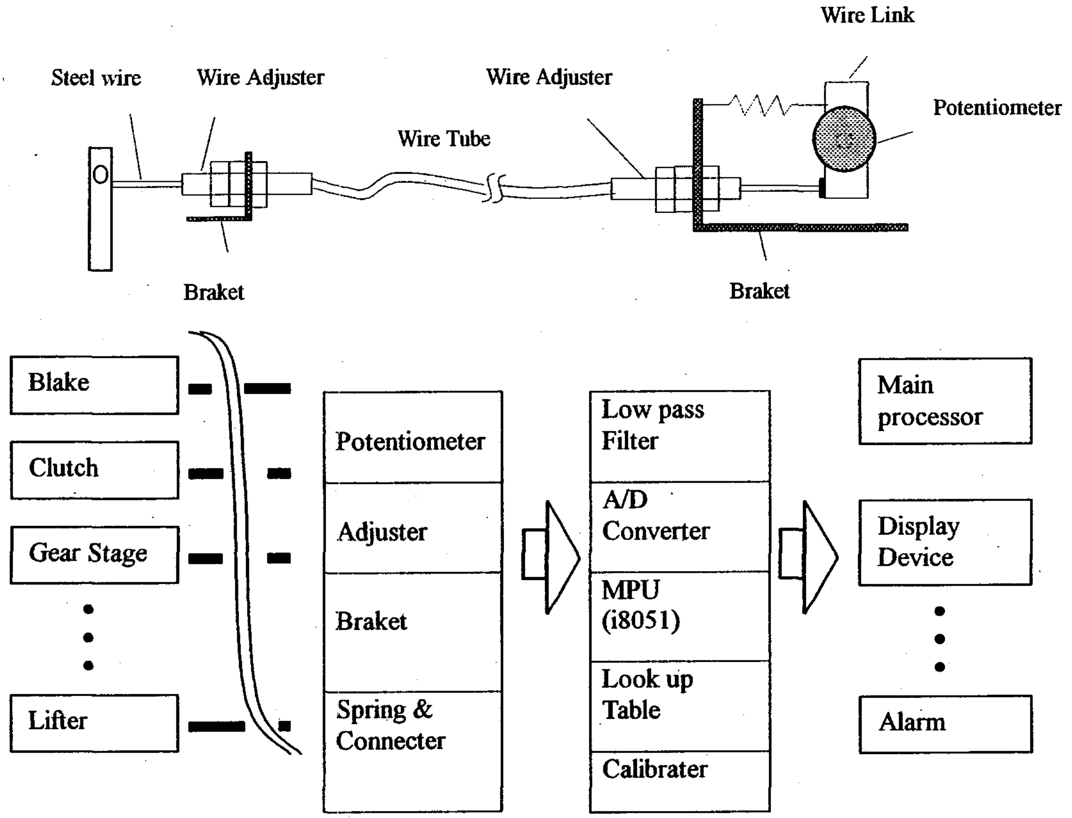


Fig.3. Schematic Diagram of Position Controller for Operating Lever

(4) Algolithm for processing sensor signal

Input analog signal from position detecter was mixing with noise caused by switching frequency of power supply and tractor vibration. To remove noise in sensor, we used low pass digital filter which was designed as 10Hz of cut off frequency. Amount of caculation in these finit impulse response filter increase rapidly according to extending filter tab of sampling frequency. To solve this problem, modified finite impulse response filter was developed by filter algolithm which is as follows

