SURF and Image Processing Techniques Applied to an Autonomous Overhead Crane

Majdeddin Kajkouj, Samer Al Shaer, Khaled Hatamleh, Iyad Salameh, Mohammad Al-Shabi, S. Andrew Gadsden, and Andrew Lee

Abstract—**This work presents the use of an autonomous overhead crane that detects a moving object. The crane matches the velocity of the object while its grabbers extend to reach its location. The position and velocity of the object are detected and tracked once the object is in range of the crane. This is achieved using image processing and image enhancement techniques. The SURF (speeded-up robust features) algorithm is used to extract the object's features and then detect its location. The centroid of the object and its location are calculated continuously to obtain the targeted position and velocity. A digital PID (proportional integral derivative) controller is used to control the crane's three DC (direct current) motors in order to acquire the target with a desired performance, such as a fast response and less than 2% overshoot. The proposed mechanism reduces the processing time of an industrial application which increases the productivity rate. The mechanism was built for experimentation and the algorithm and the controller were experimentally verified and validated.**

I. A Brief Introduction

Machine vision has been used widely in industry as it eliminates the need for sensors and reduces the overall system cost. It provides other features such as the ability to store a visualized history of the process and the ability to handle several tasks at once without additional costs. The speeded-up robust features (SURF) algorithm is one of the best approaches for feature extraction, and it has a wide range of applications especially in real-time tracking [1–7]. The idea of SURF is based on comparisons between two images of the same scene and finding the corresponding points between them. There are three steps in the process of finding these points. The first step is to detect the high-repeatability 'interest points' which generally are distinctive locations in images such as corners, 'blobs', or T-junctions. The second step is to find the interest points 'descriptors' which are called as feature vectors. This step is the core of the algorithm as it is used for locating the object in the next frame. The descriptors should be invariant to geometric and photometric deformation and robust to noise. The final step may be summarized by 'matching' the descriptor vector in the current frame with the next frame. The distinguished characteristics of the SURF algorithm are less dimensioned with fast interest point matching [1, 8]. The benefits of using SURF algorithm are summarized in the following [1 – 8]:

- It is applicable for posture recognition as it has in-plane rotation, and scalar features.
- It uses a 'box filtering' technique which is based on integral images. Features are independent of image size.
- It is independent on illumination changes.
- It handles blurring conditions better.
- It is less sensitive to noise.
- It is a very fast process, which makes it suitable for real time systems.

In this work, an automated overhead crane was built. The system consists of a machine vision algorithm/mechanism in order to track a product and pick it up with a fast response. The paper is organized as follows. The experimental setup, including the control mechanisms and system components are provided in Section 2. The detection and tracking algorithm is described in Section 3. A summary of the results is provided and the paper is concluded in the final section.

II. Experimental Setup

An overhead head crane consists of three motors: one of them is used to move the hoist on the x-axis, the second one is used to move the hoist on the y-axis, and the hoist motor which moves the hook to the targeted location along the z-axis. The overhead crane may also be referred to as the bridge crane, gantry crane, or a goliath crane depending on the variety in its features according to the ASME B30 series. Figure 1 shows the main components of the overhead crane. In industry, overhead cranes are used to move materials horizontally or vertically according to the application. For example, Gantry cranes are used in load transportation commonly used in construction. Controlling an overhead head crane could be difficult and has many problems. For example, a problem may occur when transporting the load due to the swing angle between the load and the hoist's rope. Several researchers have studied this issue in an effort to overcome limitations of the design [9, 10].

In this paper, a PID controller will be derived and used to control the dynamic performance (positioning) of the crane. Simulation results of the response of the gantry crane with the controllers were studied in both the time and frequency domains. A similar approach of this technique was used and studied in [11], where the PID algorithm was comprehensively studied and compared to obtain the proper values.

M. Kajkouj, S. Al Shaer, and I. Salameh are with the Department of Mechatronics Engineering, Philadelphia University, Amman, Jordan.

K. Hatamleh is with the Department of Mechanical Engineering, Jordan University of Science and Technology, Irbid, Jordan.

M. Al-Shabi is with the Department of Mechanical Engineering at the University of Sharjah, United Arab Emirates.

S. A. Gadsden and Andrew Lee are with the Department of Mechanical Engineering at the University of Maryland, Baltimore County, Maryland, USA, 21250 (e-mail: gadsden@umbc.edu).

