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16. Abstract (Limit: 200 words)

The purpose of this project was to determine the feasibility of using a robot to paint messages and symbols on a roadway. An existing robot arm was equipped with a standard pavement striping paint sprayer and used to perform the study. This combination was capable of painting symbols, letters, or numbers up to a maximum size of approximately 3 ft. x 3 ft. Software was developed for the system that enabled it to paint a variety of characters and symbols on the roadway. The system was tested in actual painting operations by painting on heavy textured paper to simulate pavement. The system was developed and tested over a period of 6 weeks for a total cost of $10,360.

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Improve safety and efficiency of roadway maintenance using robotics – feasibility study

Final Report

Prepared by:

Ryan G. Rosandich, Ph.D.
Department of Mechanical and Industrial Engineering
University of Minnesota Duluth

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207 Engineering Building
1303 Ordean Court
Duluth, MN 55812

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Executive Summary

The purpose of this project was to determine the feasibility of using a robot to paint messages and symbols on a roadway. An existing robot arm was equipped with a standard pavement striping paint sprayer and used to perform the study. This combination was capable of painting symbols, letters, or numbers up to a maximum size of approximately 3 ft. x 3 ft. Software was developed for the system that enabled it to paint a variety of characters and symbols on the roadway. The system was tested in actual painting operations by painting on heavy textured paper to simulate pavement. The system was developed and tested over a period of 6 weeks for a total cost of $10,360.

Chapter 1
Introduction

The purpose of this project was to test the feasibility of developing a system to address the following problem statement:

> *Placing messages onto the roadway surface including stop-walk messages or left or right turn arrows is accomplished using stencils and rollers. Can a robotic message painter be developed whereby messages could be applied automatically from an operator position?*
>
> \- Randy Resnicek, Mn/DOT

In response to this problem statement it was proposed to test the feasibility of operating a standard pavement striper via a robot arm to paint various messages and symbols on a roadway, and to demonstrate the capabilities and limitations of the technique.

The primary benefits of this project were to determine the feasibility of using a robot to paint messages and/or symbols on a roadway, and to determine the capabilities and limitations of such a system. This could lead to future funding from Mn/DOT or other sources for the development of a full-sized roadway message painter. The long-term benefits of such a system are improved safety and productivity of roadway maintenance operations.

Two projects involving robotic painting of roadway messages or symbols were found in the literature, one at the Advanced Highway Maintenance and Construction Technology Research Center at the University of California Davis [1] and the other in the Department of Mechanical Engineering at Korea University [2].

U. C. Davis has two systems under development, one that uses a gantry-style robot housed in an enclosed trailer. This system is primary used to paint photogrammetry symbols (a white X on a black background) on the pavement to support aerial surveys. The other system under development is called the Big Articulated Stenciling Robot, and consists of a large computer-controlled hydraulically powered arm that extends from the back of a truck. The arm can reach over 14 feet, and with it a single operator can conduct automated pavement marking operations from the cab of the truck.

The Korean system consists of a gantry robot with an extended transverse arm that allows lane-width painting. It is also capable of conducting automated pavement marking operations with a single operator.

Chapter 2
Methodology

A robotic painting system was developed and tested. The system used an existing GM-Fanuc Model S-10 robot arm with RH controller (Figure 1) that was equipped with a standard pavement striping paint sprayer, Model 250BP from Trusco Manufacturing (Figure 2). This combination was capable of painting symbols and letters up to a maximum size of approximately 3 ft. x 3 ft. Software was developed for the system that enabled it to paint a variety of characters and symbols. The system was tested in actual painting operations by painting on heavy textured paper to simulate pavement.

Figure 1. GM-Fanuc S-10 robot arm.

Figure 2. Pavement striper.

The standard pavement striper was disassembled, and the spray box was attached to the end effector of the robot arm. The paint valve, which was actuated manually on the pavement striper, was converted to automatic operation by using a double-acting pneumatic cylinder to actuate the valve. The cylinder was in turn actuated by a four-way solenoid valve that was energized by the robot via a 24 VDC digital output. The rest of the paint delivery system consisted of a 5-gallon paint canister that was pressurized to 140 psig by a 12 VDC air compressor. The paint canister and compressor were located near the base of the robot arm, and the paint valve was mounted on the robot arm itself. The paint was delivered from the pressurized canister to the valve and then the spray head via rubber hoses.

