Jurnal Mekanikal
Dec 2016, Vol 39, 39-51

MECHATRONIC DESIGN AND DEVELOPMENT OF A SEMI-AUTOMATED ON-THE-ROAD PAINTING MACHINE

Muhammad Khalid Mohd Jali, Musa Mailah and Shehab Ghadim

Department of Applied Mechanics & Design
Faculty of Mechanical Engineering
Universiti Teknologi Malaysia
83100 UTM Johor Bahru
MALAYSIA

ABSTRACT

The main aim of the study is to design and develop a semi-automated road-painting vehicle employing a full mechatronic approach. In the design, an electric bicycle was chosen as the prime mover to be driven by a human operator, while a mobile platfom with the automatic painting mechanism was mounted to produce the required paint pattern on the road. The mechanical, electrical/electronics and computer control parts were fully integrated to operate the machine to paint a continuous white line in the middle of the road. An Arduino microcontroller was employed to provide the complete control of the sequence of operations of various devices through a specific computer program with the incorporation of appropriate input and output (I/O) devices. A number of extra value-added features were added into the system in the form of a safety lamp, digital camera with LCD screen and a pressurised air spray paint system. The working prototype of the semi automatic on-the-road paint system was tested in the laboratory and outdoor settings. Preliminary findings show that the machine is capable to perform its basic task for a set of operating conditions. Further works should be done to improve and enhance the system performance.

Keywords: *Design process, semi-automated, Arduino microcontroller, paint system, electric bicycle*

1.0 INTRODUCTION

Malaysia is geared towards becoming a fully developed nation by the year 2020. Many areas begin to open up for development to include various sectors such as residential, industrial and agriculture. Roads are needed as a means of essential connecting medium between regions through various land transportations, i.e., bicycle, motorcycles, cars, buses, lorries, etc. Most roads in Malaysia use asphalt-based material (tar) as the main road surface medium to facilitate the land traffic consumers. Graphical guidance is needed for driving on the road to ensure safety on the part of drivers and that the traffics are properly regulated and corresponding laws enforced. The guidance comes in the form of various road line patterns or marks that are normally identified/marked using typical manual on-the-road painting machine. Road line painting machine is specifically created and designed to ease the process of producing various road line marks.

Nowadays, Malaysia is still using manual road line painting machine which needs one human operator to push the machine while at the same time, perform the painting task. This old method is tedious, consumes a lot of operator’s energy, quite slow and usually leads to corresponding human fatigue and boredom. To improve or overcome this condition, the concept of a semi-automatic on-the-road painting machine is proposed in the undertaken study and expected to open up a new development and scenario in the process of road construction in Malaysia with respect to producing an automated and more sophisticated system that could typically and potentially enhance productivity.

*Corresponding author: musa@mail.fkm.utm.my

Related works on automated or semi-automated road painting devices are relatively limited and scarce. The information on the standard road marks in Malaysia is mainly done with reference to the *Manual on Traffic Control Devices: Road Marking and Dileanation by Road Branch, Public Works Department (JKR) Malaysia* [1]. A number of designs related to the road painting machines can be found via direct observation and patent search. They include the existing manual on-the-road paint machine, road line, road mark item, existing product and concept of semi-automatic system. The road line can be divided into two: road and line scenarios. For road mark item, it is divided into material and mechanism for painting while for the existing product, a closer look at the related patents and availability of related products in the market is made. Last but not least, the concept of semi-automatic system, the focus is more on the controller and electronic parts.

Information on the existing road painting machine can be obtained by direct observation on the product that is being used actively on the road. Other information could be accessed through internet source [2]. The process of painting road marks in the existing system involved two tasks that are accomplished separately during the painting. The first task is the use of pre-marker to draw a field sketch in advance to avoid faulty marking. The road surface is pre-marked by a line using an auxiliary equipment pre-marker which determines the exact position of the road that will be painted later (e.g., in the middle, at right or left of the road). The other task is the operator moves the cold paint or thermoplastic machine over the pre-marked lines that have been prepared in the first step and spray/throwing the paint onto the road surface. Most of the road marking machines have a hydraulic guide rod to ensure the painting line is drawn accurately and in a straight line. It is useful to note that most of the available information about paint system on the roads is extracted from the company catalogues and the cities standards [3-6].

A patent search related to the road paint system was conducted to obtain information on various designs that may in turn help to trigger new ideas in the design of a proposed system. In addition, it is to instill awareness on anything or whatever works that have been done by other researchers on the related subject of interest and also the possibility of closing any gap or persisting problem that needs to be addressed and/or resolved. Through a patent search by finding a patent related to the project under study, one is able to view in greater detail on the machine specifications and paint system/mechanism that are used in the design. The patents are: Patent No. US1640776 [7], Patent No. US1725719 [8], Patent No. US1738738 [9], Patent No. US2317288 [10], Patent No. US2515865 [11], Patent No. US6276616 [12], Patent No. US8807459 [13], Patent No. US5209405 [14] and Patent No. US3003704 [15].