Filtering Algolithm

$$y_k = \sum_{m=0}^{N-1} \frac{1}{N} x_{k-m} \tag{10}$$

yk: output value of filter, xk: input value of filter
N: number of filter tab

Cut off Frequency

$$N = \frac{f_s}{f_c} \times 0.293 \tag{11}$$

fs: Sampling Frequency, fc: Cut off Frequency
N: number of filter tab

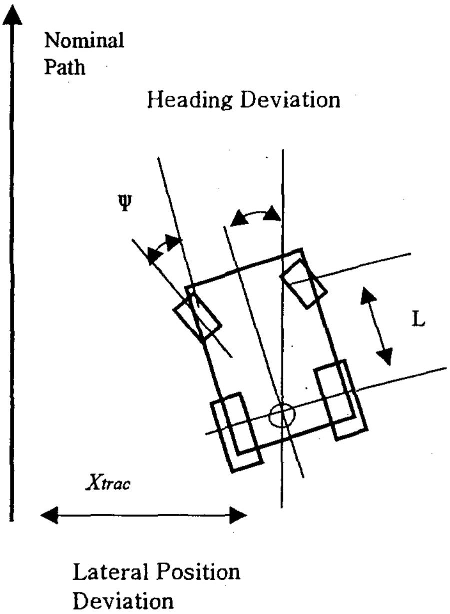
(5) **Traveling algolithm for evaluation of system**

To evaluate traveling performance of unmanned tractor, applied algolithm was as follows

$$\begin{bmatrix} X_{trac} \\ {}^{\bullet}\theta \\ {}^{\bullet}\phi \end{bmatrix} = \begin{bmatrix} 0 & V_{x0} & -\frac{V_{x0} l_1}{(l_1 + l_2)} \\ 0 & 0 & -\frac{V_{x0}}{(l_1 + l_2)} \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} X_{trac} \\ \theta \\ \phi \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} u \tag{12}$$

X_{trac}: The deviation of lateral position
${}^{\bullet}\theta$: The deviation of heading
$\dot{\phi}$: The deviation of steering angle

To bring the deviation of lateral position and tractor heading into closer zero, output steering angle was as follows



$$\phi_{x+1} = A_x {}^{\bullet}\theta + B_x X_{trac}$$

$$(A_x = \frac{L}{3V_{x0}}, B_x = k_1 (6X_{trac})^{\frac{1}{3}} (V_{x0})^{\frac{-2}{3}}) \tag{13}$$

(5) System controller

System controller was designed in order to make a decision output command that was based on the path and position data through DGPS and laser finder. Sensor data of tractor inside was also transmitted to system controller with 10Hz refresh time through serial communication.

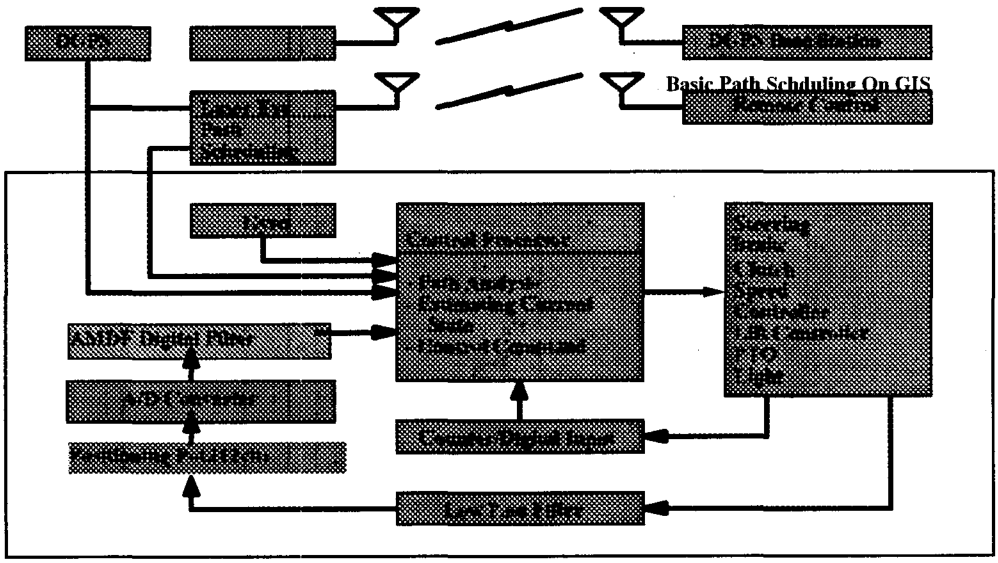


Fig.5. Schematic Diagram of System Controller

3. RESULTS AND DISCUSSIONS

3.1 steering control device

(1) control simulation

Fig. 8 shows the maximum deviation of tracking on a sinusoidal path at variable steering rate and distance of target point on x, y plane which x axis is distance to target point, y axis is deviation. Maximum deviation decreased some in range of 1.5~2.0m, included some alternant tracking in range less than 1.5m, increased rapidly in range above 2.0m as target point for tracking.

