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Metallic Scrap Collection Robot with Efficient Trajectory

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Abstract*: Metal waste management is one of the major issue in today's and future industries. Efficient metal waste management in industries is very important in order to ensure, a safe environment, make room for future operations and reuse of this material. At present, in many industries, these metal scraps are still being collected by manpower, which is a cumbersome task. Therefore, it needs to be automated, so in this work we have opted a robotic solution for the metal scrap collection. We have developed an electromagnetic robot that can recognize and collect various metal scraps spread across an area. The process of recognition is carried out with the help of the image processing techniques on the images obtained through the camera installed in the area. The robot collects the scrap using the electromagnetic arm by visiting it. Our aim in this work is to control the robot's trajectory so that all the scraps identified can be collected within a minimum time by minimizing the distance travelled by the robot. We used two algorithms, Prim's and Kruskal's, to design this trajectory. In order to show the significance of both algorithms to our problem, we performed Matlab simulations and showed their comparison in terms of the total distance traveled by the robot to collect all the metal scraps.

Keywords: Electromagnetic Arm, Metallic Scrap, Robot Trajectory

I. INTRODUCTION

Iron and steel are still considered to be the most predominant material used in many manufacturing industries such as automobiles, aerospace, avionics and constructions etc. But a significant amount of iron and steel is wasted during the process of manufacturing their products. This kind of iron and steel wastage are referred to as metallic scrap. However, due to the high value of the iron and steel, recycling of these scrap instead of disposing off it, may lead to several potential benefits. First, when a recycled metal is used to make the product, the natural resources of iron and steel are reserved. Second, production of iron or steel from scraps requires less energy than to produce it from virgin ore.

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And third, it can help to reduce the pollution. However, the amount and quality of the recovered metal mainly depends on the collection system, the possibilities and techniques used for collecting these metallic scraps. One possible way is to collect these scraps manually. However, doing so is quite tedious and have couple of drawbacks such as it requires more labors and also it consumes more time [1]. Another alternative way to cope with these drawbacks of manual scrap collection and achieve more accuracy is to automate this task of scrap collection.

For this purpose, a robotic solution can be a more promising choice. Thus, in this work, our focus is to design and develop a robotic scrap collection solution that eliminate the need of hiring labors for this work as well as to finish the task in minimum time [2].

Due to the increased accumulation of metallic waste in these recent times, it has become a matter of concern for the researchers throughout the world to come up with novel and efficient solutions to reduce the pollution caused in the environment due to these metallic scraps [3]. Most of the solution for scrap collection are focused towards Robotics. One possible methods for collecting scrap is by using a metal detector and thereafter the robot can collect it using the robotic arm [4]. But this technique might be time consuming as the robot stops each time a metal is detected and then collects it. So in order to make the robot more efficient, an automated metal scrap collector is proposed in this paper, which works on the principle of electromagnetic induction and follows an optimized path to all the metallic scraps distributed randomly in a subject area. To find this optimized path, there are a couple of questions. First, how do the robot distinguish between a metal scrap and another object. For this purpose, a camera is installed to capture the area under consideration and sends its image to the robot using WiFi module. Based on image processing technique, the robot differentiates between the metal scrap and other objects. Second, how do the robot reach these identified scraps with in minimum possible time. For this purpose, the robot first generates a graph by calibrating the coordinate position of these scraps and measure the distance using Euclidean distance formula among scraps as well as the robot. Once a graph is available, an algorithm is needed to find the optimized path so that the robot can traverse to each scrap and collect it, with a minimum amount of time [5]. For the aforementioned required algorithm, we employed couple of well-known algorithms named Prim's [6] and Kruskal's [7] and conducted a comparison between them. The main contribution of this work can be summarized as follows:

- Designed a problem for collecting metallic scraps randomly distributed in an area within a minimum possible time.