Sangkyun *et al*. developed a robotic system for road lane painting [16]. The system is capable of tracking the existing faded lane mark and performing re-painting operations on-site, so that the dangerous and time consuming manual operations can be eliminated. An autonomous wheeled mobile robot (WMR) has been designed and developed to perform a basic road painting task with the paint mechanism and controller mounted on the robot platform [17]. The system is capable to perform the task reasonably well though it is quite complicated, intricate and incurs high cost.

The proposed research contains a number of value-added features and a forthright attempt to automate the road painting process. The semi-automatic on-the-road painting machine essentially comprises two main parts, namely the prime mover and mobile platform with paint mechanism mounted on it. The prime mover should be the main vehicle that is used to transport the mobile platform with its accessories according to specific requirements such as maximum payload, speed, types of power source/drive, types of transmission, etc. This maybe in the form of various wheeled based systems, i.e., two-wheeled system such as bicycle and motorcycle [18] or a four wheeled system as in car or motorised wheelchair [19]. In the study, the obvious choice of the prime mover is an electric bicycle which apart from low cost, it is relatively easy and safe to operate. It also fulfills the proposed minimum design requirements defined by the user. An important thing to note is that the prime mover should be operated manually by a human operator in terms of controlling the steerability and speed of the vehicle. The fact that the road painting task does not require high speed makes it an attractive option.

2.0 PAINTED ROAD MARKS

There are two main types of road mark paint systems used in Malaysia, namely, those that are based on cold and thermoplastic paints. Cold paint is widely used in road mark painting across the world. It has low drying speed, short lifetime of usage and is low cost. It is performed using a single unit road marking machine, unlike the thermoplastic method. According to the marking mode, the cold paint road marking machinery is divided into high-pressure airless type and low-pressure air spray type. However it is dependent on the property of the paint material itself like viscosity and concentration. It can be divided into cold solvent; cold water based and heated solvent types.

It is accepted worldwide that thermoplastic road marking is considered the more advanced type of marking due its longer life, high reflectivity and high skid resistance. Thermoplastic road marking paint is a solid powder at 25^{o} C. In construction, the thermoplastic paint powders is supplied to a pre-heater, used to melt the solid powder coating and transform it into a viscous liquid form, thereby, guaranteed the road marking machine with a steady stream of paint supply in the process. The melting paint is next transferred into the paint tank of the hand-push marking machine, and then the molten coating will be conveyed into the marking container. When the marking starts, the container should be located on the road surface and that the gap of the marking pedal controls the coating thickness.

There are three types of pavement marking, i.e., longitudinal lines, transverse lines and others lines [1]. Longitudinal lines consist of broken or unbroken line or combination of both line in the direction of travel. Longitudinal line such as center line, lane line, continuity line, pavement edge line, turn line, climbing line, warning arrow and no passing zones marking. A centre line is used to designate the centre of the travelled part of a roadway carrying traffic in both direction.

3.0 DESIGN OF THE MOBILE PLATFORM AND PAINT MECHANISM

A typical and complete engineering design process [20] is carried out in developing the system that also employs a full mechatronic approach. The mobile platform with its painting accessories is in fact the most important part of the design. This is where the microcomputer-based or digital controller is located that produces the semi-automatic operation. This may come in the form of PC (personal computer), programmable logic controller (PLC) and peripheral interface controller (PIC) or microcontroller [21]. The controller serves to coordinate and control effectively all the data communication of the input and output signals (i.e., I/O signals involving sensors, switches, actuators, lamps, etc.) through a written computer program that is related to the various sequence of operations related to the painting task. Note that the I/O devices are appropriately connected through electrical/electronic circuitry that includes appropriate power supplies to drive the electrical/electronic components. The choice of the controller is again largely dependent on the cost factor, i.e., the lower the better. Thus, the lowest end of the microcomputer-based controller is obviously the PIC type, i.e., microcontroller. However, further scrutiny should be done to select the most appropriate type; the *Arduino* system is deemed to be the best in this category due to its simplicity, low cost and very popular [22].

All the information that is acquired in the literature review is critically analysed and studied. A list of the *Product Design Specifications* (PDS) or requirements for the project can be presented as follows:

i. Economic factor, i.e., low cost
ii. Proposed system should produce a single continuous line pattern using cold white paint
iii. Road line produced should be sharp and nice
iv. The paint system or accessories should be light, compact and manageable
v. An electric bicycle is chosen as the main prime mover
vi. Maximum load (weight) that the mobile platform could support the paint accessories: 50 kg (excluding the weights of a human operator and bicycle)
vii. Maximum speed of the prime mover: 10 km/h
viii. Extra features of the proposed system:

- Semi-automatic operation using *Arduino* microcontroller system
- Installation of rear camera and LCD screen to observe the real-time painting process/task
- Mounting of a safety lamp to enable good visibility of the system during operation, obviously for safety reason

ix. Use rechargeable lithium-ion batteries as DC power sources
x. Aesthetics in mobile design to include compact design
xi. Simple in design and easy to fabricate

The prime mover and mobile platform with paint mechanism mounted on it. The detailed description of the mobile platform with the paint accessories, particularly in relation to its complete design process/methodology and subsequent development shall be accordingly described. Due to its relevance and importance, the project design methodology framework is again reproduced to cover the followings: functional analysis, morphological chart, conceptual ideas, evaluation matrix, concept development, detail sketching and CAD model.

