Autonomous Mobile Robotic System for On-the-Road Painting

MOHAMMED A.H. ALI, M. MAILAH AND TANG HOWE HING
Department of Applied Mechanics and Design
Faculty of Mechanical Engineering
Universiti Teknologi Malaysia
81310 Skudai, Johor
MALAYSIA
moh.ali.hashim@gmail.com, musa@fkm.utm.my, tanghh@fkm.utm.my

Abstract: - The development of an autonomous mobile robotic system for on-the-road marks painting is presented in this paper. The whole system involves two main parts, namely, the autonomous mobile robot navigation system and automated road mark painting system. The focus is on the painting system which is incorporated into the mobile robot platform and executed within the same computing environment. The main purpose of the proposed system is to accomplish its tasks using the autonomous navigation component for road detection and airless spray system for the painting. The painting of the marks on the road is performed while the autonomous system of mobile robot is continuously navigating the road. The benefit of such system is to minimise blocking of the roads during painting and repainting of the faded marks; also the time needed to perform the painting is smaller compared to the manual two-machines system. In addition, the autonomous system is accurate enough since the process is performed autonomously with minimal human intervention. The experimental results of the painting show the capability of the proposed algorithms in performing the road marks painting.

Key-Words: - Autonomous mobile robot, road marks, laser range finder, airless spray system, cold painting, thermoplastic road marks

1 Introduction

Road mark paintings are used on the paved roadways to provide guidance and information to the drivers and pedestrians. A number of the markings on the roads can be be classified into five categories [1], i.e., longitudinal, lateral, merging-diverging, symbols & letters and special situations.

The painting of road marks in the existing systems involves two main tasks, which are accomplished separately during the road marking painting. Firstly, pre-marker is used to draw a field sketch in advance to avoid faulty marking. The road surface is pre-marked by a line using auxiliary equipment pre-marker as in Fig. 1(a), which determines the exact position of the road that will be painted such as in the middle, at right or left, etc. In the second stage, the user will move the thermoplastic or cold paint machine over the pre-marked lines that have been prepared in the first step and spray/throwing the paint to the road. Most of the road marking machine has a hydraulic guide rod to ensure the painting line is accurate and straight as in Fig. 1(b).

It is observed that most of the available information about painting system on the roads is coming from the companies’ catalogues and the cities standards [1-3]. There are a few technical papers in the side of the enhancing paint material for long time and including beads to the paints [4-6].

2 Road Mark Painting Materials

Two main kinds of painting material can be found for the road marks painting task: thermoplastic paint and cold paint as described in the following sections.

2.1 Thermoplastic Paint

Thermoplastic road markings are accepted worldwide as an advanced marking technique due its longer life, high reflectivity and high skid resistance. Thermoplastic road marking paint is in solid powder form at 25°C. In construction, the thermoplastic paint powder is supplied to a pre-heater, which is used to melt the solid powder coating into a viscous liquid, guaranteed the road marking machine has a steady stream of paint supply in the construction process. Then the melt paint is transferred into the paint tank of hand-push marking machine, and then the molten coating will be introduced into the marking bucket and the
material insulated remains molten. When the marking work starts, the marking bucket should be on the road surface. Because there is a certain gap between marking pedal and the ground, when the marking car was pulled forward, by automatically flowing, a neat marking lines was scraped out, glass beads sow can automatically and evenly spread a layer of reflective glass beads on the coating lines. The gap of marking pedal controlled the thickness of the coating.

1.2 Cold Paint

Cold road marking paint is a traditionally and commonly used in on-the-road painting task. It has low drying speed, short lifetime of usage, but with a low cost, which is widely used in city roads and common roads consisted of asphalt pavement and cement pavement. There are three colors to choose: white, yellow and blue.

The cold paint road marking is very common with a long history. Different from thermoplastic it is performed only by one unit road marking machine. In accordance with marking modes, the cold paint road marking machinery is divided into high-pressure airless type and low-pressure air spray type. According to the paints it uses, it is divided into cold solvent; cold water based and heated solvent types.

The road marking machinery for cold painting as in Fig. 1, is divided into marking vehicle, driving type like: DY-BSAL-I/II, DY-MSAL, DY-SSAL, DY-BAAM, DY-MAAM, DY-SAAM, truck-mounted type like: DY-TMAL-I(A/B), DY-TMAL-II(A/B), self-propelled type and hand-push type like: DY-HAL-I/II, DY-HAL-III/IV, DY-HAL-V/VI.