- To solve the problem, an experimental setup is developed including a robot and a vision system.
- With the help of the vision system, the coordinates of the scraps are determined.
- The coordinates of scraps are mapped into a graph.
- Based on the generated graph, the robot moves through the area in an efficient path calculated by one of the two algorithm namely Prim's and Kruskal's.
- Finally, simulation results are presented to demonstrate the efficiency of both algorithms in terms of average distance travelled by the robot in order to collect all the metal scraps.

The remaining paper is organized as follows: section 2 describes the related works that were performed on automated metal scrap collector, section 3 discusses about the proposed system and the algorithms used, section 4 shows simulation results and section 5 concludes the paper.

II. RELATED WORK

While most factories around the globe are still gathering the scrap at present, using the manual method, with the aid of human workforce. Furthermore, however, many works related to the automation and reuse of the waste industry have been published in recent years. For example, [8] describes a robot system that can be used to gather and process waste. The autonomous robot can perform tasks such as avoiding obstacles and detecting metals. The robot takes a random route to collect all the scraps. The authors in [4] describe an automated electromagnetic scrap collection AGV that avoids obstacles, and the robot went blindly, only taking the avoidance of obstacles into account. [9] defines an automated scrap collection system for metal extraction using a magnet and an IR detector. No algorithm is given to choose the efficient path of a robot. [3] describes a robotic prototype that can automatically locate and target specific targets and maneuver through a receptacle without hitting obstacles, and retrieve the target with a robotic arm. This robot locates scrap based on an image processing method and uses Dijkstra's algorithm to track the scrap collection path. [10] describes a robot that can be used for garbage cleaning, powered by a solar panel, and uses image processing and ultrasonic sensors. Image processing effectively separated metal scraps without taking into account any other performance parameters.

III. PROPOSED FRAMEWORK

A. System Design

An electromagnet based metal scrap collection robot collects all the metal fragments in a given space of interest by performing the following tasks. First of all, the image of the full view of a room is taken by a camera which is installed inside the room (area of interest). The Robot then receives this image from the camera via a Wi-Fi unit. Using an image processing technique, the robot recognizes and identifies the

Table-I: Summary of related works

Ref,Year	Description	Objectives	Remarks
[1], 2010	Automated Garbage Collection Robot	Used image processing to create a graph and then the Dijkstra algorithm to find the minimum distance node	The proposed method can be used to find only a minimum distance between any two nodes of the connected graph.
[2], 2014	Metal Waste Collection Robot	Only hardware design and implementation are discussed.	No analysis or experimental results have been shown.
[3] 2017	Electromagnetic Metal Collection Robot	Only implementation of the prototype is presented.	No analysis or experimental results have been shown.
[4] 2018	Object Detection Based Garbage Collection Robot	Presented a robot hardware for scrap detection using image processing.	No analysis or experimental results have been shown.
[5] 2018	Electromagnetic Scrap Collection Machine with Vacuum System	The hardware implementation of the machine is presented. Performance parameters are not considered.	No analysis or experimental results have been shown.

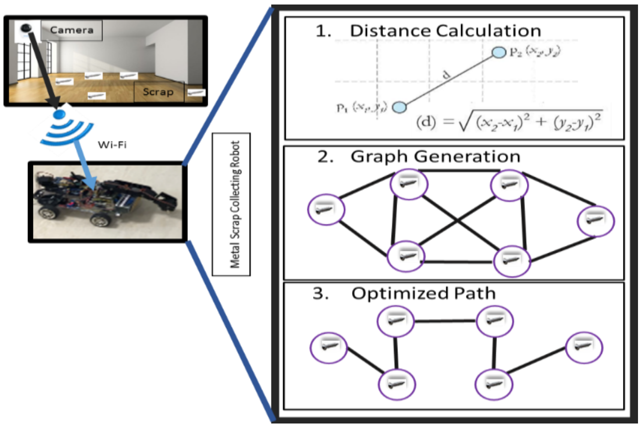

Fig. 1. Architecture of the Proposed System.

Metal scraps scattered from other objects in the room. Once the metallic scraps are identified; the robot calibrates the coordinate locations of all the scraps. Using these coordinates, the robot determines the distance of each scrap with respect to all other scraps. The robot accepts only the minimum value of the distance calculated from each node, to form a connected graph.