Functional analysis is an important activity to be carried out to realize or develop the proposed machine. The system is designed and developed from studying and analyzing the existing product, patent and product design specifications. In determining the systems of the machine, we are focusing only on the mechanical based concept and not considering other aspects such as electronic component. After studying and analyzing based on literature review, the machine consists of four sub-systems: driver mechanism, platform, container and paint mechanism. If one of these parts is not available or missing, then the whole machine would not work well. Morphological chart is the part to getting ideas for the system in functional analysis. Several ideas for each of the system can be produced and presented through brainstorming and discussion. Figure 1 shows a morphological chart for the design.

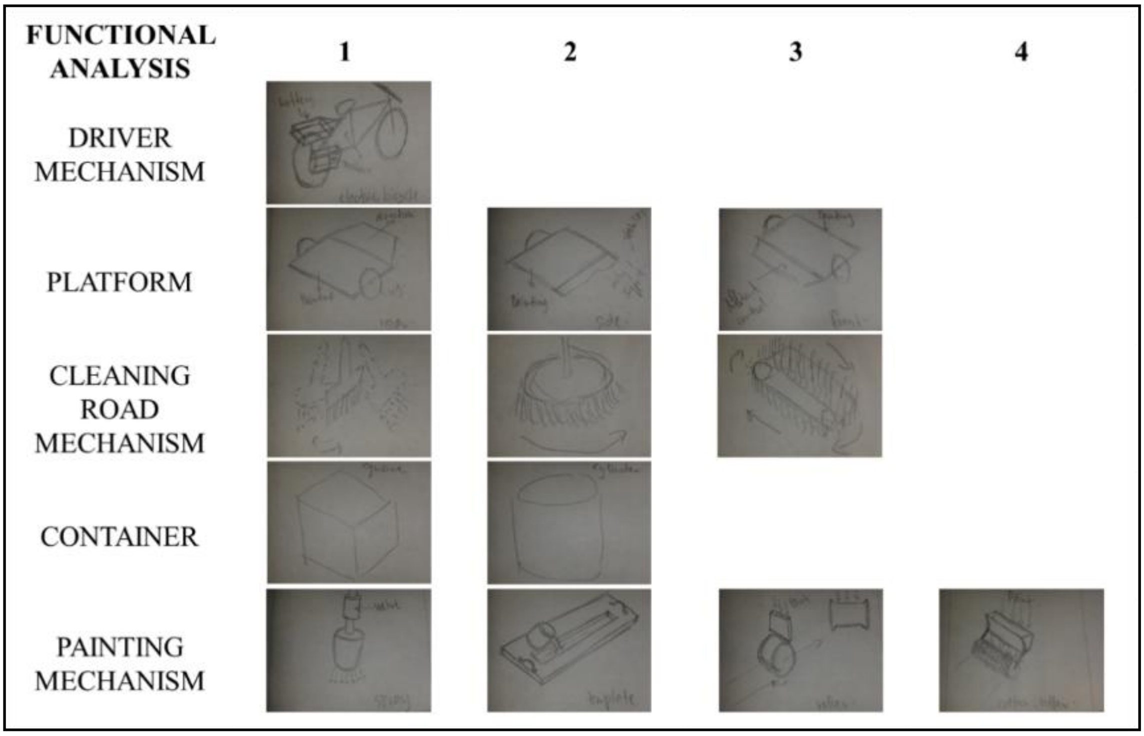

Figure 1: Morphological chart of the design

From the morphological chart, a number of conceptual ideas are presented that show the corresponding design and sketches of the proposed system with particular emphasis on the design of the mobile platform with its painting accessories. Then each of the conceptual idea is individually and rigorously analysed with specific reference to the design philosophy and criteria (specifications or requirements) deliberately set in the proposed design. They are then evaluated based on a set of design criteria through an evaluation matrix as shown in Table 1 that in turn will provide the scores considering the given weightage, their distribution of which are determined to be appropriate for the design.

Table 1: Evaluation matrix

No.	Selection Criteria	Weightage	Rating*				Score*			
			C1	***C2***	***C3***	***C4***	***C1***	***C2***	***C3***	***C4***
1.	Aesthetics of body	5	4	3	2	4	20	15	10	20
2.	Easy to fabricate	10	2	4	2	3	30	40	20	30
3.	Economic factor	10	1	4	2	3	10	40	20	30
4.	Sharp and nice road mark	20	4	2	4	4	80	40	80	80
5.	Safe to use	20	3	3	2	3	60	60	40	60
6.	Easy to access	10	2	3	2	3	20	30	20	30
7.	User friendly	5	4	3	1	4	20	15	5	20
8.	Power management	5	1	4	2	3	5	20	10	15
9.	Sustainable	5	3	3	3	3	15	15	15	15
10.	Line types handling	10	4	2	4	2	40	20	40	20
	Total score						300	295	260	320

* Rating is based on numerical values of 1 to 4 (worst to best) and the score is the product of rating and weightage, both for the four conceptual designs (*C1* to *C4*)