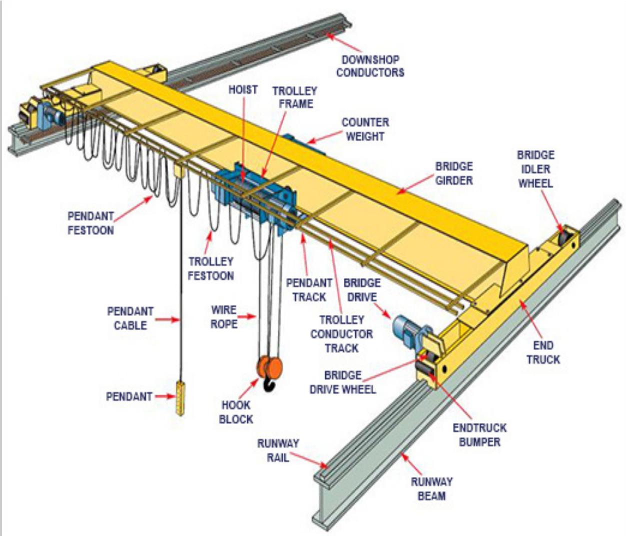

Figure 1. Overhead crane components, as per [9, 10].

The system built for experimentation is shown in Fig. 2. The middle beam (yellow) moves along the horizontal direction for backward-forward movements to allow for a degree of freedom along the y-axis. On that beam, a slider is used to move to the right and to the left of the beam which is used as the x-axis degree of freedom. A gripper, attached to the slider with a metallic rope, moves up and down along the z-axis. The camera is attached to the slider to be able to move in the X-Y plane in order to follow the object center under the crane area. The system was built from a CAD model that was designed, as shown in Fig. 3. Figure 4 summarizes the main system components. The block diagram of the tracking system (to be described in more detail later) is shown in Fig. 5.

Figure 2. The experimental setup (overhead crane).

Figure 3. CAD model of the overhead crane.

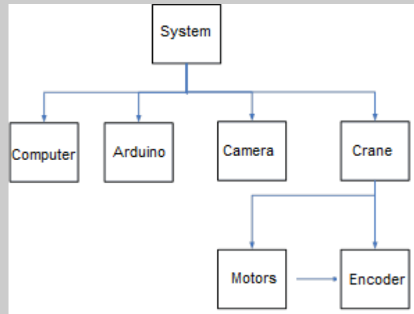

Figure 4. System components.

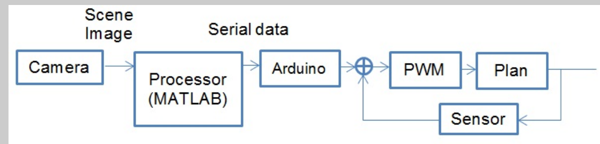

Figure 5. Block diagram of the tracking system.

The scene image (SI) array (taken by the camera) will be processed and compared with the reference image (RI), which is saved within a MATLAB database. The images will be compared using the SURF algorithm and will determine if the object is under the overhead crane. The proposed MATLAB algorithm will extract the object information. In other words, the centroid location will be found according to the centroid of the moving camera frame (also known as scene frame, SR). This information will be sent to the Arduino microcontroller. An Arduino algorithm sends control signals to operate the motors in order to match the SI and RI centroids. The algorithm also determines the motors speed according to the distance between the RI's centroid and SI's centroid.

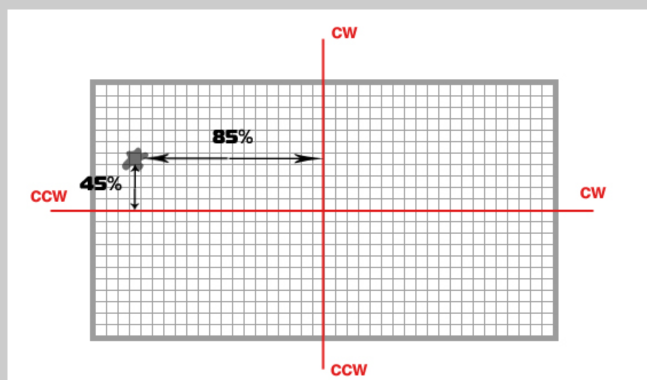

Figure 6. The distance of centroid SI with respect to the centroid RI as a percentage of value.