To make the trajectory of the robot more efficient, Prim's and Kruskal's algorithm are applied on the obtained graph. These algorithms help the robot to identify the shortest and optimized path to collect all the scraps in a minimum time. The simulation results are obtained from the Prim's and Kruskal's algorithms and their performance is compared on the basis of the average distance travelled by the robot to collect all the metal scraps, by varying the area of the room and by varying the number of nodes.

B. Robot Design

[1] The automated metal scrap collecting robot is built using microcontroller, sensors, motors and an electromagnetic arm. The Arduino Mega microcontroller is attached to four DC motors which help the robot move around. Two ultrasonic sensors in the front of the robot are used to detect any obstacle in its way to gather metal scraps.

The robot is programmed to avoid any obstacles and to follow a specific trajectory based on Kruskal's and Prim's algorithm. The robot arm helps the robot to collect all the metal scraps. The arm consists of stepper motors and an electromagnet, which attracts and collects all the metal scraps scattered in the area of interest. These metal scraps collected are then placed in a bin that is mounted on the robot.

An ultrasonic sensor is placed in the bin sense if the bin is overflowing. If so, a buzzer will be turned on and the robot will call to a stored number to indicate an emergency to clear the bin.

C. Scrap Identification

The image received from the camera provides a full view of the area of interest. Therefore, it is necessary for the robot to identify and recognize metal scrap from all other objects. Scale invariant function (SIFT) algorithm, proposed by David Lowe's, is one of the most widely used object recognition algorithms. Even for the images taken with a rotated, translated, illuminated, scaled view of the camera, SIFT extracts the stable features. The SIFT algorithm [11] recognizes objects by generating key-points descriptors for the Nearest Neighbor Search (NNS) algorithm that detects similarity between key-points. The SIFT algorithm undergoes four steps to generate key-point descriptors.

The first step is to generate extrema, the key candidate for image detection, by examining the image across all scales and octaves. It isolates different points from their surroundings on the image. The basic principle behind this is to choose the candidate key-points by applying Gaussian Difference to theblurred input image. The resulting key-points are rotational and scale invariant.Key-point location: Key-points with low contrast and poor positioning along edges are excluded from the large number of candidate key-points. This step is processed by calculating the Taylor expansion value D(X) of the second order in the offset X. It is determined by calculating and setting the derivative of this function with respect to X to zero.Orientation assignment: In this step, each key point defined in Step 2 is transformed with its magnitude and direction into a set of vectors. By considering 16x16 square window around each detected element, an orientation to each key-point is rendered with the help of a gradient histogram. The algorithm now identifies the final set of key-points which should be taken into account during the last step.In this step the algorithm splits the 16x16 window into 4x4 grid cells and calculates another histogram for each cell orientation. Eventually, with eight orientation vectors, we get a set of 128 dimensional key-point descriptors for each cell. Each descriptor is transformed into an image feature by measuring the normalized sum of these descriptor vectors.

Fig. 2. Robot Design

The algorithm is implemented using the Matlab Image Processing Toolbox. Each key-point descriptor found in the input image is compared to the descriptor list extracted from all matching training process images. The best match is recognized for each descriptor using the Nearest Neighbor search (NNS) algorithm. Thus, this algorithm identifies all metal scraps within the area of interest and provides the coordinate position of each scrap location.

D. Graph generation

The scrap collection robot can efficiently collect all the known scraps only if the robot estimates a fixed path for scrap collection rather than a random path. Initially, the scrap coordinates determined by the SIFT algorithm are considered in order to initiate the graph generation process. Using the axis coordinate values of the scrap position, the distance between the two scraps can be calculated using the distance formula:

$$d = \sqrt{(y_2 - y_1)^2 + (x_2 - x_1)^2} \quad (1)$$

The distance from each scrap node to all other scrap nodes is determined. Therefore, if we consider all these calculated values, it will result into a complicated graph. To get a simple weighted connected graph, we set a limit on the measured distance value between any two nodes. The distances between any two nodes within the limits set shall be accepted and the remaining distances calculated shall be rejected. In compliance with this criterion, the robot generates a connected and weighted graph. Therefore, the generated graph can be used to define the robot's path to travel in order to collect from these nodes all the metal scraps.