The conceptual idea which gives the highest score is deemed as the 'best' or 'optimised' design that will eventually be chosen as the final design. Once chosen, a more detailed design shall be carried out until a production drawing is produced for fabrication purpose. The flow of the initial ideas are described in the following sections. Evaluation matrix is used to give the mark for each conceptual idea (*C1* to *C4*) presented earlier. The highest mark will be selected as the final conceptual idea that may be further developed. Evaluation matrix consists of the selection criteria, weightage, conceptual ideas, mark and scoring. The selection criteria are based on the product design specifications. The weightage is fully dependent on the priority. Higher priority will be given higher weightage and the total of all weightage for the criteria must be equal to one (100%). The mark is valued based on score 1 to 4 (worst to best) and its scoring is the product of weightage and rating. From Table 2, the highest scoring is produced by *C4* and hence it is selected as the final conceptual idea that is to be further developed and refined. Concept development is the stage to describe further development of the final conceptual idea (*C4*). The concept might be ideal in some cases and hence, at this stage, some changes and modifications have to be done to further enhance or improve the system performance in order to make it realisable or develop it according to the availability of parts or components and other conditions related to fabrication and cost. There are three selection criteria in which the score for *C4* is lower than *C2*, i.e., easy to fabricate, economical cost and power management. The lower score is caused by type of cleaning mechanism that is used in *C2*, i.e., it uses a rotary brush that consists of only one motor and circular brush but *C4* is using treadmill component that consists of two motors and treadmill brush. Comparing one motor with two motors is enough to obtain lower score for economical cost and power management. The criterion related to easy to fabricate is also having a lower score because of difficulty in assembling the paint mechanism in the machine. Rotary brush only attaches the motor vertically downward on the platform and attaches circular brush on the motor. Treadmill brush is more difficult. Some attachments or brackets must be designed so as to mount the motor horizontally and assembly treadmill brush needs to be sufficiently tight in tension. The preferred container is cylindrical shape as square container typically consists of sharp edge and corner that might trap the paint material compared to cylindrical container that is almost free from sharp edges and corners. Furthermore, cylindrical shape has higher aesthetic value than square prism due to the curves. Apart from the two components, there are no other changes that need to be done. A detail sketching of *C4*was done to provide more information on the design that may include the parts dimensions, mechanical and electrical systems to be procured and controller design to get to the final design. The detailing should strictly follows the product design specifications or requirements. Once decided, the next step is to produce the detailed drawings using a CAD model.

The CAD model is normally the final stage before fabrication. Using *Solid Works* software, the model of the proposed painting machine was built and drawn. During modelling, some necessary modifications were done due to problems related to space, smoothness of the system and possibility that some parts might be in collision. Figure 2 shows a CAD model of the proposed system.

