Gantry Robot with Extended Workspace for Pavement Sign Painting Operations

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The current method for pavement sign marking operations is labor-intensive and very dangerous due to the exposure of workers to passing traffic. It also requires blocking traffic for a long period of time resulting serious traffic jam. This paper deals with the development of a robotic system for automating the pavement sign painting operations. The robotic system consists of gantry frame equipped with transverse drive rail and automatic paint spray system. The workspace of the gantry robot is extended to one-lane width with the transverse rail system. This research also includes the development of font data structures that contain the shape information of pavement signs, such as Korean letters, English letters and symbols. The robot path is generated with this font data through the procedures of scaling up/down and partitioning the signs to be painted depending on the workspace size.

Key Words : Field Robot, Construction Automation, Parement Sign Painting

1. Introduction

Traffic signs are utilized to provide the drivers of passing vehicles with the information about the state and characteristics of the road. With the aid of the traffic signs, traffic flow can be maintained safely and efficiently. The traffic signs are classified into three kinds; regulatory signs, warning signs, and guidance signs. Among these, the signs that are painted on the pavement surface are referred as 'pavement signs' in this paper. They are very difficult to maintain because of frequent damage due to passing vehicles and complex installing

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processes. The current method that is adopted in most of countries to apply the roadway symbols and signs requires the placement of a stencil on the pavement followed with either the application of paint or torch-down of a thermoplastic type material. These procedures are manually conducted, which exposes maintenance-employees to traffic accidents and possible injuries. They are also very slow and labor-intensive operations. Furthermore, these manual operations require blocking traffic for a long period of time and bring serious traffic jam.

There have been just a few studies to automate the sign painting operations in worldwide. Kochekali and Ravani (1994) derived a path planning algorithm for stenciling robot of roadway marking. They developed very big articulated robot system for the stenciling operations. Researching path planning algorithm using robotic system, Bui et al.(2003) suggested an adaptive control methods for tracking welding path of two-wheeled welding mobile robot. And Park et al.(2002) designed a path generation algorithm of automatic guided vehicle with sensor scanning. Kotani et al.(1993) proposed a method for detecting and following a half-faded lane mark on pavement surface using image processing. They built a prototype robot that could repaint half-faded lane mark (Kotani et al., 1994). Although there has not been much research on the robotic painting of pavement signs, many researchers have been worked on the subjects of robotic painting of free-form surfaces, such as automobile bodies. Chen et al.(2002) developed a CAD-guided paint gun trajectory generation system for free-form surfaces. Suh et al.(1991) developed an Automatic Trajectory Planning System (ATPS) for spray painting robot. Their method was based on individual parametric surface patches divided from a compound surface. Sheng et al.(2000) developed an algorithm to cover a compound surface. Although their algorithm guaranteed the coverage of a compound surface, the problem of paint thickness was not addressed. Antonio (1994) developed a framework for optimal trajectory planning to deal with the optimal paint thickness problem. However, the paint gun path and the paint deposition rate must be specified. In practice, it is very difficult to get the paint deposition rate for a free-form surface. Asakawa and Takeuchi (1997) dealt with the automatic spray-painting by a 6-DOF industrial robot equipped with an air spray gun. This study aimed at making robot control without any special knowledge on spray-painting.

Most of researchers listed above have focused on the automatic trajectory generation for painting robot in automotive manufacturing lines. These studies have been performed mainly to achieve uniformity in paint thickness, time-efficiency, and minimal wastage of paint. The issue of automating the pavement sign painting operations has been addressed only by Kochekali and Ravani (1994), Kotani et al.(1993, 1994), and Lee et al.(2002). However, Kochekali and Ravani (1994) just proposed path generation algorithm for painting letter signs with general-purpose articulated robot and Kotani et al.(1993, 1994) focused on detecting and re-painting existing half-faded lane. This paper deals with fully automating the pavement sign painting operations utilizing robotic technology. Lee et al.(2002) developed fully automatic robot system for automating pavement sign marking operations. However, they used different approach, such that omni-directional wheel sets are used to extend the workspace. Also, they just provided font structure focused on English alphabet. This study includes a novel design of robot structure that can cover one-lane width, data structure of sign font, trajectory generation algorithm for paint nozzle motion, robot simulator, and experimental verification of the designed system. With this robot system, a single operator within a cab is capable of planning and performing the sign painting operations on-site, so that the dangerous and time consuming manual operations can be eliminated. This system utilizes a transverse rail drive to extend the workspace of gantry robot. The whole body of the robot structure can be either mounted under a truck or towed by a truck, still maintaining one-lane width of workspace. This paper also includes the font data structure for Korean alphabet. The robot path is generated with these font data through the procedures of scaling up/down and partitioning the signs to be painted depending on the workspace size. The robotic sign painting equipment and related control algorithms are tested with real painting experiments of various signs, which shows satisfactory results.

