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A Review on Wireless Embedded System for Vision Guided Robot Arm for Object Sorting

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Abstract— A robot arm/manipulator finds its applications in variety of areas to takeaway the processes which are repetitive, highly multifaceted and perilous, destructive or of high-precision in its nature. Robot manipulators are intended to use in object sorting applications because of its high accuracy and precision operation. Robot manipulator shows many advantages when it is networked and automated with an embedded system by providing the vision system. The present work gives the earlier, current developmental status and design considerations of existing object sorting systems, modeling and analysis of robot arm, embedded wireless control for robots, and image processing techniques for automated vision guided robot manipulators. The above said significant areas are covered in the review. The intention of the present work is to develop the feature research work in the field of wireless cooperative robot manipulators for object sorting system.

Index Terms— Autonomous, Embedded Control, Industrial Applications, Object Sorting System, Robot Arm, Wireless, Vision System.

1 Introduction

In this modern era the industrial robot arms are extensively adopted in several application areas where the work is complex, critical and repetitive. Industrial robot applications includes pick and place operations of the objects to the desired location, assembling of spares in automobile industries, process control operations in nuclear industries. The competitive edge of manufacturing industrial robot arm to outfit for multiple applications from welding, material handling and thermal spraying to painting and drilling is its designing and programming.

The knowledge of robot comprises of three main engineering areas; electrical, mechanical and computing. The electrical contains the sensing, amplifying, filtering, displaying and controlling schemes; mechanical composes of mathematical modeling of dynamics and kinematics of robot arm, computing consists of another two important fields in the form of hardware and software to design an electronic contorller through programming for specified application in a time domain constraint which can also called as embedded system. Robots show many advantages when it is networked using wireless communication, automated by providing vision and controlled through an embedded system.

Sorting systems remain essential in numerous areas with diverse applications such as in manufacturing industry, libraries, factories, warehouses, pharmacies, supermarkets etc. General procedure of sorting system constitutes phases like searching the specified object depending on the nature of interest, focusing, reading and investigating, grasping and sorting them to the pre-programmed place depending upon the object category. This task is implementing in almost all places like libraries, pharmacies, warehouses, factories etc. In many sorting systems, the above steps are tied into one and cannot be separated clearly.

The main steps of proposed work for sorting application involves three important systems they are vision system, wireless embedded control system and robot system. The vision system can reach the generic operations like searching the object, focusing and reading. A Personal Computer (PC) investigates and processes the data from vision system, transmits the joint angles of robot arm using wireless communication and the embedded control system receives the joint angles through wireless communication and form as robot controller. The robot sytem which is a robot arm manipulator performs the grasping and sorting operations.

The main aim of this paper is to deliver an outline of an embedded system based control for wireless networking robot arm for sorting systems in order to recognize and takeout the subsequent:

- Design and development of an object sorting system using vision and embedded systems for robot experimentations and exercise circumstances related to the operation, programming, and control.
- Examine the literature on object sorting sytems which includes the research on mathematical modeling of the robot arm, wireless communication system, vision system and embedded system based control.
- Implement theoretical and experimental assessment on the robot arm procedures and control logic, to progress the complete understanding of robot arm manipualtors.

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2 Literature Riview

The present work is aimed on providing the survey and design aspects of wireless object sorting system which comprises of two stations, tramsmission station and receiption station. The transmission station is a Personal Computer (PC) with an input device (CCD/CMOS Sensor) and a wireless transmission module (Bluetooth / WiFi / Zigbee). The input

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device captures the image of the object on the assembly line and the image data will sent to PC for image processinng to find out the genre of the object. Image processing techniques identifies the genre of the object from the stored data base. Depending upon the object type and robot arm position, PC finds the solution for the forward and inverse kinematic problems of robot arm for pick and place operation of the object to its dedicated container. PC calculates the position and orientation of the robot arm's end effector using forward kinematics and joint angles by using inverse kinematics to pick the object. Calculated joint angles are transmitted to the receiver station by using wireless communication.

Receiption station is an embedded system with a wireless network module and the robot arm. Wireless module is meant to receive the joint angles from the transmission station. The received joint angles is converted into Pulse Width Modulation (PWM) signals to control the robot arm. Since robot arm is designed by using DC servo motors, no feedback sensors are required to find out the position of the motor, because PWM signal will decide the position of the servo motor as well as robot arm.

Since, the above work constitutes vision system, robot arm modeling and wireless embedded control for object sorting, literature review was extensively done on the above said areas.

