ABSTRACT

The advent of the era of machines has limited human interaction and this has in-creased their presence in the last decade. The requirement to increase the effectiveness, durability and reliability in the robots has also risen quite drastically too. Present paper covers the various embedded system and computer vision methodologies, techniques and innovations used in the field of spray-painting robots. There have been many advancements in the sphere of painting robots utilized for high rise buildings, wall painting, road marking paintings, etc. Review focuses on image processing, computational and computer vision techniques that can be applied in the product to increase efficiency of the performance drastically. Image analysis, filtering, enhancement, object detection, edge detection methods, path and localization methods and fine tuning of parameters are being discussed in depth to use while developing such products. Dynamic system design is being deliberated by using which results in reduction of human interaction, environment sustainability and better quality of work in detail. Embedded systems involving the micro-controllers, processors, communicating devices, sensors and actuators, software to use them; is being explained for end-to-end development and enhancement of accuracy and precision in Spray Painting Robots.
1 Introduction

In the era of growing robotics, one needs to focus on the technological advancement by which the performance complexity of the robot is reduced and the feasibility of implementing the same increases. In today’s world, there is a huge requirement of automation in painting applications. Use spray painting robots for it, and for that the intensity of paint, accuracy and precision of the painted path, paint and energy consumption, cost efficiency and durability should be looked upon carefully before the development. Hence, a detailed study of these diverse topics is necessary for manufacturing products of similar application. This paper provides brief and sufficient insights about the latest trends and technologies currently in use or under research in the field of image processing and embedded computing and benefits of using spray painting techniques over manual methods specially in rare location. Various Image Processing algorithms, methods and techniques that are used in Spray Painting Robots are being discussed. The insights about sundry components of the embedded system including the sensors, actuators, micro-controllers, processors etc. are deliberated. All the technologies that are conferred are presented in adequate detail and in a lucid manner.

2 Image Processing and Computer Vision

Image Processing is a technique that is used to performing various operations on a digitized image and aimed to enhance the quality, manipulation of the image, identifying the objects or activities inside the image feed, analyzing and drawing out certain results and assumptions out of it, etc. by using various mathematical models and transforms to be applied on the pixel-level matrix of the image. Image-Processing techniques can be applied significantly in the embedded systems [1], resulting into precise and efficient outputs to the overall working of the system. The live video-feed is being processed and required operations are applied on the image field inside the processor; providing a virtual view for the control system and can perform desired tasks upon that; eradicating the control dependent only on the physical-parameters and static programming methods. Image Processing can be effectively used for fully automated and dynamic Painting applications [2] by the high-pressure air spray nozzles; which get triggered when certain conditions or favorable parameters are detected in the video-feed; hence providing intelligence to the system.

2.1 Object Detection

Object detection is a Computer Vision [3] technique that deals with detecting instances of semantic objects of predefined classes for the applications of recognition of the target image and hence can take certain actions upon the static, dynamic or live image-feed into the system. An Object Detection detects the probability of an object in an image depending on the previously trained model for the particular object to be detected. In Robotics application, in real time, apart from the detection of the object, shape determination, accurate tracking [4], object localization, reinforcement learning [6] can be used.

2.1.1 Deep Learning Methods

One of the widely used transfer-learning algorithms for live image detection is YOLO [8]. “You Look Only Once (YOLO)” algorithm involves fetching all the pixels are taken all at the same time as an input to the deep learning model. YOLO V3[9] algorithm has around 80 different classes which also includes precise detection of person, bus, bicycle, traffic signs, car, motorbike etc. like obstacles that may come in the way of the automated spray-painting robot. It might be computationally expensive to detect many classes at the same time, so GPU-assisted processors must be used. Pretrained Models have gained popularity due to easy deployment, better architecture and high accuracy. Some other models can be used for Object Detection are Mobile Net SSD [10], R-CNN [11], Mask R-CNN [12], OverFeat, YOLOv1, etc. and for image classification InceptionV3 [13], Google Net [14], EasyNet, ResNet etc. can be used. 

To identify the objects, the classical, yet widely used method is making use of Deep Learning [15]. To detect the particular set of objects in the image, the dataset of the cropped images of the target objects are used for training [16] the model. It is passed through different layers of the neural net [17]. The highest-probability class denotes the detected object. The weights of the neural network can be saved after the training for future usage. By this, the customized objects can be trained and can classify objects like potholes, uneven surfaces, traffic signs, road markings (where it has to paint) etc.

2.2 Color Detection

Color Detection was classically done by using the color-intensity sensors, which based on their intensity values could predict the color of the object; in which the sensor contain a white light emitter to illuminate the surface, and by the help of activation of the three filters (red, blue and green) color is classified. The Color detection sensors don’t work in...
the absence of light, require frequent calibration, has short range (<40cm) making them obsolete for today’s industrial applications. Computer Vision has proved to be more efficient solution for color detection [18]; which involves required mathematical operations on the image, binarization, gray-scaling, masking, thresholding, bitwise operations etc.