2. Gantry Robot with Extended Workspace

2.1 Pavement signs

Pavement signs can be classified into letters and symbols. The letter signs include alphabetic words, for example, '정지', '한남대교', 'STOP', 'SLOW', '25', etc. Others are the symbolic signs whose representative examples are the arrows that indicate traffic flow directions. Although the regulations for drawing the symbols and letters on pavement surface are slightly different in each country, the following common conditions for designing the sign painting robot can be derived.

(1) Maximum lane width is approximately 3.6 m.

(2) Heights of letters and signs are usually about 2 m in urban area. However, they become longer in high-speed roadway and sometimes reach up to 5 m.

(3) A single word sign almost always consists of at least more than two characters, for example, 'STOP' sign has 4 characters. Therefore, there is virtually no case that a single character is painted bigger than half-lane width.

(4) Line width of letter signs is approximately 15 cm.

(5) Sign painting operations require many heavy components, such as pump, heater, generator, compressed air, etc.

(6) Robot system is operated in harsh environment.

(7) Minimum number of working crew should be able to safely operate the robotic system inside truck cab.

(8) Blocking traffic flow must be minimized.

2.2 Gantry robot mechanism

Based on the design considerations investigated previously, basic robot structure proper to the sign painting operations needs to be determined. Cartesian robots consist of two or three prismatic joints that are orthogonally aligned each other, which are sometimes called as gantry robot in industry. The gantry robots are generally very rigid and easy to control, but comprise small workspace compared to their body size. The most important considerations in designing the structure of the sign painting robot are big workspace to cover one lane width and ruggedness. However, both of them can not be simultaneously achieved with conventional gantry robots. As such, we proposed a novel idea of robot structure, of which drive mechanism to transversely transport the entire gantry frame is attached to the base of the robot. Fig. 1 shows the constructed robot mechanism. The overall system consists of the basic gantry frame that has (X, Y) 2 degrees of freedom in Cartesian plane, the transverse rails and the associated rack and pinion, and paint spray system.

Gantry robot is a most common type of Cartesian robots. Moving frame (referred as X-axis) is mounted on the linear guides attached on the frame aligned perpendicular to the moving frame. This perpendicular frame is referred as Y-axis and the X-axis is powered by belt-drive mechanism fixed along the Y-axis. Also, a moving head that holds a paint nozzle slides along the X-axis by belt-drive mechanism. The height of the head unit from pavement surface is determined by manually adjusting lead screw attached

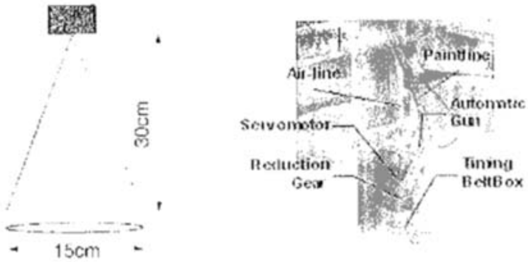
Fig. 1 Picture of the proposed robot mechanism

along the Z direction. All the belt-drive mechanisms are sealed to prevent the permeation of paint and dust. The basic gantry frame is designed to have an effective workspace of 1000×2000 mm^2, assuming that most of signs are formed with at least more than three characters. Therefore, a single character in most of signs can be drawn without moving this gantry frame itself. Also, this size of robot frame can be easily mounted under or towed by the support truck that carries other equipments, since its width fits into that of most commercial truck.

The width of one lane is normally 2~3 m, which is bigger than the gantry frame. Therefore, the workspace of the gantry frame is extended by adding additional guide rail and drive mechanism. As such, the gantry frame is mounted on the transverse guide rails and driven by rack and pinion mechanism. So, the basic gantry can slide off to side way to cover one lane width. The longitudinal distance of the workspace can also be covered by moving the truck forward. In this way, the letters and symbols bigger than the basic frame size can be drawn. However, an appropriate algorithm is required to adequately partition the total workspace into sub-regions and to plan the robot paths. This will be described in later chapters.