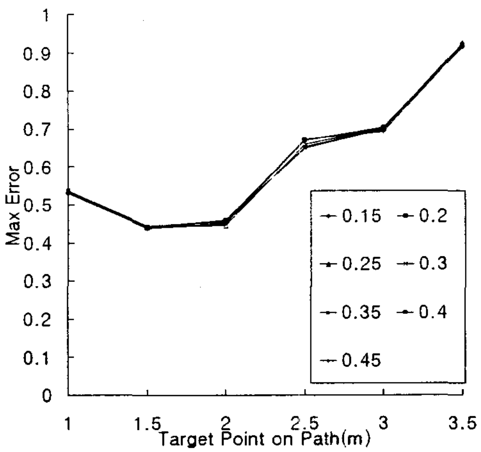


Fig. 8. Maximum error at each target point and steering rate on sinusoidal path.

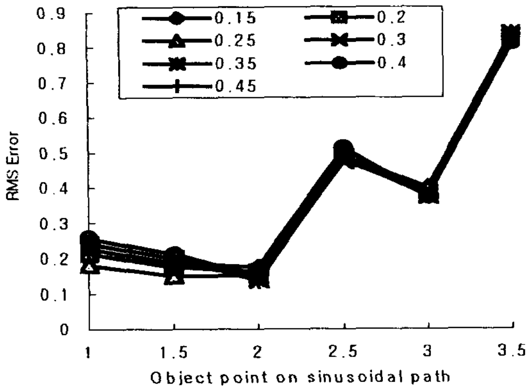


Fig.9. RMS error at each object point and steering rate on sinusoidal path

Fig.9 shows rms deviation of tracking on a sinusoidal path at variable steering rate and distance of target point on x, y plane which x axis is distance to target point, y axis is deviation. Deviation in rms was influenced by steering rate when target point was less then 2.0m, influenced by only distance to target point when target point was above 2.0m, increased by alternant tracking when target point was less then 1.5m.

Steering simulation by virture model of tractor indicated roughly the characteristic of steering , but its results was restricted to predefined condition for traveling

(2) Manufacturing and test

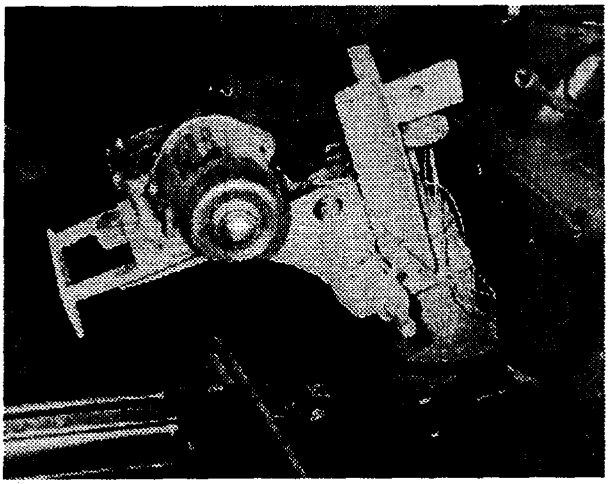


Fig.10. Picture of Steering Control Unit

Steering actuator was manufactured by fabricating DC moter with reduction gear and rotary potentiometer with non contact type 5 turns. Initialization time of this actuator was about 3.6 sec. And able to control speed from 1.6 sec to 9.4 in full steering angle(-35~+35) with keeping 180 N cm as load torque.