First, the image is acquired in a grayscale form and then stored in the system’s memory. To perform color detection on RGB image, we can perform in MATLAB [19] or OpenCV. HSV color space can be used over the RGB space because of the efficient separation of the image luminance from the color information. A threshold-ed image is generated which has only the HSV ranges of the upper and lower levels of the specific color, which is called Masking [20]. To obtain the desired color detected image, the threshold image is operated bitwise AND on the host image; and so hence only the common color ranges are found in the final image. The detected color in the image is highlighted by the bounding boxes and then this information it can be used for further I/O operations on the Robot. Once the system is properly calibrated, the camera along with detection of the color of the road to be painted (white, black, yellow etc.) but also object detection, edge capturing, contouring etc. tasks can be per-formed on the same system; which considerably supports dynamic systems if required processing power is made suffice.

2.3 Edge Detection

Edge Detection [21] is a mathematical model to find the edges around the target by detecting discontinuities in brightness of the images obtained. In Spray Painting system, there is a high possibility of luminance intensity variations and blurring of the frames in the live video feed.

The Edges in an image are the significant local level changes, which occur on the boundary between two different regions; which is usually associated with a discontinuity in the image intensity or the first derivative of image intensity. These discontinuities are broadly of two types as explained in [22]; (1) step discontinuities; where the image intensity changes abruptly (2) line discontinuities; where the image intensities changes abruptly but then returns to the starting values within some finite distance. To detect the discontinuous significant local points in the image, discrete approximation to the gradient; which is the measure of the change in the function used for edge detection is applied on the pixel array of the target image. The samples of some continuous function of image intensity are stored in the array data structure. The Gradient is the two-dimensional equivalent of the first derivative, which is stored as a vector. The edge detection involves:

2.3.1 Image Filtering and Enhancement

Image filtering [23] is a process in which the unwanted noises from the image are removed and overall visual color quality can be improved. For instance, the captured image of the target is blur and to produce a clear image, Mean Filter is used; which performs average smoothening on the image by taking the average of each pixel value that surrounds it. There are Linear Smoothing filtering techniques like Box blur, Hann Window, Gaussian Blur etc. and Non-linear Smoothing techniques like Median filtering, Binary Morphological Operations, Min/Max Filters, etc. Also, some special techniques are used for smoothing like Spatial filters (can be applied on a dynamic system), Temporal filters etc. for noise reduction and quality improvisation. Image Enhancement [24] is used complimentary with filtering, which provides improvised sharpening and smoothening of the features. Enhancing of digital images leads to better object detection, segmentations, masking, color identifications and edge de-terminations. Some of the popular techniques are Histogram equalization, Adaptive Histogram equalization, Fuzzy Logic Technique, Nuro Fuzzy Technique, Unsharp Masking, Contrast Stretching, Log transformation, Local Enhancement etc. are used as per application [25].
2.3.2 Detection and Localization

The points with strong edge content are only considered as edges and they are localized in the image by using contours or bounding boxes. There are various detectors developed in the past two decades. The Edge detectors are of two types (1) first derivative operators – Sobel Operator, Roberts Operator, Prewitt Operator etc. (2) second derivative operators – Laplacian Operator, Gaussian Edge detector, Canny Edge Detector, etc. It is evaluated on the factors like probability of false edges, probability of missing edges and error in estimation of edge angle. Localization includes the formation of the Contours [26] around the detected pixels of the edges and hence giving the dynamic system the intelligence to focus only on the region inside the contour; which here in our case can be fully automating the painting by detecting the edges on the roads, pavements etc. and painting only in the region inside the contour. Painting inside the contour area is yet a challenging task; for which a bright red-color light can be emitted from the robot using VL6180X-LIDAR distance sensor’ to the area to be painting. The moment sharp red color is detected inside the contour region by the system [27,28]. By this, the system is made dynamic and can take decisions on basis the situational analysis where we do not need to explicitly program, efficient painting and avoiding all the menace caused due to the programmed delay time for the mo-tors to operate while painting [29].

3 Embedded System

3.1 Software

The Spray-Painting Robot as a whole system requires frequent decision making, in-formation processing, data storage, communication, I/O operations, data tracking and many such operations all at the same time [31]. To handle these kinds of operations, programming software are used to structure and organize the work of the whole system. The Software are used for programming the controllers, processors, performing image processing, training models, making conditional and logical decisions in real time, communicating wirelessly via Bluetooth, Radio frequency methods etc. By software programming, the resource utilization is made efficient [32,33].