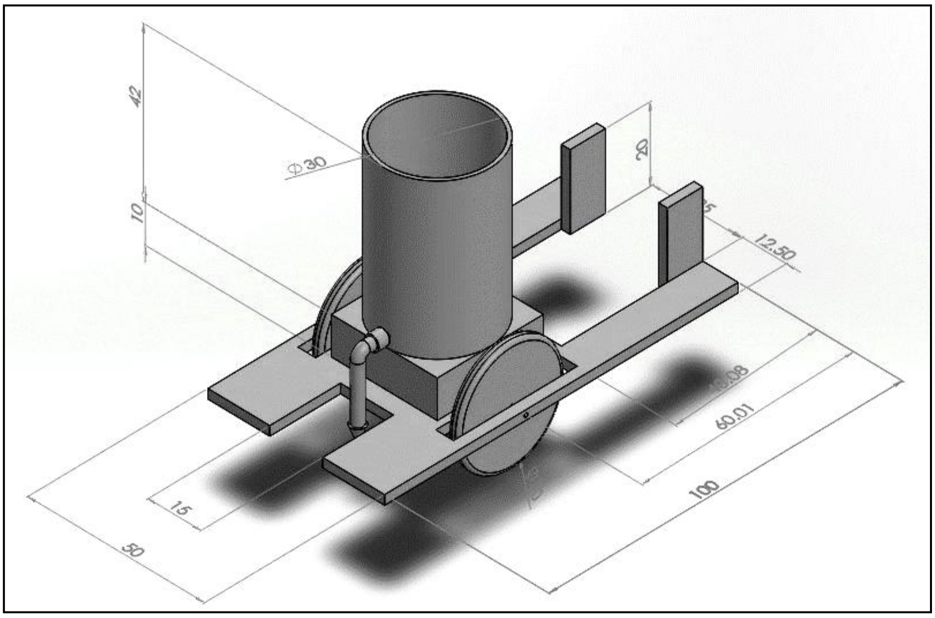

Figure 2: An isometric view of the CAD model of the paint platform

After getting CAD model, fabrication is performed involving some necessary modifications in the design to simplify the fabrication. The fabrication is divided into two part; i.e., the mobile platform and arm connector. The mobile platform serves as the place to mount all the paint mechanism and its accessories. The arm connector functions as a physical (mechanical) link between the prime mover (bicycle) and mobile platform. The mobile platform is made from mild steel with dimension, 500 mm × 500 mm × 10 mm. There is a square hole located roughly in the middle of the platform, which is 200 mm × 200 mm in dimension, the main function of which is to locate the main part of the paint mechanism, e.g., spray gun nozzle, small video camera or others. Three wheels were placed under the platform. Two rear wheels can only move in straight while the other one in front can freely rotate which enable the platform to make a turn if necessary, thereby may cause the platform to move in a curve path. The arm connector provides the important link between the bicycle and mobile platform. It is also made from mild steel and it is a combination of three items. The first item is the plate with dimension 800 mm × 50 mm × 2 mm. This plate is bend according to a steep V shape but curve at the bottom end to accommodate a cylindrical bar. The second component is the cylindrical with a diameter of 16 mm diameter and 200 mm in length. This bar is welded to the first plate at the bending curved point. The third item is a plate with dimension 200 mm × 100 cm × 5 mm. This plate contains a hole of 20 mm diameter and is attached to the platform. The free end of the cylindrical bar is inserted into the hole at the third plate.

The paint mechanism with its accessories is deemed as the most important section in this project. A spray painting concept is chosen as the main paint mechanism that conveys the paint onto the road surface. Compared with the concept that uses a slot guide casing and roller, the spray is considered a more modern approach and it has not been used in Malaysia for on-the-road painting but widely used in oversea countries for road line and house painting. Therefore, this concept is chosen and the fact that this system uses compressed air to atomise the paint, it would produce the paint impression of higher quality even though on uneven surfaces. The compressor is connected to a 12 V DC battery power supply. The positive terminal cable is connected to the control device. Then, once activated, the compressor provided the compressed air through a pressure regulator. The pressure regulator will allow the amount of air into the system. Eventually, it will go into the mini spray gun (with a nozzle). Since the paint is gravitationally flowing downward, the paint coming out of the mini spray gun is atomised by the compressed air. Figure 3 shows a schematic of the paint system.

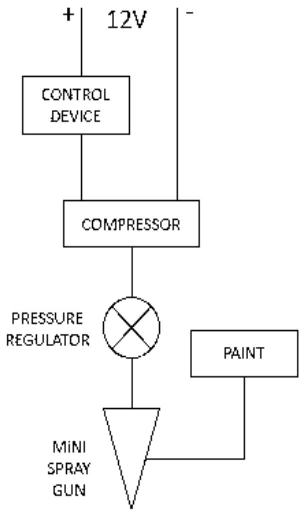

Figure 3: Schematic of the paint system including its control

Compressed air is produced by mini compressor just like the one used in portable tyre pump. This compressor can reach a maximum pressure of about 150 psi (10.34 bar) when pumping a tyre which is enough for atomising the paint but when the compressor operates, it can only supply a pressure of about 20 psi (1.38 bar) only, perhaps due to more open flow of air in the system compared to that of tyre. The required pressurised air to atomise the paint is set by the pressure regulator. This component range is 0–250 psi (0-17.24 bar). The spray gun is the tool used to unite the paint and air by controlling the triggered output. The paint flows gravitationally downward and is controlled by the spray gun at the end of the tube carrying the paint. All the painting accessories are assembled on the mobile platform as shown in Figure 4.

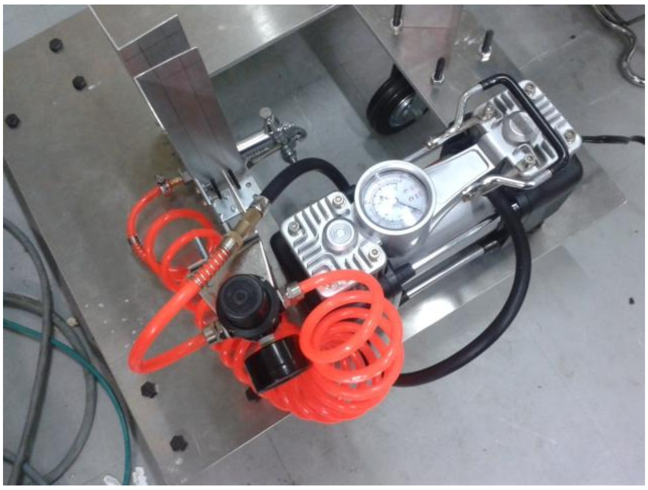

Figure 4: Assembled paint system on the mobile platform

It should be noted that the total weight of the complete mobile platform comprising the paint mechanism and its components (platform, wheel, camera, safety lamp, battery and paint spray mechanism) is not that critical due to the very fact that an electric prime mover (bicycle) is used to move the system; as it is, the weight of the mobile paint system is approximately 30 kg which can be easily supported and transported by the bicycle. The other components with reference to LCD screen and control box are firmly mounted on the handle of the bicycle. The fact that the electric bicycle is able to accommodate an extra passenger at the back of the bicycle with a load exceeding 50 kg, the paint mechanism with its platform and mounted devices should not pose any problem for the prime mover to handle and operate.