2.3 Paint spray system

The paint spray system is composed of three components, airless pump, automatic spray gun, and air compressor. The airless pump is the device to compress paint and maintain regular pressure. Maintaining regular pressure is an important performance of the airless pump for the best quality of painting result. Automatic spray gun is equipped with solenoid valve for spray timing control that is managed by system controller. According to the shape of spraying trace, many different types of nozzles can be used. Since gothic font letters and symbols are appropriate for roadway signs, a flat-type nozzle is selected in this work. As shown in Fig. 2, the spraying pattern with this nozzle is a beeline whose length can be adjusted by the height of the nozzle from the pavement surface. In order to prevent the dispersion of paint spray by wind, compressed air curtain is installed surrounding the nozzle. It is also important to keep the beeline pattern of the paint spray perpendicular to the direction of nozzle movement in order to maintain uniform width of signs. As such, a rotational joint is added to the end-effecter. Consequently, the end effecter of the gantry system has total (X, Y, θ) motion capability and any shape of signs can be drawn by appropriately sweeping the beeline on pavement surface. The block diagram for the paint spray system including its control is shown in Fig. 3.



(a) Side view of the paint spray (b) Picture of the actual spray system

Fig. 2 Paint spray system

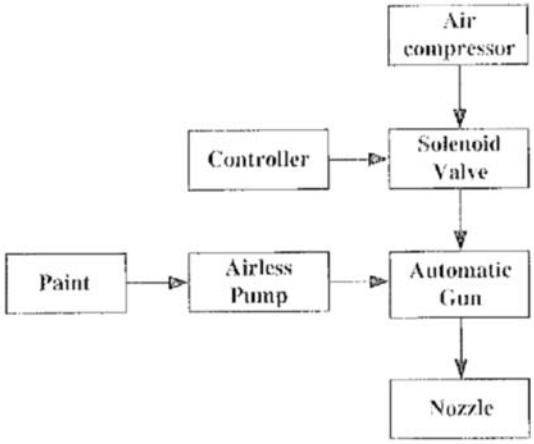


Fig. 3 Block diagram of paint spray control system

3. Modeling of Pavement Signs

Many countries have their own regulations on the size of roadway signs. In Korea, they are defined in traffic regulation code 3-5 relative to the application of the Road Traffic Act. It says that the length of roadway sign must be longer than its width due to driver's observation angle and the limitations on the width of roadway signs. These regulations are far less enough to define the size of various roadway signs in different painting situations. Although it paradoxically provides more flexibility in manually painting the signs, more strict definitions are required for automating the sign painting operations. There are many factors to be considered when automating the operations, such as how to define the shapes of the signs, how to place the signs on a given workspace, how to generate robot paths, and so on. The following sections contain the descriptions for resolving these matters.

3.1 Font file system for pavement signs

It is necessary to know the shape information of roadway signs before painting operations in order to generate the path of the painting robot. The data structure that contains the shapes of characters is usually referred as font file system. That is, the font is a file that has the information of letters and figures. Existing font file systems are largely divided into bitmap and vector types by the method describing geometric entity. The bitmap font is composed of the set of points that is called as pixels, and the vector font is composed of the set of lines and curves. The bitmap font is made by binary area coding method. In the area coding method, the area associated with a sign is defined as the number '1' and the other blank area as the number '0'. As a result of area coding, a sign can be represented by binary code and the binary code is converted into decimal or hexadecimal code for storage. This font is advantageous in decoding and scanning speed but is disadvantageous in causing unnatural shape in case of magnification and reduction of the font size. The vector font is composed of the characteristic points that are extracted from letters and figures. The characteristic points are analogous to bone joints in human body. According to the composition of functional code, the vector font can have a different structure. The vector font data consist of position and functional code. The position code represents the coordinates of the characteristic points and the functional code represents the function that must be carried out for the specific characteristic points. Because of these reasons, this font has more complex data structure than the bitmap font. However, the performance of vector font on the function of scaling up and down is better than that of bitmap font because the vector font is composed of the combination of line and curves.

Most of existing vector fonts that are recently used for computer system define the outline of character shape. However, the spray pattern with the robot system equipped with a flat nozzle is a line and a sign is drawn by sweeping this line along the centerlines of the sign. Thus, the existing outline fonts are not appropriate to applying to the paint robot. Accordingly, a novel font system for roadway sign modeling has been developed based on the vector font. In the new font system, the characteristic points are selected based on the centerlines considering the operating concept of the roadway sign painting system (Shin et al., 2002).