![Fig. 1: Road painting processes (a) road pre-marking (b) thermoplastic painting](image)

2 Autonomous Navigation System

There are so many cases in the roads have been studied with autonomous mobile robot platform like road following, road roundabout, obstacles detection. In the painting, it is usual that the robot should detect the middle or the sides of the roads for the road following case. This case will be explained here and for the other cases see [7-12].

In the road following area, the camera, encoders and laser are combined together to determine the free-collision path. The camera was used for road intersection detection based on laser simulator approach [9, 12]. The laser range finder was utilized for detecting the road curbs and localizing the robot in an environment. The encoder’s measurements were used for estimating the current position of robot within environments. The generation of robot path can be described as follows:

First of all, the path of robot within the curbs of road as illustrated in Fig. 2 is chosen. Plane I is selected as planned path in the position laser2 (here, the middle of the curbs was chosen) for the robot as shown in Fig. 2, where the robot current position is laser1 and plane (II). The two differential drive wheels should be rotated by angular velocity equal to $\varphi$ which can be calculated as follows:

$$\varphi = \frac{V_r - V_l}{b}$$

$$\varphi b = \frac{V_r - V_l}{t_{\text{max}} - t_0} = \frac{b \varphi_{\text{max}}}{T} = \frac{L}{T}$$

Where $V_r$ and $V_l$ are the velocity of the right and left wheels. $b$ is the distance between the two differential drive wheels. Eq. (1) can be rewritten in tan equivalent form as shown in Eq. (2). $T$ is the sampling time and $L$ is the distance that the robot should shift as in Fig. 2.

The coordinate system in $X$ and $Y$ direction for the planned position can be calculated as in Eq. (3):

$$X_{\text{laser}} = h_l - (\text{abs} (h_l z) + h_l) \cdot R$$

$$Y_{\text{laser}} = \Delta T \cdot V$$

where

$$V = \frac{V_r + V_l}{2}$$

$(X_{\text{laser}}, Y_{\text{laser}})$ is the coordinate dimension of the planned position. $R$ determines the location where the robot is planned to move; if $R = 0.5$, it means that the robot will move in the middle of the curbed road.
The linear distance $L$ with $\phi$ rotation as illustrated in Fig. 2 can be calculated as:

$$L = X_{\text{laser}} \frac{\sin(\alpha)}{\sin(\frac{\pi + \phi}{2})}$$

where $\alpha = \frac{\pi}{2} - \phi$

### 3 Road Marks Painting System

This system is attached to the mobile robot platform to produce autonomous robotic system for road marks painting. In this system, the autonomous navigation system will be used to detect the exact position of the road that will be painted like in the middle, at right or left. Based on the types of the road lane marks, the painting system shall include controlling the time period for spraying the paint on the roads. The timing control of the spray is done using the main controller, considering the same program with the navigation system (sharing the common part of the program).

#### 3.1 Airless spray painting

In the spray cold painting as in our system, a high pressure is needed to spray effectively the painting on the road. An airless pump (model $TITAN$-$450e$) was used for this purpose, which can pressurise the liquid until 214 bar and with 1.8 l/min. As the motor driving the pump is supplied by an AC source (240 V/6.0 A), a DC to AC inverter ($LSM$ $2000W$) to convert the 12V DC battery voltage to 230 V AC.

The spray gun is a manual ($TITAN$-$LX$-$80II$) with multiple diameter needles and it is left always open in the design. It is a metal construction and has tungsten carbide ball valve and seat to ensure long life and durability. It is equipped with $in$-$handle$ filter to reduce clogging and increasing tip life, $swivel$ for reducing the hose kinks and effortless control and $S17$ $SC$-$6$ reversible tip. The rated pressure of the valve can reach 210 bar. The spray gun is supported on the platform through a specially fabricated holder that can adjust and change the position of gun easily. A small tank for keeping the paint is attached with the platform. Fig. 3 shows the various components of this system mounted on the platform.