3.2 Brake control device

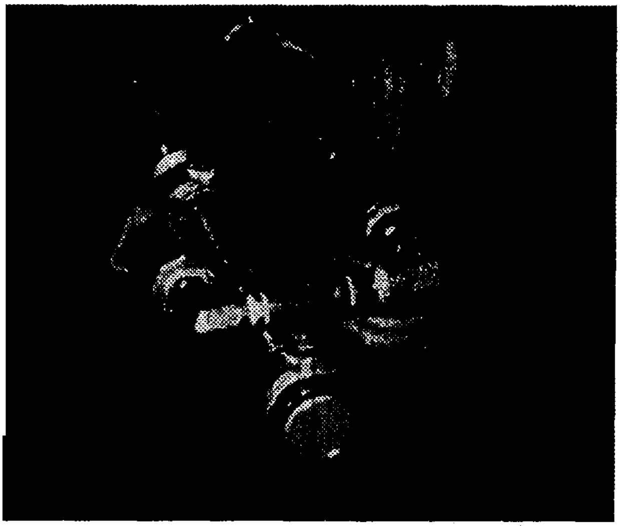
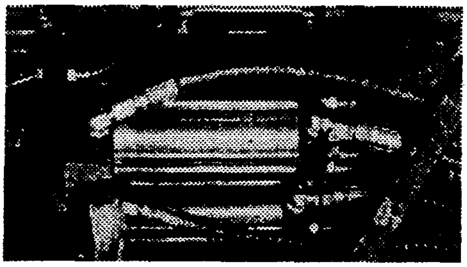


Fig.11. Picture of Brake Control Unit

Brake actuator manufactured by fabricating hydraulic cylinder and pressure trasducer for realization of Hedrick's experimental formula like as fig. 11.
This actuator had 160 ms as response time, about 0.13Mpa as resolution of control pressure and able to control by 16 Hz as PWM frequency.

3.3 Transmission control device



Gear shifter was manufactured by fabricating hydraulic cylinder and position switch for changing speed. Characteristic constant of tranmission in fomula(9) was set as a= 0.0157, b=-0.0614, c=0.3456, d=0.2357
This device was controlled by processor which can recieve current engine speed from magnetic pick up sensor and set speed as input, which can output control command for governer and gear shifter.
When stage of reduction gear was changed, Generated fluctuation of engine speed was from 80rpm to 250rpm, Tested results of changing speed was as follows

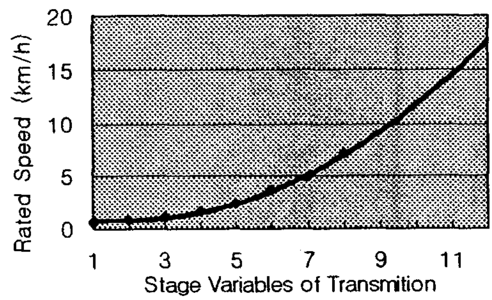


Fig.12. The Result of Speed Controller

3.4 Field test

Manufactued each control device, DGPS, rate gyro and wireless modem was mounted on base tractor (26 ps) made by Daedong in korea(Fig. 13). Tractor weight increased as 78 kg, but did not appear to change turn radus and steering performance except increasing of 7 cm in brake distance at 21km/h as maximum speed.