3.2 Data structure of basic font file system

The data structure of the font file system that is newly designed based on the concept of centerline tracking with flat spray is composed of functional code and position code. The position code defines the coordinates of the position of characteristic points and the functional code defines the functions to be executed for the corresponding characteristic points. The defined items in the functional code are motion pattern of the spray system (straight line or curve), on/off state of the paint spray, spray nozzle angle, the information of magnification or reduction of a sign, etc. Fig. 4 shows the explanation of each digit in the functional code. Fig. 5 shows the concept of extracting the characteristic points for robot path generation and the corresponding data structure with the example of handicapped sign.

Each sign is made of several strokes that are geometric entities such as lines and curves. The line stroke is defined with two end points. Bezier function that is widely used in design and manu-

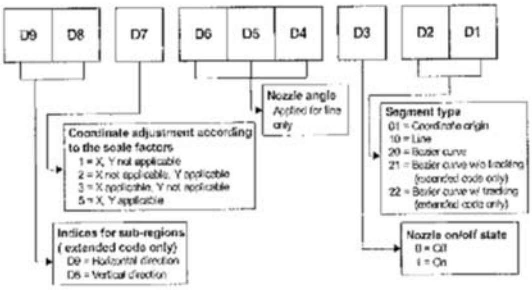
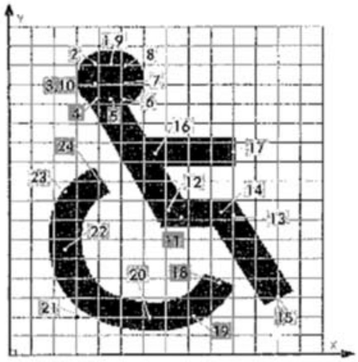


Fig. 4 Description of each digit in functional code



(a) Characteristic points of handicapped sign

No	Function code	X	Y	No	Function Code	X	Y	No	Function code	X	Y
1	5090001	250	1400	9	5000120	250	1400	17	5000010	800	950
2	5000120	175	1400	10	5000010	175	1325	18	5000010	740	290
3	5000120	175	1325	11	5000010	533	625	19	5000120	650	100
4	5000120	175	1250	12	5000010	483	635	20	5000120	450	100
5	5000120	250	1250	13	5000010	780	635	21	5000120	60	110
6	5000120	325	1250	14	5000010	733	680	22	5000120	50	500
7	5000120	325	1325	15	5000010	1000	200	23	5000120	50	720
8	5000120	325	1400	16	5000010	400	950	24	5000120	210	800

(b) Data structure for the corresponding characteristic points

Fig. 5 Example of extracting characteristic points and their data structures

facturing areas is employed to represent the curve stroke in this paper. The general equation of the n^{th} order Bezier function that is made of $n+1$ control points, p_i is expressed as (Faux and Pratt, 1981),

$$p(u)=\sum_{i=0}^{n} {}_nC_i u^i (1-u)^{n-i} p_i, \ (0 \leq u \leq 1) \quad (1)$$

where

$${}_nC_i = \frac{n!}{i!(n-i)!} \quad (2)$$

The shape of the Bezier curve can be adjusted with dragging the control points. For most of traffic signs, the 2^{nd} order Bezier curve is enough to precisely describe their shapes, which is simply expressed as

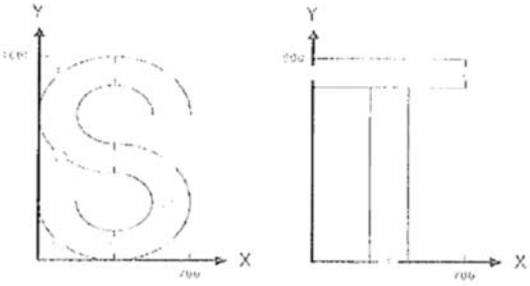
$$p(u)=(1-u)^2 p_0 + 2u(1-u) p_1 + u^2 p_2, \quad (0 \leq u \leq 1) \quad (3)$$

where p_0, p_2 are two end points and p_1 is the control point around the middle of the curve.