The robot arm was connected to a model RH controller which was programmed using the KAREL language. Programs were developed for the symbols and letters shown in Table 1. The letters were use to spell “STOP” and “BULLDOGS”. The listings for the programs can be found in Appendix A. Using these programs, testing was conducted to determine the capabilities and limitations of the system, and to experiment with paint pressure and viscosity and painting speed.

Table 1. KAREL Programs developed for testing.

Symbol	KAREL Program Name
Square	AN08SQR.KL
Circle	AN08CIR.KL
Triangle	AN08TRI.KL
Filled Triangle	AN08TRIF.KL
Turn Arrow	AN08ARW.KL
Handicap	AN08HND.KL
Letter B	AN08B.KL
Letter D	AN08D.KL
Letter G	AN08G.KL
Letter L	AN08L.KL
Letter O	AN08O.KL
Letter P	AN08P.KL
Letter S	AN08S.KL
Letter T	AN08T.KL
Letter U	AN08U.KL

Chapter 3
Results and Conclusions

The results of some of the painting tests are shown on the following page (Figures 3-8). Experiments with paint pressure indicated that performance deteriorated at pressures below 100 psig. The result was a line width less than the 4 in. target width (see Figure 3). Experiments with paint viscosity indicated that proper viscosity was important to paint quality, with high viscosity resulting in narrow line width similar to the low-pressure effect and low viscosity leading to excess splattering (see Figure 4). Experiments with speed indicated that painting speed was also important, with low speed resulting in puddling and high speed resulting in sparse coverage.

Experience with painting several symbols revealed some mechanical and control limitations in the system. First, due to the limited lengths of the hoses that were supplied with the paint striper, the paint valve was mounted on the robot arm with a length of hose extending from the valve to the spray head. This resulted in some paint dripping out of the spray nozzle after the valve was shut off. There were also some limitations in the control of the robot arm, some of which could be overcome with improved programming. One example is the lack of square corners in the square symbol (see Figure 6) due to less than optimum terminations being used in the robot path commands. When the terminations were improved, the results were much better, as in the upper left corner of the letter P (see Figure 7).

The conclusions of this feasibility study are as follows:

1. It is feasible to paint symbols, letters, and numbers on pavement using a robotic actuator.

2. Paint pressure should be greater than 100 psig. and most tests were done at 140 psig.

3. Painting speed should be approximately 1000 mm/sec. (40 in./sec.).

4. Painting performance was best when the viscosity test was 30 seconds using the viscosity test cup supplied with the pavement striper.

5. The paint valve should be located directly at the paint nozzle to minimize dripping.

6. Limitations in programming and control could be overcome by using a machine-tool type of controller such as those supplied by Galil Motion Control.

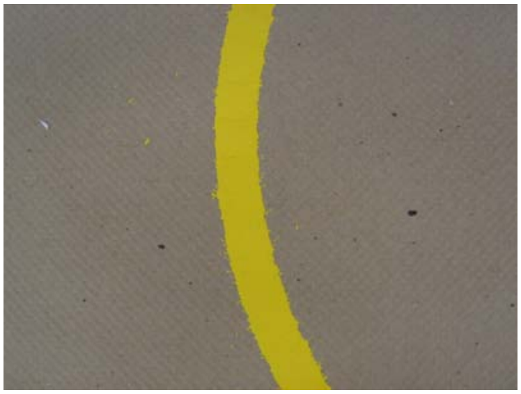

Figure 3. Pressure too low.

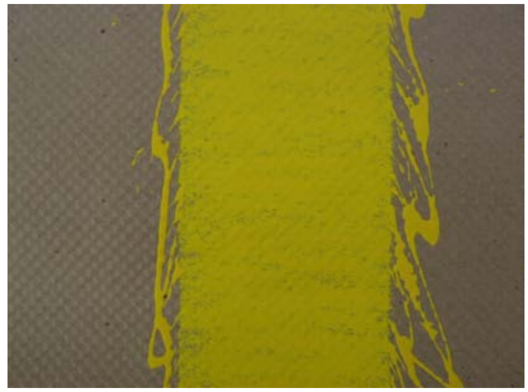

Figure 4. Viscosity too low.