4.0 SYSTEM INTEGRATION, TESTING AND EVALUATION

A complete integration and interlinking of all the hardware and software of the prototype, with particular emphasis on the electrical circuits, development of *Arduino* microcontroller and related computer programming. The extra and novel features of the developed system are first presented followed by a more detailed description of the controller system development including the installation of the control box at the frontal part of the prime mover (bicycle) and the related electrical wiring (connections). A number of photograph images related to the development of the proposed system realised and developed in the laboratory setting are presented. The complete system is in fact a working prototype of the on-the-road painting machine that comprises two main components, namely, the prime mover in the form of an electric bicycle (the drive mechanism) and the paint mechanism that is mounted on the mobile platform. The testing of the complete system and evaluation of some of the findings of the study are also presented in this chapter. The safety lamp used in the project is a yellow safety beacon type which is widely and typically used in construction site and also on the rooftops of big lorries and tankers. This lamp is used for high visibility and also to warn other operators surrounding the machine about its existence (safety). This lamp is mounted on top of the mobile platform through a support bracket near to the bicycle at a height of 1.5 m from the surface of platform.

Figures 5 (a) and (b) show the camera and LCD screen, respectively that are used to enable the operator to monitor closely the conditions of the line being painted under the mobile platform through the use of a paint spray gun which faces downward towards the road surface during the drive operation of the bicycle. The camera is mounted appropriately on the mobile platform next to the base of safety lamp support bracket and facing down towards the spray paint that comes out from the nozzle of spray gun. The LCD screen is attached on the instrument casing of the bicycle's handle facing the operator/rider.

(a) (b)

Figure 5: (a) Camera attached below the platform and (b) LCD screen mounted on top of the bicycle handle

The brain of the automated part of the system that does the partial decision making is the *Arduino* microcontroller system. It uses the *Arduino* Mega card that comes with the input and output (I/O) ports. Since this project is still in deemed developmental, only some of the ports were used related to the I/O devices used in the project. Hopefully the other ports will be used full for next developmental project. Beside the *Arduino* system, other related devices used are relay *SRS-12VDC-5* which is used as a switch controlled by *Arduino.* This section shows how the electrical parts are interconnected through a schematic of electrical circuit as shown in Figure 6. The *Arduino*, relay, electrically operated air compressor, safety lamp, camera with LCD screen are all connected to a battery, 12 V DC power supply. Three parts, namely, the safety lamp, compressor and LCD screen are connected to one switch. The positive connection of the power supply for the compressor and safety lamp is also attached to the relay that in turn is controlled by *Arduino* microcontroller.

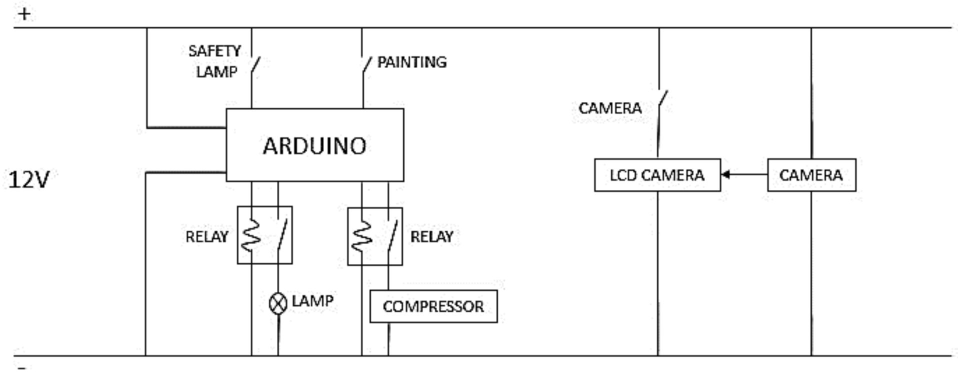

Figure 6: Schematic of the electrical circuit

All the control tools and instrumentation such as the switch, relay and *Arduino Mega* card are assembled in one control box as can be seen in Figure 7. This control box is installed at the front part of the bicycle.


(a)


(b)

Figure 7: Inside the control box: (a) complete components (b) closed-up view of the *Arduino* board

When the compressor is activated by switching on the *Arduino* controller, it will start to operate after a delay of about 5 seconds. This delay is deliberately set to enable the operator to move the bicycle first. The compressor will stop when *Arduino* controller is deactivated. In any case, as a safety measure, if the compressor is not deactivated, it will automatically shut down after 10 minutes continuous running. This is to prevent overheating of the compressor after 10 minutes continuous running. Figures 8 (a) to (c) shows a flow chart of the operation sequence related to the compressor, safety lamp and camera, respectively, of the system.