Basic code is the font data file system designed for standard frame size before applying to real workspace. When a sign is applied to real workspace whose size is different from the standard size, this code is evolved to extended code in order to account for scaling up/down and partitioning the sign to be fitted into the real workspace. The functional code in the basic font file is composed of seven figures. The digit D7 gives the information of scaling up/down in the (X, Y) coordinates. This function is to translate and rotate the coordinates of the characteristic points in order to fit the target sign into the real workspace that is different from the basic frame size. The number 1 in D7 means that this characteristic point has nothing to do with the coordinate translation and rotation. Thus, the coordinates of this point must not change on all occasions. In case of number 2 or 3, the coordinates of the characteristic point are translated toward the direction of either X-axis or Y-axis only according to given scale factor. In case of figure 5, the coordinate of characteristic point is translated toward the directions of both of X and Y-axis. The digits D4~D6 represent the information of desired nozzle angle. The digit D3 determines the action of spray system. The figure 1 and 0 in this place mean the action of nozzle on or off, respectively. The digits D2~D1 represent the form of trajectory of spray system. The number '10' in this place represents the trajectory of straight line and the number '20' represents a Bezier curve. Fig. 6 shows the examples of the basic codes about the letter 'S' and 'T'.

3.3 Extended font code

Extended code is the font data structure redefined as actual size by considering environmental variables, such as scale factor, vehicle position,

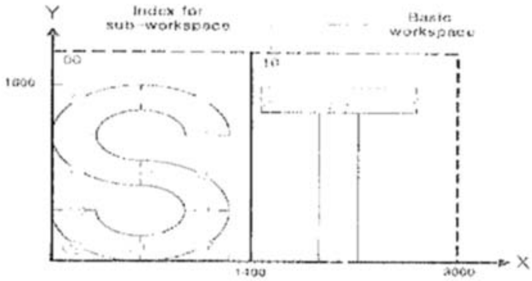


(a) 'S' (b) 'T'

Letter	Moving Direction	No	Function Code	Coordinate X	Coordinate Y	Description of bold-typed functional code
S	Origin		5000001	0	0	Coordinate origin
	[illegible]	1	5000010	625	1160	No spray, nozzle off
	[illegible]	2	5400120	625	1525	Bezier curve
		3	5490130	350	1525	Spray, nozzle on
	[illegible]	4	5000150	75	1525	Nozzle angle, automatic
		5	5000120	75	1160	Scale factor applicable to (X,Y)
	[illegible]	6	5000120	75	800	
		7	5000150	350	800	
	[illegible]	8	5000120	625	670	
		9	5000150	625	110	
	[illegible]	10	5000120	625	75	
		11	5000120	350	75	
	[illegible]	12	5000120	75	75	
		13	5000120	75	150	
T	Origin		5000010	0	0	
	[illegible]	1	2000010	0	1525	Scale factor applicable to (Y) only
	[illegible]	2	5000110	700	1525	Nozzle angle (90)°
	[illegible]	3	5020010	350	1500	Straight line
	[illegible]	4	5000110	350	0	Spray, nozzle off

(c) Basic code for 'S' and 'T'

Fig. 6 Example of basic codes for 'S' and 'T'



(a) Magnified 'S' and 'T' in X

Letter	Moving Direction	No	Functional Code	Coordinate X	Coordinate Y	Description of bold-typed functional code
S	Origin		5000001	0	0	Coordinate origin
	O → 1	1	5000010	1116	1160	Straight line motion
	[illegible]	2	5000120	1116	1525	Bezier curve control point
		3	5000130	625	1525	Spray, nozzle on
	[illegible]	4	5000120	134	1525	Scale factor applicable to (X,Y)
		5	5000120	134	1160	Nozzle angle, automatic
	[illegible]	6	5000120	134	800	Sub-region (0)
		7	5000120	625	800	
	[illegible]	8	5000120	1116	800	
		9	5000120	1116	110	
	[illegible]	10	5000120	1116	75	
		11	5000120	625	75	
	[illegible]	12	5000120	1334	75	
		13	5000130	1334	140	
T	Origin		10500010	1500	0	Sub region (0)
	O → [illegible]	1	102000010	1400	1525	Scale factor applicable to (Y) only
	[illegible]	2	10509010	2650	1525	Nozzle angle (90)
	[illegible]	3	10500010	2025	1500	Straight line
	[illegible]	4	10500110	2025	0	Nozzle on

(b) Extended code for the magnified 'S' and 'T'

Fig. 7 Example of extended codes for 'S' and 'T' magnified in X direction with the scale factor of two

etc. The real painting operations are directly performed by this extended code. The date structure of the extended code is similar to that of the basic code except one different point. That is, the functional code of the extended code has two more digits to represent sub-regions resulting nine figures. The added information is concerned with the operational workspace of the system. The digit D8 represents the number of sub-regions in the direction of Y-axis. Also, the digit D9 represents the number of sub-regions in the direction of X-axis. Fig. 7 shows the examples of the extended codes about the letter 'S' and 'T'. The detail procedures to partition the whole workspace into the sub-regions will be described in following sections.