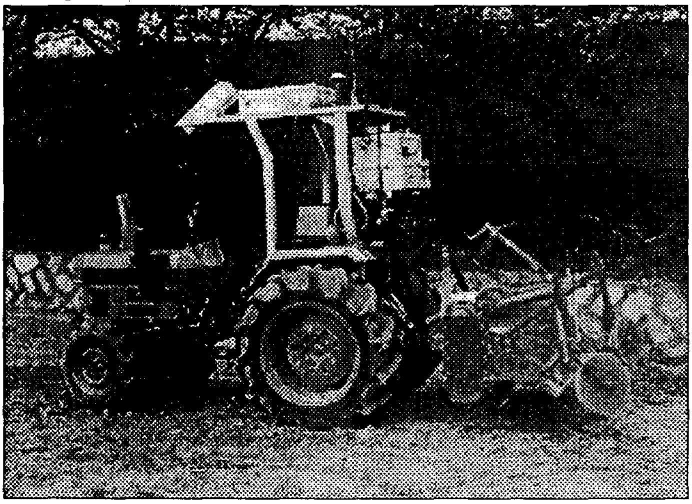


Fig.13. Picture of Prototype Autonomous Tractor

The tests were performed at the experimental farm of NAMRI coordinated by DGPS as shown Fig.1. When tractor started to part from 1m at desired path, Tractor approached to desired path in 3 sec. with less than 30cm as tracing error. During tracking path, tractor kept less than 20cm on strait path and kept less than 50cm on sinusoidal path with 6m turning radius as shown fig. 15.