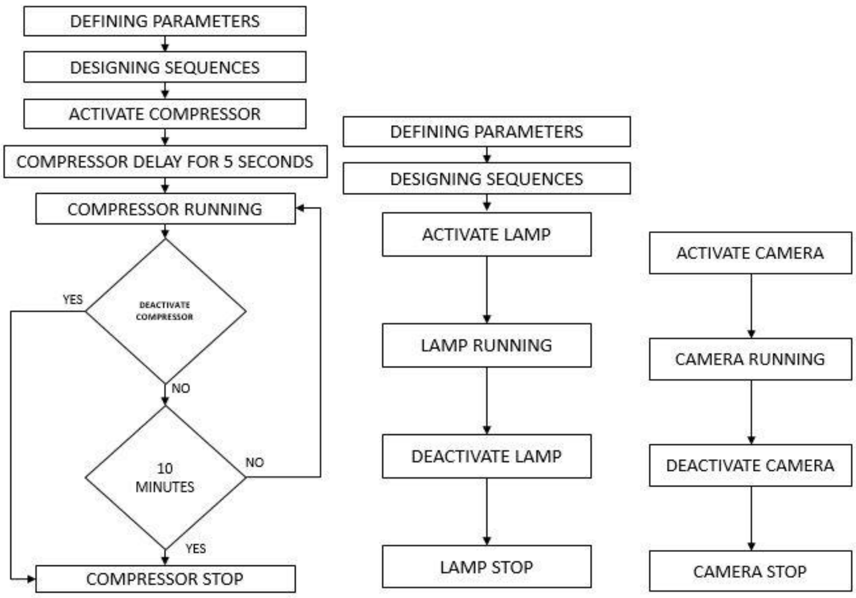

Figure 8: Operation sequence for the (a) compressor (b) safety lamp and (c) camera

Programming is done using an open-source *Arduino* Software (IDE) which can be downloaded from the *Arduino* website. A suitable program related to the project that includes the operation of air compressor and safety lamp could be written based from the operation sequences of the related task as follows:

```
int compPin = 13;              // relay of comp connected to digital pin 13
int lampPin =  14;             // relay of safety lamp connected to digital pin 14
int ckeyPin = 15;              // Switch of the comp is connected to digital pin 15
int lkeyPin = 16;              // Switch of the safety lamp is connected to digital pin 16

void setup()
{
  pinMode(compPin, OUTPUT);    // sets the digital pin as output
  pinMode(lampPin, OUTPUT);    // sets the digital pin as output
   pinMode(ckeyPin, INTPUT);   // sets the digital pin as input
  pinMode(lkeyPin, INTPUT);    // sets the digital pin as input
}

void loop()
{
if (ckeyPin = HIGH) {
  digitalWrite(compPin, HIGH);        // sets the Comp on
  delay(5000);                        // waits for 5 seconds
}
else {
      digitalWrite(compPin, LOW);     // sets the Comp off
}
if (lkeyPin = HIGH) {
  digitalWrite(lampPin, HIGH);        // sets the Safety lamp on
}
else {
      digitalWrite(lampPin, LOW);     // sets the safety Lamp off
}
  digitalWrite(compPin, LOW);         // sets the Comp off
  delay(600000);                      // time of the automatic off
}
```

The working prototype is realised after all the assembly tasks have been carried out in relation to integration of two important sections, i.e., the prime mover (bicycle) and the mobile platform with the painting accessories mounted on top of the platform as shown in Figure 9.


(a) (b)

Figure 9: (a) Mobile paint platform and (b) full assembly of the prototype on the road

The paint mechanism can be considered as one the most important parts in this project. Some rough tests for the paint mechanism have been done to ensure that acceptable results can be obtained. It is found that the system is still quite crude and subjects to further study/works to make it more practical and feasible. In the first test, a water based paint was utilized as the 'liquid paint' for this project without any mixture. During testing, there are clogging at the connecting port of the paint storage and spray gun that cause the paint comes out in the form of many 'spots'. The paint cannot be atomized completely by the compressed air with a pressure of 20 psi (1.38 bar). For the second test, clean water was used to check whether the problem is caused by the paint material or paint mechanism. When the test is run, the compressed air is able to atomize the clean water and the outcome is smooth spray pattern from the gun. In the third test, the paint was mixed with the clean water with ratio 1:1 to reduce the concentration of paint. The mixture shows that it can be atomized by the compressed air. The result is deemed reasonable and appropriate. From the rough testing procedure carried out, it is felt that there should be an optimum ratio of paint mixture with water. The concentration of paint shout not be too high such that the compressed air cannot atomize the paint or too weak to the extent that the paint impression left by the paint will be very light and not clearly visible. In the fourth test, the aim is to increase the pressure of the compressed air. When the test is run using paint without any mixture, the pressure regulator was adjusted to have a higher compressed air. The pressure regulator still maintains a constant pressure at 20 psi and the result still shows many 'spots' coming out from the spray gun. When the compressor was operated freely, the pressure of air is still 20 psi. Thus there is a need to have a bigger power of the air compressor. The fifth test is to adjust the nozzle size. When the test was run using paint without mixture, the pressure of the nozzle located at the front of spray gun was manually adjusted by moving it forward and backward. The result is still the same; the spray gun still produce many spots.