4. Robot Path Generation Algorithm

The tracking performance on the desired trajectory of spray system is the most important of all the consideration factors. The desired trajectory of the system is generated with the information of the font data modeled by characteristic points. After the trajectory is determined, it is sent to the controller of actuators. The following sections include the descriptions of these processes.

4.1 Input target sign

In the painting operation, the trajectory of the spray system is mainly determined by the coordinates of the target sign's characteristic points. Once a target sign is inputted, it is decomposed into characters. The letters are composed of the combination of the elementary alphabets. According to the principle of making letters, original extracting algorithm is needed for the system to extract the element of alphabet systematically. The extraction algorithm for Korean letters is more complex than that for the other languages because the Korean letters are composed of 259 consonants and vowels whose sizes are various

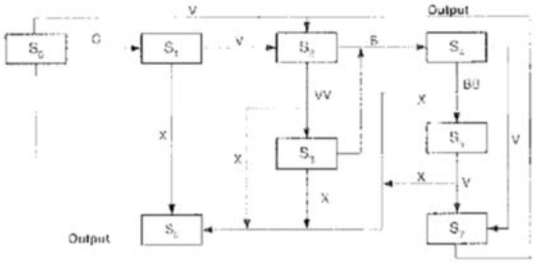


Fig. 8 Hangul automata state transition block diagram

according to the position. In this case, automata algorithm to select suitable font data of the alphabet element is needed. The model used for the combination rule of Korean alphabet is called as Hangul automata. Fig. 8 shows the state transition diagram of the Hangul automata. On the other hand, English is possible without automata algorithm by using the combination of 26 alphabets, ANSI code only. And symbols are selected from database.

4.2 Path partition

In case the size of the target sign is larger than that of gantry, the concept of path partition is necessary. Fig. 9 shows a path partition concept when the total workspace is divided into 4 sub-workspaces. In this case, the order of operations about the sub-regions must be determined systematically by path partition algorithm. Judging from Fig. 9, the optimal painting operations must be carried out in the sequence of workspace number 00, 10, 11, 01 in turn.

As a result of partitioning the workspace, new extended codes are generated. The intersecting points at the boundary lines of sub-workspaces must be included in the new code. Therefore, the first step of the path partitioning operations is to determine the gantry's moving direction, position, and the order of operations by using the information of the actual painting size of the sign and the basic size of the gantry's workspace. The next step is to rearrange and redefine the font data with the additive information. Those are the indices for sub-workspaces and the coordinates of intersecting points at the boundary lines between the sub-workspaces as shown in Fig. 9.