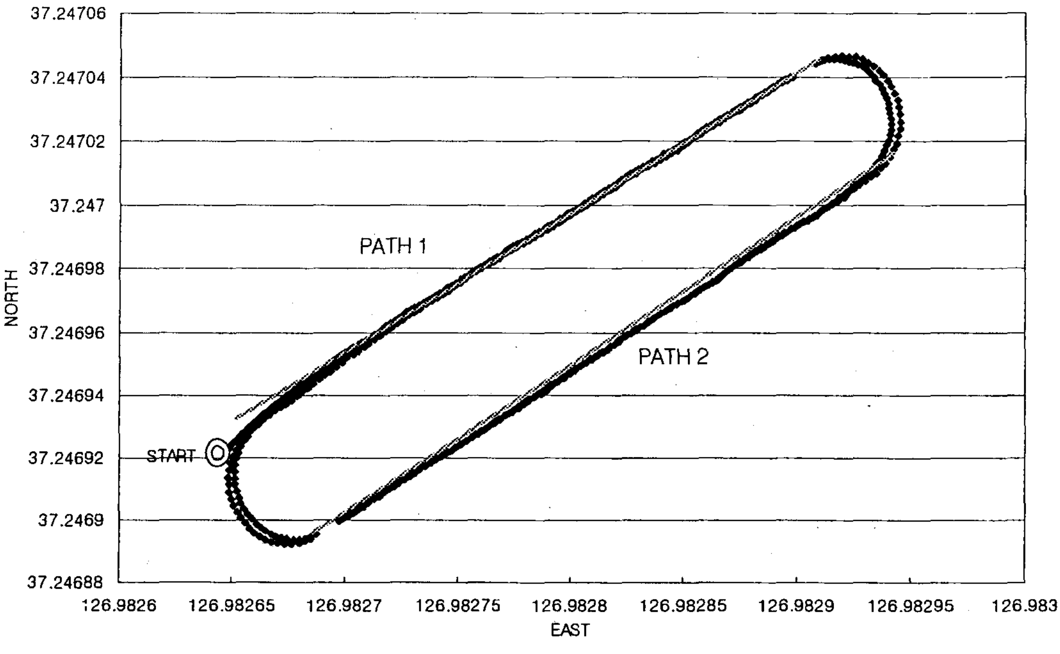


Fig.14. The Result of Tracking Path by DGPS Coodinates

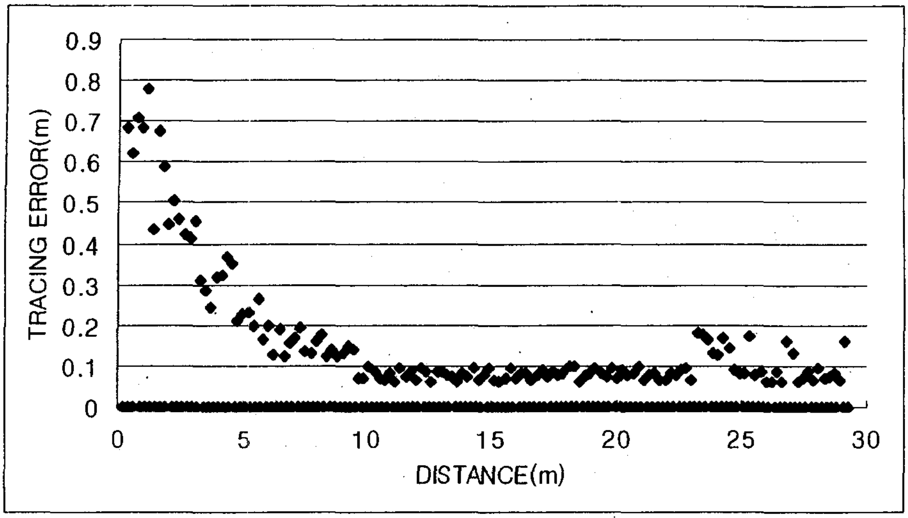


Fig.15. Error Range During Tracking Desired Path

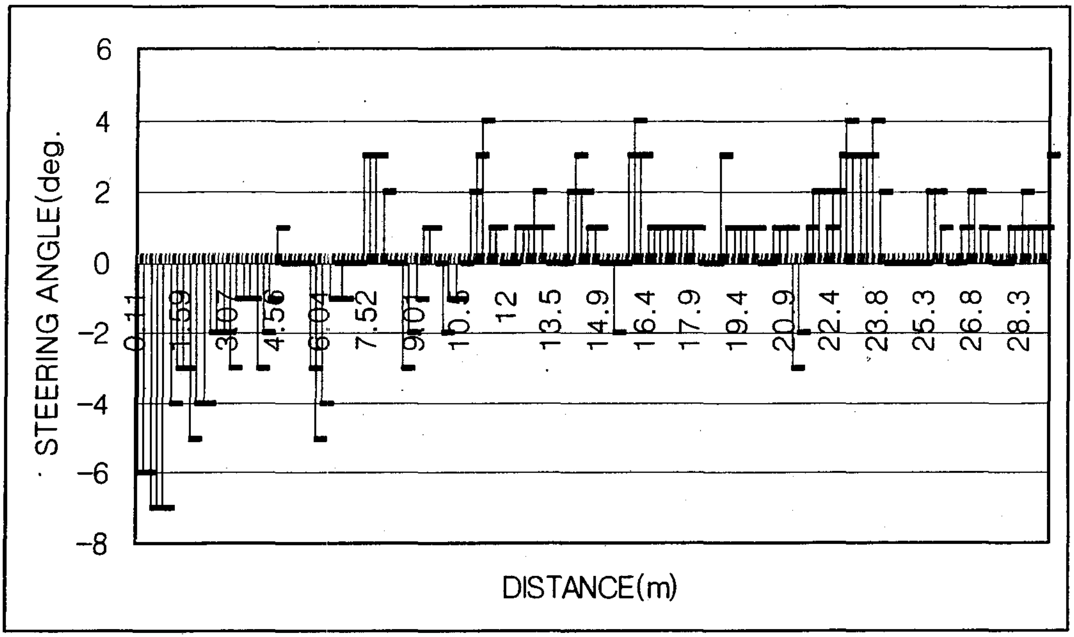


Fig.16. Output Signal for Steering Control During Tracking Path

4. CONCLUSIONS

(1) Steering control unit in closed loop using a DC motor and a encoder was fabricated and the test results showed that the resolution of control angle, full steering angle, and full steering time were 0.2° , ± 35° , and 1.8seconds, respectively.

(2) Using a hydraulic cylinder, a pressure transducer and Hedrick's experimental equation, brake control unit was constructed. Its response time and pressure control resolution were 160ms and 1.33kg/㎠

(3) A sensor block and a interface unit that could measure the position of actuators remotely were developed with the combination of wire links. To obtain stable signal, AMDF digital filter was designed with the cutoff frequency of 11Hz.
(4) Speed control unit was developed with the combination of a gear shift and a governor controller.
(5) When the developed autonomous tractor was tested on the planned path with the position signal from GPS receiver, the RMS position errors were 20cm for straight paths and 50cm for curved paths.

5. REFERENCES

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