From all the tests, it can be concluded that if the paint without water mixture were to be used, a bigger and more powerful compressor and a bigger nozzle spray gun should be acquired. When a human operator drives or ride the electric bicycle as the prime mover of the system, a number of problems have been discovered. The first problem is that the bicycle is not that stable if the speed is too low, i.e., very slow operation. The operator needs to use the leg to 'stand up' the bicycle. The stable condition can be achieved when the bicycle, is driven at a fast pace i.e., higher speed but at the expense of producing poor paint outcome. The bicycle needs to be attached with additional mechanism to stabilise, e.g., attaching third and/or fourth stabiliser wheel/tyre, just like the toddler's cycle. The second problem is related to the speed of the bicycle which is dependent on the how much the operator 'throttles' the bicycle by squeezing and turning clockwise with hand the speed controller at the tip of the right handle. If the operator turns the 'throttle' too little, then the bicycle become unstable due to very slow speed operation. On the other hand, if the operator turns the throttle too much, then the paint quality becomes poor due to the fact that the spray paint is not able to cover all areas of the paint mark. In other words, the paint mark will be quite insignificant and shows a poorly distributed impression of the road line on the road surface. If the operator inconsistently turn the ‘throttle’, then the paint outcome will be also inconsistent. Thus, there is a need for constant speed operation and that this speed should be optimised.

5.0 CONCLUSION

A working prototype of the semi-automatic on-the-road painting machine has been designed, developed and tested based on a mechatronics approach in which the mechanical parts, electrical/electronic components and computer control program were completely integrated. The prime mover, which is the electric bicycle, is operated by a human operator while the mobile platform with the paint accessories mounted on it, serves to provide the automatic operation of the painting process through the use of *Arduino* microcontroller system that interconnects the input and output devices and communicated digitally via the developed written computer program. It can also be said that three novel features were successfully incorporated into the prototype, i.e., the safety lamp for visibility and safety during operation, video camera and LCD screen for real-time monitoring of the painting task and most important of all, the semi-automatic operation of the machine is made possible via the use of the *Arduino* microcontroller system.

ACKNOWLEDGEMENTS

The authors are grateful to UTM for providing the financial and technical support. The research is supported through a research grant (Vote No. 0H472).

REFERENCES

1. Public Work Department Malaysia, 1985, *Manual on Traffic Control Device: Road Marking and Dileanation*, Kuala Lumpur: Road Branch Public Works Department Malaysia.

2. R.S. Machineries Sdn. Bhd., 2014, *Roadline Marking Machines*, http://www.thersgroup.com.my/prod01.htm October 2014.

3. City of Edmonton, 2012, *Design and Construction Standards: Marking Pavements Guidelines*. Edmonton.

4. Road Safety Markings Association Department, 2010, *Top Marks: A Guide To The Road Marking Industry in UK*, UK.

5. Department of Transportation and Main Roads, 2013, *Guideline Pavements Marking 2013, Part D: Materials and Equipments*. Queensland, http://www.tmr.qld.gov.au/business-industry/Technical-standards-publications.aspx 1 June 2015.

6. Witt A., Smith R. and Visser A., 2000. Durability and Cost Effectiveness of Road Marking Paint, *South African Transport Conference*, South Africa.

7. Henry O.K., 1927, *United States Patent No. US1640776,* Ohio: United States Patent Office.

8. John O.O., 1929, *Unite States Patent No. US1725719*, Florida: United States Patent Office.

9. Samuel J.S. Jr., 1929, *United States Patent No. US1738738,* Ohio: United States Patent Office.

10. Ross C.M., 1943, *United States Patent No. US2317288*, Auburn: United States Patent Office.
11. George A.F., 1950, *United States Patent No. US2515865*, Pittsburgh: United States Patent Office.

12. Jason R.J., 2001, *United States Patent No. US6276616*, Boulder: United States Patent Office.

13. Matthew A., 2014, *United States Patent No. US8807459*, Omaha: United States Patent Office.

14. Frank A.R., 1993, *United States Patent No. US5209405*, Toledo, Ohio: United States Patent Office.

15. Andre R., 1961, *United States Patent No. US3003704*, Bouches du Rhone, France: United States Patent Office.

16. Sangkyun W., Daehie H., Woo-Chang L., Jae-Hun C. and Tae-Hyung K., 2005, A robotic system for road lane painting, *Automation in Construction*, 17(2), 122‑129.

17. Mohamed A.H.A., 2014, *Autonomous Mobile Robot Navigation and Control in the Road Following and Roundabout Setting Incorporating Laser Range Finder and Vision System*, PhD Thesis, Universiti Teknologi Malaysia.

18. Tirmant H., Baloh M., Vermeiren L., Guerra T.M. and Parent M., 2002, B2, an alternative two wheeled vehicle for an automated urban transportation system, *IEEE Intelligent Vehicle Symposium*, 17-21 June 2002, Versailles, France, 2, 594 – 603.

19. Terashima M., Ashikaga T., Mizuno T., Natori K., Fujiwara N. and Yada M., 1997, Novel motors and controllers for high-performance electric vehicle with four in-wheel motors, *IEEE Transactions on Industrial Electronics*, 44, 128 – 38

20. Seyyed K., 2005, *Engineering Design Process.* California, Solectron Corporation.

21. John I., 2004, *PIC Microcontroller Project Book 2*, New York, NY, USA: McGraw-Hill, Inc.

22. Simon M., 2013, *30 Arduino Projects for the Evil Genius*, Second edition, United States of America: McGraw-Hill Education.