Figure 6 shows a sample case when the object is 85% of the maximum distance from the centroid SI along the x-axis, and 45% of the maximum distance along the y-axis. These values are converted to speed percentages of the motors maximum speed. The maximum distance requires the motor to operate at its highest speed. PID control is used to control the motors in an effort to achieve some level of performance. In this case, the desired performance is a rise time of less than 0.1 seconds and an overshoot of less than 2%.

III. Detection and Tracking Algorithm

The detection algorithm is summarized in Figure 7. Note that the RI must be saved in the same directory (MATLAB workspace) after transfer to gray scale. The SI is captured by the camera (and will be compared to the RI). Next, the colored SI is transformed to gray scale in order to minimize processing time. An image smoother filter followed by an image sharpen filter are applied in order to refine and emphasis the image of the object. The 'SURF algorithm' extracts the features of the image (reference and momentarily captured images). These features are then matched to obtain the location of the detected object (as the algorithm reaches the recognition stage).

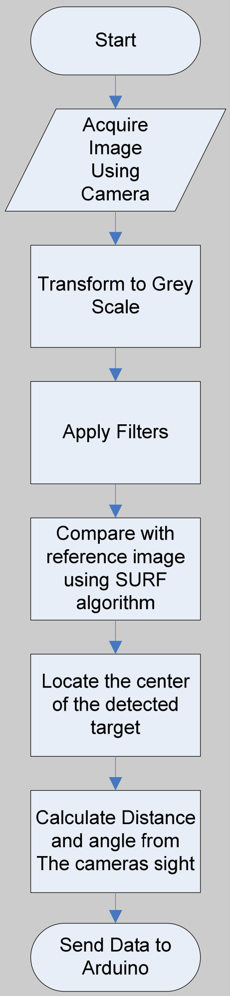

Figure 7. Flowchart of the detection algorithm.

The following list summarizes the SURF implementation and process used in this paper:

- Obtain the RI, as per Fig. 8.
- Obtain the SI, as per Fig. 9.
- Detect feature points in both images, as per Fig. 10.
- Visualize the strongest feature points found in both the RI and SI, as per Fig. 10.
- Extract the feature descriptors at the interest points in both images.
- Match the features using descriptors, as per Fig. 11.
- Display the matched features, as per Fig. 11.
- Locate the object in the SI using 'putative' matches, as per Fig. 12.
- Obtain the bounded polygon which surrounds the sub-image and obtain the RI center, as per Fig. 13.
- Transform the polygon into the SI coordinate system.
- Display the detected object, as per Fig. 13.
- Calculate the centroid location, as per Fig. 14.
- Locate the RI centroid with respect to the SI centroid as illustrated by Fig. 15.

Figure 8. Define the RI.

Figure 9. Capture the SI.

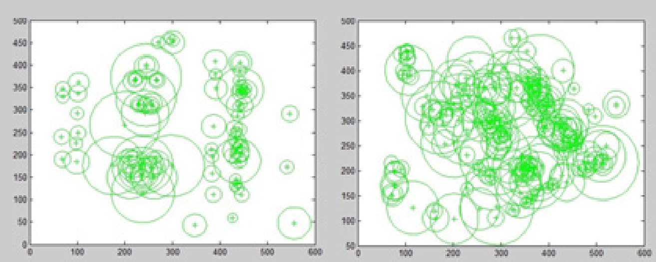

Figure 10. Detect and visualize the strongest feature point between the RI to the left and SI to the right.

Figure 11. Match and display the matched features.

Figure 12. Locate the strongest features and the object orientation using these matches.

Figure 13. Display the detected object with a bounded polygon surrounding it.

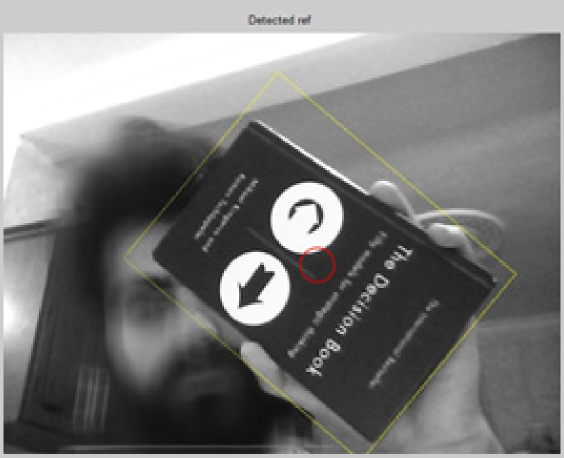

Figure 14. Detect the object centroid (red circle).