E. Algorithm

To make the collection of robot scrap even more effective, the robot must define the minimum spanning tree (MST) for the above created weighted connected graph [12]. A certain algorithm is needed to obtain MST that enables the robot to collect all the scraps in defined nodes within a minimum period of time. The Prim's Algorithm and the Kruskal's Algorithm are the two widely used algorithms to find MST.

F. Prim's Algorithm

[6] Prim's Algorithm is a kind of greedy algorithm that calculates the MST for a weighted undirected connected graph. [13] It generates a subset of tree edges that includes every node such that the total weight of all edges is the minimum among all other possible trajectories. We have a connected graph with a set of vertices V, where each vertex represents a scrap. The root node is initially set. Consider each node v separately, which is an element of V, Find a minimum distance from v to other neighboring nodes in V. The minimum distance node is labeled u and the distance d(u, v) is recorded. The node u is then assigned as the parent node of v [7]. Set V is updated by removing v whose parent has been selected. Later this procedure is repeated for all nodes until the V set is emptied and the parents of all nodes are determined except the root node.

Algorithm 1 Prim's Algorithm.

Input: G (V, E), connected graph with scraps at vertex V and E the corresponding edges.
Output: T, Minimum spanning tree
$cost[v] \leftarrow \infty, \forall v \in V$
$cost[v] \leftarrow 0$ where r is the root node.
$parent[v] = NULL, \forall v \in V.$
while $V \neq$ **do**
  Find $\min_{\forall u \in V} d(u, v)$
  $parent[v] \leftarrow u$
  $cost[v] \leftarrow d(u, v)$
  $V = V - \{v\}$
endwhile
  $T \leftarrow \{V, parent[v] - \{r\}\}$ =0

G. Kruskal's Algorithm

Kruskal's algorithm is another greedy algorithm which finds the minimum spanning tree in graph theory for a connected weighted graph [7]. It finds the subset of edges which includes all the vertices of the graph so as to form a tree such that the total weight of all the edges will be the minimum [14].

Algorithm 2 Kruskal's Algorithm.

Input: G (V, E), connected graph with scraps at vertex V and E the corresponding edges.
Output: A, Minimum spanning tree.
A = w (v, e) $where E.V \forall$ e $\in E$
while $E \neq$ **do**
  Find $\min_{for all e \in E}$
  $E = E - e$
  A = A ∪ {(u, v)} *where* u and v ∈ V and represent vertex of e
endwhile
  If (u,v) form a loop then $A = A-$ {u,v} ∀ {u,v}
  Return A

We consider a connected graph G(V,E) as input, where V(scrap) is the total number of vertex and E is the total number of edges in the graph. A is the Minimum spanning tree which is considered as the output in the algorithm. Initially the edges of the graph with the least weight w(v,e) is selected, where v is an element of V and e which is an element of E. Based on the ascending order of weight of the edges, each edge of the graph is sorted and added repeatedly to A, to form a connected tree. Once all edges are added to A, then the edges that forms a loop with any other minimum weighted edge, is discarded from A. The resulting A is the Minimum spanning tree, using Kruskal's algorithm.

IV. SIMULATION RESULTS

Matlab simulation is performed to measure the performance of the Prim's and Kruskal's algorithms for our problem. The distance traveled by the robot to collect all the scraps is considered to be the performance metric, provided that the scraps are distributed uniformly in the given region. The distance traveled by the robot collecting scrap is measured by varying the number of scraps (nodes) and the area of that region.