Software that are used for the Spray-Painting Robot depends upon the functionalities for which it is developed. For microcontrollers, Arduino, Atmel Studio, Codeblocks, etc. For implementation of computer vision algorithms into the Robotic system; Python, C++, MATLAB etc. [34] languages are used. These high-level programming languages have wide range of libraries for image processing like OpenCV, Scikit-image, SciPy, PIL, Pycairo, Pgmagick, SimpleITK, Mahotas etc. and has inbuilt function for various image processing tasks. To train and deploy deep learning models, neural networks and adaptive learning methods, the libraries and high-end APIs such as TensorFlow, Keras, PyTorch, Numpy, Pandas etc. can be used. For the communication between hardware and software, ROS (Robot Operating System) [35] is a framework or a Meta OS which can also be used for communication and as an intermediary between the sensors and actuators; where the algorithms, system calls, drivers etc. are handled, which is operated on an OS (Linux) platform. ROS can be used for integrating all the hardware components of the Robot and controlling by one single platform. Moreover, PLC/HMI [36], can be used to satisfy the time demand requirements and matches industrial standards and hence multiple industrial components can be incorporated with the same system for hybrid applications.
3.2 Electronics

3.2.1 Microcontrollers

For small scale and explicit programmable systems, Microcontrollers serve as the most affordable as well as the fastest control system for the sensors, actuators, communicators on the Robot. Arduino family [37] controllers, ATMEGA family, etc. microcontrollers are used which has no memory or processor allocated for the execution of the commands [38]. Implementation of Image Processing Algorithms has to be done by external camera feed device and cannot be integrating with the control system of the Robot in this case.

3.2.2 Microprocessors

The applications that involve high computations, precise decision, computational ability, memory storage and access and frequent read-write operations, implementation of Image Processing and Computer Vision techniques etc. the microprocessors are used as the central control unit of the Robot. They provide high accuracy and durability in the application and thus leading to better decision-making for the Robot. Some of the microprocessors that can be incorporated are Raspberry PI family [39], NVidea JETSON NANO etc. for performing real time decision making and information processing [40].

3.2.3 Sensors

The sensors can be used in various domains for Spray Painting Robot. Environmental-sensor Modules [41] that include Temperature Sensors (LM35 etc.), Smoke detector sensors (MQ2 etc.), Relative Humidity Sensors (DHT11 etc.), etc. can be used for safety measures of the Robot and interrupt the painting process if any harmful signal values are received by the Environmental Sensor Modules [42]. The Ultrasonic sensors can be placed on the side of the robot facing the ground, which can detect the potholes [43], sinkholes etc. on the roads; hence ensuring safety for the robot from damage. Line Tracking Sensors [44] can also be incorporated to detect lines on the Roads and hence path can be well maintained. For some less precise and intrinsic applications, color sensors like white-line detectors etc. can also be used for Color Detection, which can be connected on the bottom of the Robot body. For carrying out image processing, Cameras of high quality must be mounted on the Robot. Use of Tachometer can be done to measure speed of the robot [45,46].

3.2.4 Communicating Devices

For short range applications, Bluetooth devices prove to be the most efficient as they can be easily connected with the mobile devices or computers. HC-05 is an example of such Bluetooth device family as in [46,47]. BLE (Bluetooth Low Energy) devices have gained popularity due to considerably low power consumption. For long range, HC-01 can be used which has 1KM line of sight range. NodeMCU or ESP8266 Wi-Fi modules can also be used for communication for comparatively longer range than Bluetooth devices. For long range communications, XBee or LORA can be used, which works on Radio frequency protocols.

3.2.5 Industrial Tools

PLC or Programmable Logic Controller is an industrial grade controller which can be used for industrially compliant results of the spray painting[48,49]. It has fast processing and precision in performance to enhance results. It can handle a variety of peripheral devices, including various sensors and camera. HMI or Human Machine Interface is a device which can display real time information and can be used to alter the state of the machine whenever required and thus the name Human Machine Interface [50]. In spray painting robots it can be used to change the on/off timer or speed, or any other such parameters as required by simply touch or hardware-based input system. The HMI is connected to the controller and sends commands to it.
4 Conclusion

The human interaction has been replaced by automation drastically and thus the demand for increasing the efficiency, durability and reliability in Robotics applications is substantial. When developing and designing Spray painting robots, many aspects come into consideration relating to the electrical and electronics system, mechanical and dynamics and computation and software technologies. This paper produces a detailed description about the recent advancements and research in areas which includes information about various image processing techniques, pretrained models, image analysis and dynamic and real time decisions by the system, which can be used as a reference significantly for manufacturing Spray-Painting Robots and similar applications in order to increase the accuracy and effectiveness to a greater extent. A thorough analysis of the various software tools, electronics actuators, sensors, microcontrollers and microprocessors cumulated to design and develop the Embedded Systems for Spray Painting Robots is being presented and also provides insights for justified selection as per requirement of the application. Furthermore, the present review accumulates the different technologies and parameters which result in reduction of cost, human interaction, environment sustainability and quality of work in detail. Thus, by integrating the various technologies for development of automated or semi-automatic dynamic systems using the latest technologies; resourceful, durable and efficient robots can be developed.

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