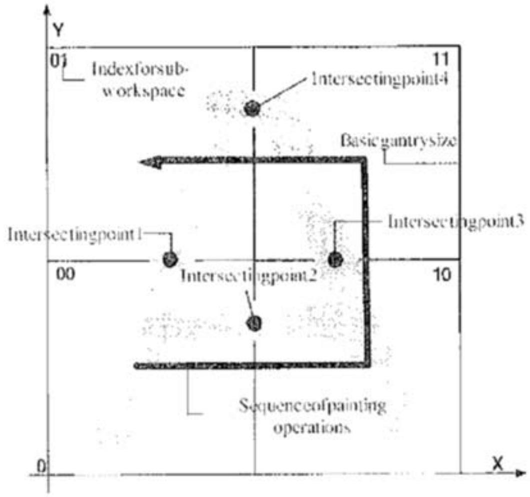


Fig. 9 Generating extended code due to workspace partitioning

5. Experimental Results

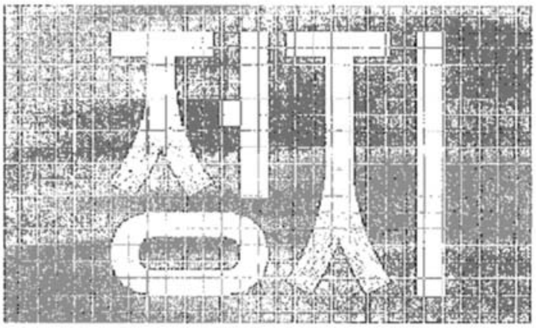
5.1 Virtual sign painting

If sign paintings are incorrectly applied on pavement surface, it is very hard to remove them. Therefore, very careful attention must be paid when generating robot path for a sign to be painted. In order to aid the verification of the robot path, off-line graphic program is developed, which is referred as Virtual Sign Painting (VSP). This is an auxiliary system for supporting the actual robot system. The VSP is programmed with OpenGL and simulates the kinematic motion of the robot system with 3 dimensional graphical image. This is merged into the control program, so that when operator inputs a sign to be painted and related parameters, it can virtually verify the painting results in prior to applying real paint spray on pavement surface. The VSP can be also utilized as a virtual trainer to educate a new crew to learn the operational procedures of the sign painting robot system.

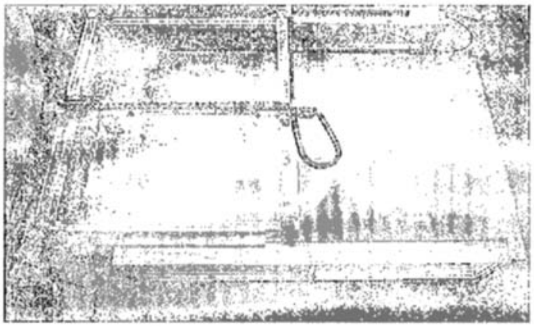
5.2 Experiments

The experiments were carried out with the VSP and the actual painting robot system. The performance of this system was measured by comparing the results to the VSP screen. The following factors were considered when executing the experiments ; the average time for painting one Korean letter, the quality of painted shape, the effect of scaling up and down, and the painting shape of skewed signs.

The Figs. 10～15 show the results by VSP and the actual robot system. These experiments were performed with three kinds of signs and with changing painting conditions. Figs. 10～11 are the painting results of Korean letter signs. Figs. 12～13 are the painting results of English letter signs. Figs. 14～15 are the painting results of symbol signs. More specifically, Fig. 10 shows the actual painting result of basic code test. The necessary painting time was 145 seconds. Fig. 11 shows the actual painting result of extended code test that requires path partitioning. In this experiment, these letters were scaled up 1.2 times to lateral direction. The painting time was 103 seconds. Fig. 12 shows another painting result of basic code test. The painting time was 103 seconds. Fig. 13 shows the actual painting result of a skewed sign. In this experiment, these letters were scaled down 0.85 times to both directions

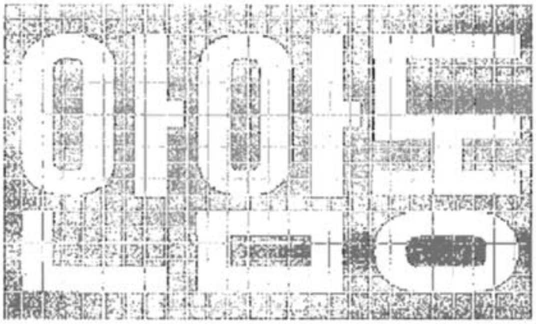


(a) VSP result



(b) Experimental result

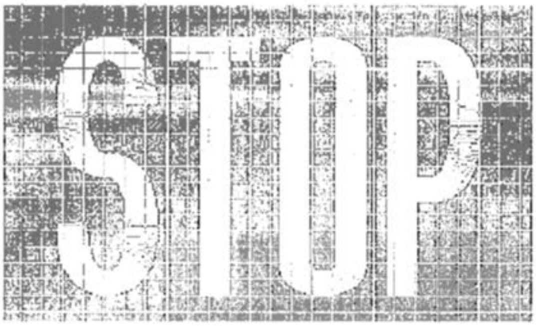
Fig. 11 Extended code test ; scaling up to lateral direction with 1.2 factor



(a) VSP result

(b) Experimental result

Fig. 10 Basic code test with Korean word '안양동'

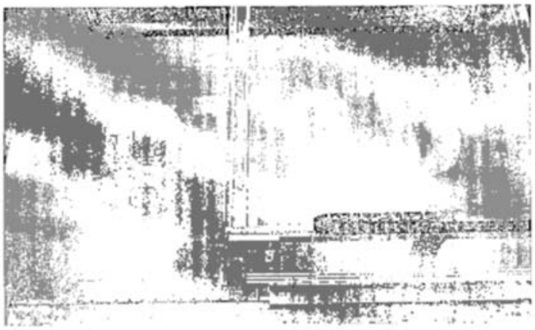


(a) VSP result

(b) Experimental result

Fig. 12 Basic code test with English word 'STOP'