![Fig. 3: Mobile robot platform with various components of the painting system (a) a 3D drawing model (b) working prototype (experimental setup)](image-url)
3.1.1 Timing of the spray gun

Two interval times $T_{on}$ and $T_{off}$ need to be defined before starting the painting process. The time periods were calculated as a function related to the velocity of the robot and the type of road lane marking which determines the length of the spray and the non-painting area on the road as described by Eq. (6). $T_{on}$ indicates the interval time that the operation starts when the electrical valve is ‘open’, and ends when it is ‘close’. However, $T_{off}$ specifies the time period for the non-painting area, where the spray gun and valve remain closed.

$$T_{on} = \frac{L_p}{V_m}, \quad T_{off} = \frac{L_r}{V_m}$$  \hspace{1cm} (6)

Where $L_p$ and $L_r$ are the dimensions of the paint and non-paint, respectively for the road lane obtained from the standard catalogue. $V_m$ is the robot velocity calculated by the encoders.

3.1.2 Control of spray flow

The control of the spray flow of the paint is accomplished using two methods in the proposed design:

1. Switching on/off the pump’s motor with the timing of the spray that is computed using Eq. (6) in the general program in the host controller. This operation is performed using a breakout solid state relay, S108T02. A solid-state relay (SSR) is an electronic switching device, in which a small control signal controls a larger load current or voltage. A supply voltage of 5 V DC signal is only needed to activate the SSR and 0 V to switch off the SSR.

2. High pressure electrical valve is installed between the pump and the spray gun. When the motor of pump is switched off, the paint material is still in the pipe and some of it leaks out from the spray gun. To solve this problem, this valve is located near the spray gun so that it can cut the supply of paint abruptly. The valve used is AUTOMA-ATM0020 which is equipped with a special induction motor that can be switched on/off the valve; it produces a high starting torque and is thermally protected from overheating. The valve, can be powered by voltage source of 110/220 V AC (50/60 Hz) and controlled by 5 A, 250 V AC signals that is in turn regulated by SONGLE-SRD12VDC-SL-C that works with 12 V DC source and allow to control a load with 250 V AC and 10 A.

3.2 Embedded system interface

The interface between the painting system and navigation system will be accomplished with output card IFC-0C04 that is connected through the main controller (IFC-IC00) to the on-board computer as depicted in Fig. 4. The output card, IFC-0C04 offers four outputs that can be used to drive relays or solenoids. The voltage is selectable for each output port, either 12 V or 24 V. The maximum current of each output is limited to 3 A and is protected by a resettable fuse. In our design the output card is connected to SS108T02 relay that operate the pump motor and SRD-12DC-SL. C relay that operates the electrical valve. The spray gun stays always open and the spray of the paint will be controlled signals coming from the main controller to trigger the valve and pump motor as shown in Fig. 4.

4 Implementation of the Autonomous Road Painting System

The road following algorithm is applied on the road painting with two curbs as shown in Fig. 5. The results show the ability of the platform to carry out the road painting system and perform the painting
with small deviation as in Fig. 5, this is due to the effects of the LRF accuracy (10 – 30 mm) and encoder errors.

![Graph](image)

**Fig. 5:** Road marks painting via proposed system (a) laser measurements (b) mobile robot path (c) dashed lines with solid lines in the middle (d) dashed lines

**5 Conclusion**

An autonomous mobile robotic system in the form of a crude working prototype has been designed and developed to perform an on-the-road painting task. The task of the road painting that were mostly done manually with more than one machine involved was accomplished in this system using a small mobile robot prototype that was equipped with components of a painting system mounted on its platform. Many benefits from such system can be derived such as avoiding the vehicle blocking of roads during painting and repainting of the faded marks; minimizing the time needed to perform the painting and getting suitable accurate through using the autonomous system. The experimental results show the effectiveness of the proposed algorithms for performing the road marks painting. Future works may include the improved design and implementation of the spray gun accessories that takes into account the road mark template (depending on the pattern itself) to ensure better accuracy, paint distribution and sharpness of the paint marks.

**References:**


for mobile robot based on laser range finder
and camera, *Applied Mechanics and Materials*,

Autonomous mobile robot platform for on the
road painting, *Advanced Material Research*,

Implementation of Laser Simulator Search
Graph for Detection and Path Planning in
Roundabout Environments, *WSEAS
Transaction on Signal Processing*, Vol.10,
2014, pp. 118-126.