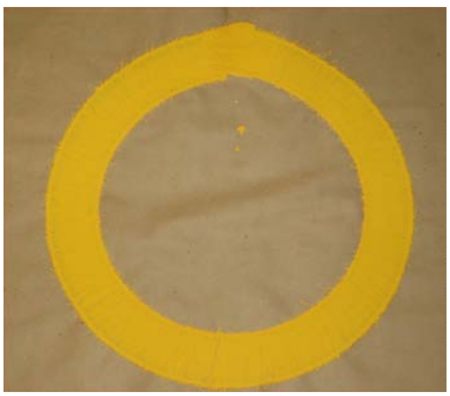

Figure 5. Circle.

Figure 6. Square.

Figure 7. Letter P.

Figure 8. Handicap symbol.

References

1. "Stenciling Machine" and "General Purpose Sign Painting System", http://www.ahmct.ucdavis.edu/index.php?title=OtherMarkersSigns, Advanced Highway Maintenance and Construction Technology Research Center, University of California Davis (Accessed 10/15/2007).

2. D. Hong, W. Lee, B. Chu, and T. Kim, "Gantry Robot with Extended Workspace for Pavement Sign Painting Operations," *Journal of Mechanical Science and Technology*, Vol. 19 No. 6 pp. 1268-1279 (2005).

Appendix A

KAREL Program Listings

Square

```
program an08sqr
var
home,start: position
square:path
begin
$speed=400
$motype=joint
move to home
move to start
with $speed=1000,$motype=linear move along square,
when time 1 after node[0] do dout[19]=on
when time 250 before node[8] do dout[19]=off
endmove
dout[19]=off
delay 10000
move to home
end an08sqr
```

Circle

```
program an08cir
var
home,start: position
circle:path
begin
$speed=400
$motype=joint
move to home
move to start
with $speed=1000,$motype=circular move along circle,
when time 1 after node[0] do dout[19]=on
when time 250 before node[4] do dout[19]=off
endmove
dout[19]=off
delay 10000
move to home
end an08cir
```

Triangle

```
program an08tri
var
home,start: position
triangle:path
begin
$speed=400
$motype=joint
move to home
move to start
with $speed=1000,$motype=linear move along triangle,
when time 1 after node[0] do dout[19]=on
when time 250 before node[6] do dout[19]=off
endmove
dout[19]=off
delay 10000
move to home
end an08tri
```

Filled Triangle

```
program an08trif
var
home,start: position
triangle:path
begin
$speed=400
$motype=joint
move to home
move to start
with $speed=1000,$motype=linear move along triangle,
when time 1 after node[0] do dout[19]=on
when time 250 before node[6] do dout[19]=off
when time 1 after node[7] do dout[19]=on
when time 250 before node[13] do dout[19]=off
when time 1 after node[14] do dout[19]=on
when time 250 before node[20] do dout[19]=off
endmove
dout[19]=off
delay 10000
move to home
end an08trif
```

Turn Arrow

```
program an08arw
var
home,start: position
arrow:path
begin
$speed=400
$motype=joint
move to home
move to start
with $speed=1000,$motype=linear move along arrow,
when time 1 after node[0] do dout[19]=on
when time 250 before node[3] do dout[19]=off
when time 1 after node[4] do dout[19]=on
when time 250 before node[10] do dout[19]=off
when time 1 after node[11]do dout[19]=on
when time 250 before node[12] do dout[19]=off
when time 1 after node[13] do dout[19]=on
when time 250 before node[14] do dout[19]=off
endmove
dout[19]=off
delay 10000
move to home
end an08arw
```