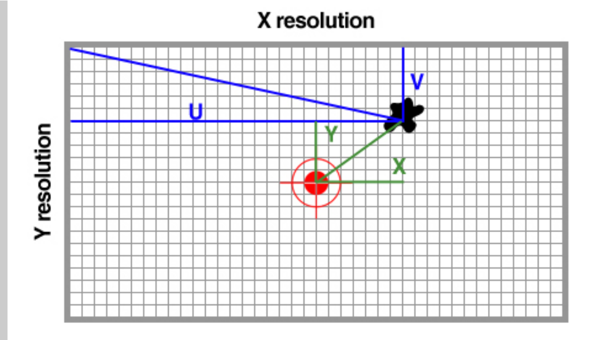

Figure 15. Location of the centroid RI to the SI frame as a vector [U, V].

Three motors are used in order to force the crane to move in 3-D space. Each motor is used to develop a translation motion along one of the axes. The distance between the centroids of the RI and SI is defined as per Fig. 15. The coordinates of the distance are then used as feedback signals to the controller. A manually tuned PID controller is used to obtain the required performance. The controller outputs are transferred to the motor to implement the required system actions. The steps are illustrated in Fig. 16.

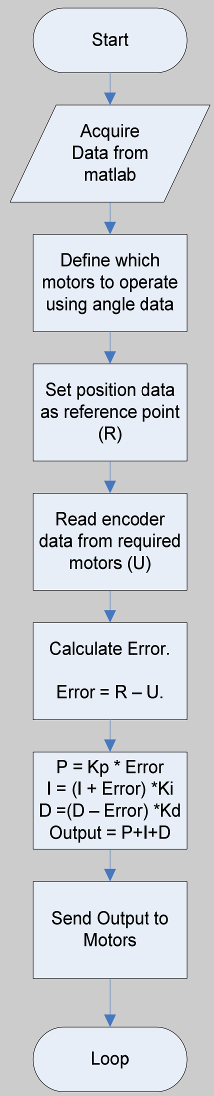

Figure 16. Flowchart of the PID controller.

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IV. Summary of Results and Conclusions

The proposed system demonstrated good results. The z-axis motor of the crane was used successfully to collect the object and drop it at a safe place. The image processing algorithm responded quickly and calculated the error that was used by the PID controller. The response of the movements along the three axes demonstrated a fast response with overshoot of less than 2%. The maximum speed of each motor was around 5 cm/sec. It is important to note that the wire rope used for the crane was assumed to be rigid in order to reduce the complexity of the problem. Figure 17 summarizes the experimental setup of the system. Future work will look at implementing other types of control strategies for comparison purposes.

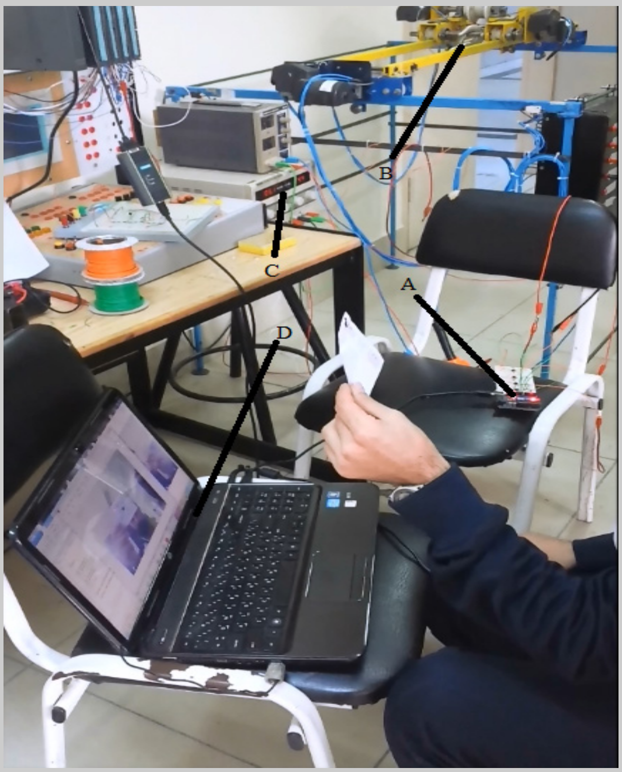

Figure 17. Experimental setup, where: A) Arduino and conditioning circuit for the crane's motor, B) overhead crane system, C) system power supplies, and D) camera and computer to support the image processing algorithm.

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