(a) VSP result



(b) Experimental result

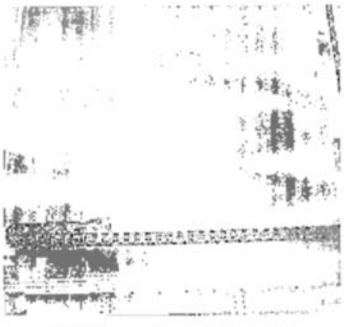
Fig. 13 Extended code test ; scaling down and correcting skewed workspace (width scale= 0.86, tilt angle=6°)

and rotated 6 degrees about Z-axis. The actual painting time was 90 seconds. Figs. 14 and 15 show the actual painting results of symbolic signs, handicapped and directional signs. The painting times were 120 and 65 seconds, respectively.

The comparative analysis of experimental results displayed satisfactory results. Especially, we obtained the satisfactory results in the consideration of average requiring times. It took about 1 minute in average sense to paint a single sign with the actual system. Compared to the manual operation that roughly takes about 20–30 min, this is tremendous increase in productivity.

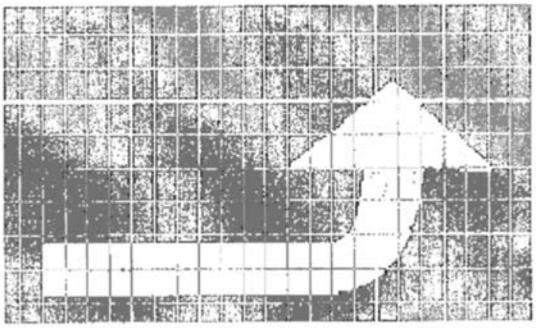
The quality of painted results is determined by paint spray quantity and timing. The amount of spray paint must be constant all over the painting operation and the automatic gun must be operated at the exact time by the controller. Through the analysis of painted signs, we found out the facts that the quality was not good at the starting and finishing points. This phenomenon takes place by the delayed command of spray timing. Strictly speaking, the spray quantity at the starting point

(a) VSP result

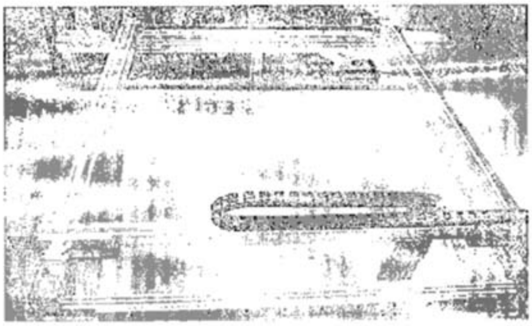


(b) Experimental result

Fig. 14 Symbolic sign test (handicapped sign)



(a) VSP result



(b) Experimental result

Fig. 15 Symbolic sign test (directional sign) is less than that of steady state. On the other hand, the spray quantity at the finishing point is larger than that of steady state. Therefore, the method of trial and error is needed to overcome these problems. The factors related with spray timing are the height of the nozzle, air compressor pressure, airless pump pressure, the density of the paint, and the moving velocity of spray system.

7. Conclusions

In this paper, a novel roadway sign painting system which is capable of painting all kinds of signs, is proposed and constructed. The overall mechanism of the robot system determined through carefully analyzing the operational requirements is a gantry frame equipped with the transverse rail and associated drive mechanism. The transverse rails that make the basic gantry frame slide off to sideways are used to extend the workspace of the robot system to one-lane width while maintaining the footprint of the robot system within the width of normal truck size. A new path generation algorithm for the robot system is also developed, which uses the newly defined font data structures that is quite adequate to flat nozzle paint spray. For the case that the workspace is larger than the basic gantry frame size, the algorithm for partitioning the robot path and the corresponding font data is proposed. Through actual painting experiments, the validity of the proposed gantry structure with extended workspace is confirmed as one of the best structure for roadway sign painting operations. The sign painting operation with this system is at least 10~20 times faster and needs less workers than current manual operations. Finally, the most important thing of using this system is that the safety of working crew will be ensured and the traffic jam will be reduced owing to the fast operations.

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