Handicap Symbol

```
program an08hnd
var
home,start: position
handicap:path
begin
$speed=400
$motype=joint
move to home
move to start
with $speed=1000,$motype=linear move along handicap,
when time 1 after node[0] do dout[19]=on
when time 250 before node[5] do dout[19]=off
when time 1 after node[7] do dout[19]=on
when time 250 before node[11] do dout[19]=off
when time 1 after node[12] do dout[19]=on
when time 250 before node[16] do dout[19]=off
endmove
dout[19]=off
delay 10000
move to home
end an08hnd
```

Letter B

```
program an08b
var
home,start: position
b:path
begin
$speed=400
$motype=joint
move to home
move to start
with $speed=1000,$motype=linear move along b,
when time 1 after node[0] do dout[19]=on
when time 250 before node[1] do dout[19]=off
when time 1 after node[1] do dout[19]=on
when time 250 before node[5] do dout[19]=off
when time 1 after node[6] do dout[19]=on
when time 250 before node[9] do dout[19]=on
endmove
dout[19]=off
delay 10000
move to home
end an08b
```

Letter D

```
program an08d
var
home,start: position
d:path
begin
$speed=400
$motype=joint
move to home
move to start
with $speed=1000,$motype=circular move along d,
when time 1 after node[0] do dout[19]=on
when time 250 before node[1] do dout[19]=off
when time 1 after node[2] do dout[19]=on
when time 250 before node[8] do dout[19]=off
endmove
dout[19]=off
delay 10000
move to home
end an08d
```

Letter G

```
program an08g
var
home,start: position
g:path
begin
$speed=400
$motype=joint
move to home
move to start
with $speed=1000,$motype=circular move along g,
when time 1 after node[0] do dout[19]=on
when time 250 before node[5] do dout[19]=off
when time 1 after node[6] do dout[19]=on
when time 250 before node[7] do dout[19]=off
endmove
dout[19]=off
delay 10000
move to home
end an08g
```

Letter L

```
program an08l
var
home,start: position
l:path
begin
$speed=400
$motype=joint
move to home
move to start
with $speed=1000,$motype=linear move along l,
when time 1 after node[0] do dout[19]=on
when time 250 before node[1] do dout[19]=off
when time 1 after node[2] do dout[19]=on
when time 250 before node[3] do dout[19]=off
endmove
dout[19]=off
delay 10000
move to home
end an08l
```

Letter O

```
program an08o
var
home,start: position
o:path
begin
$speed=400
$motype=joint
move to home
move to start
with $speed=1000,$motype=linear move along o,
when time 1 after node[0] do dout[19]=on
when time 250 before node[6] do dout[19]=off
endmove
dout[19]=off
delay 10000
move to home
end an08o
```

Letter P

```
program an08b
var
home,start: position
p:path
begin
$speed=400
$motype=joint
move to home
move to start
with $speed=1000,$motype=linear move along p,
when time 1 after node[0] do dout[7]=on
when time 250 before node[1] do dout[7]=off
when time 1 after node[1] do dout[7]=on
when time 250 before node[5] do dout[7]=off
endmove
dout[7]=off
delay 10000
move to home
end an08b
```

Letter S

```
program an08s
var
home,start: position
s:path
begin
$speed=400
$motype=joint
move to home
move to start
with $speed=1000,$motype=circular move along s,
when time 1 after node[0] do dout[19]=on
when time 250 before node[6] do dout[19]=off
endmove
dout[19]=off
delay 10000
move to home
end an08s
```

Letter T

```
program an08t
var
home,start: position
t:path
begin
$speed=400
$motype=joint
move to home
move to start
with $speed=1000,$motype=linear move along t,
when time 1 after node[0] do dout[19]=on
when time 250 before node[1] do dout[19]=off
when time 1 after node[2] do dout[19]=on
when time 250 before node[3] do dout[19]=off
endmove
dout[19]=off
delay 10000
move to home
end an08t
```

Letter U

```
program an08u
var
home,start: position
u:path
begin
$speed=400
$motype=joint
move to home
move to start
with $speed=1000,$motype=linear move along u,
when time 1 after node[0] do dout[19]=on
when time 250 before node[4] do dout[19]=off
endmove
dout[19]=off
delay 10000
move to home
end an08u
```