Fig. 3 gives a comparison of Prim's and Kruskal's algorithm for the average distance travelled by the robot and the area of the region of interest, considering fixed number of scrap nodes. The area of region is varied from 10m2 to 70m2 and number of scraps fixed at 6. In Fig.3, it can be understood that as the area of region increases, the average distance travelled by the robot also increases. Thus from the result obtained in Fig.3, it can be concluded that the prim's algorithm performance is better than that of Kruskal's. This is because as the area increases, the distance between the scraps increases. In Kruskal's the possibility of the robot to travel towards each node more than once is high, thereby the average distance travelled increases. Whereas in Prim's each node is visited only once, so repeating each node travel more than once is avoided, thereby reducing the average distance travelled by robot.

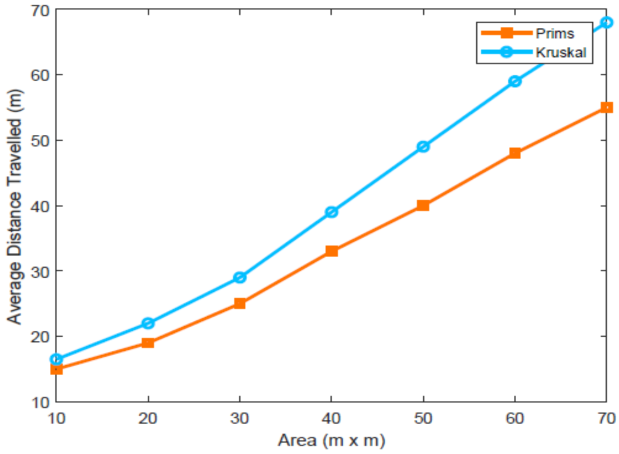

Fig. 3. Average distance comparison with variable area and fixed scrap

Fig. 4 shows the relationship between the distance traveled and the total number of scraps, given that the area of the region concerned is constant. The number of nodes varies from 2 to 45 and the area of the region is fixed at 100m2. It can be seen from the result that the distance traveled increases as the number of scraps increases. However, Prim's performance is better than Kruskal's with an increased number of scraps, because it is highly possible for Kruskal's to visit many nodes more than once, while Prim's only travels each node once.

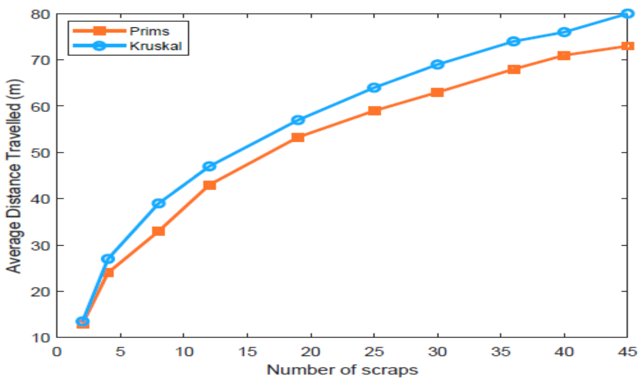

Fig. 4. Average distance comparison with variable scraps and fixed area

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V. CONCLUSIONS

Metal waste collection in various industries, such as the automotive industry, is physically demanding, along with the fact that it may expose workers to a variety of hazardous situations. In this work a robot is designed to collect metallic waste for industries with the aid of an electromagnetic arm and then dispose it at a single location from where it can be used for the recycling process. Our robot first collects a pictorial view of the subject area with the help of multiple cameras mounted across this area. Once it has images, it differentiates metal scraps from other objects using the image processing techniques and calibrates their position to form a graph. Once a graph is attained, the robot uses an algorithm to find its trajectory so that it can collect all the scraps identified within a minimum of time by traveling the minimum distance possible. We used two algorithms, namely Prim's and Kruskal's, and presented a comparison between them in terms of distance travelled. Two simulation graphs are obtained, one by varying the number of scraps in a defined area and the other by varying the area of region of interest with constant number of scraps. It is evident from the result that Prim's performs better than Kruskal's, as it visits only once every scrap pointed by a node in the graph. This robot can be used for various industries by modifying the design of the robot in the working environment of its applications.

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