The first object sorting system was designed by Robert G. Husome and his associates, it is a tomato sorter aimed at removing the culls, e.g. green tomatoes from the good and red tomatoes [1]. Joseph R. Perkins designed an autonomous sorting system which has an inclined surface along which objects are sorted out through gravity [2]. P. Dario, discusses object characterization and sorting using active touch through multiple sensors where the information from the sensors are processed in parallel for exploratory parameters like contact force, direction, velocity to sort a specified object in a given set [10]. Yang Tao discusses the advantage of image processing in sorting applications by implementing a sorting system based on the hue extraction of an image captured from the image sensor and image processor performs a color transformation to obtain a single composite hue value for each object or piece of fruit to be sorted [3]. Thomas C. Pearson describes the object sorting system based on video image of an object [4]. An impulsive manipulation and air floating object sorting device was developed using computer simulation by hirai [13].

Yuji Matsumoto in his invention, sorting objects based on physical characteristics, data from the sensors regarding to the object tobe detected is stored in the data storage unit and the object is determined by a high-speed detecting process [5]. Tao wang and ong zhang designed an algorithm which is capable of separation of objects of two different classes using simulation tools [15]. The problem of collective sorting was discussed with multiple robots under simple reactive control where objects of different classes are separated into clusters and each cluster contains objects of only one class [17]. David Salomon Garcia palmero simulated object recognition and sorting technique using virtual Cartesian robot with artificial intelligence and it is capable of recognizing 26 Spanish alphabets [14]. Raihan Ferdous Sajal and associates designed an efficient machine vision algorithm for real time image analysis and recognition of different features of Bangladeshi bank notes by using an automatic banknotes sorting system [25]. A material sorting system was developed to overcome the drawbacks of the existing sorting system (based on barcode), the new intelligent sorting system is based on intelligent recognition algorithm which acts as decision-maker [26]. A vision based robot system was developed for 3D pose estimation and picking of the objects in which a video camera surrounded by eight flashes is used to capture the images and CAD tool is used to find the edges of the object using a fully projective formulation [ACB98] of Lowe's model based pose estimation algorithm [21]. Mohamad Bdiwi discusses about the control system and vision algorithms for library automation and book sorting using integrated vision/force robot control [11]. The aspects of top-down, bottom-up attention and foveated attention were discussed for robotic object grasping using stereo-based vision system frame work [22]. Roland Szabo implemented an object sorting system based on color using robot arm where web cam is used to identify the color of the object and robot arm is used to place the object in appropriate place [12].

3 Embedded System based Control for Wireless Autonomous Vision Guided Robot Manipulator for Object Sorting System - Design Aspects

The practical design aspects and approaches intended to develop the projected wireless embedded system for autonomous vision guided robot manipulator for object sorting system is explained in this section.

3.1 Description of Object Sorting System

Figure 1 shows the block diagram of the transmission station of the object sorting system. The transmission station sonsists of a PC with USB, Serial Communication and software development tool to organize the work. The image sensor is a CMOS sensor which is capable of capturing static images and sequence of images to avi format. This CMOS sensor is connected to the USB of the PC to process the static images for object recognition.

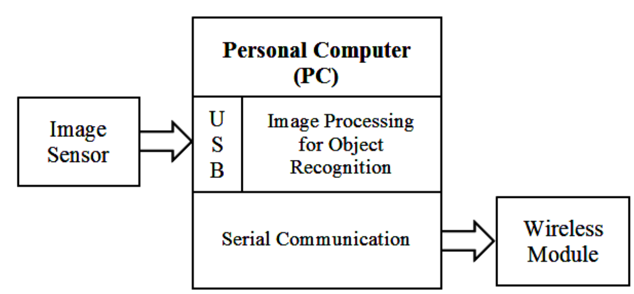

Fig. 1. Transmission Station of Object Sorting System.

A software development tool like LabVIEW/Matlab is used for image processing and to solve the forward and inverse kinematic problem by producing the joint angles of the robot arm using Denavit Hartenberg (DH) convention method. Serial communication is used to connect with the wireless network which works with RS232 standards. This serial communication is used to transmit the joint angles of the robot arm which is calculated by the software development tool. Wireless networks used to transmit the data from one machine to another machine is discussed in the embedded wireless control section.

Figure 2 shows the receiver station of the object sorting system with an embedded system, wireless network module and robot arm.The controller used in the present work is Advanced RISC Machine (ARM) which is capable of driving the servo with its PWM channels provided on-chip. The ARM7 processor is used for the design and development of instrumentation system to control the robot arm manipulator depending upon the joint angles received from the PC. Due to their robust packaging for industrial applications and low power consumption LPC214x are ideal for applications where miniaturization is a key requirement, handheld devices such as access control, portable field measuring devices.

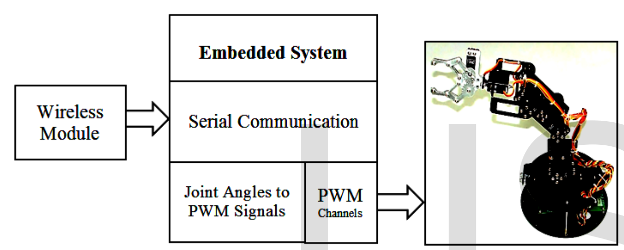

Fig. 2. Receiver Station of Object Sorting System.

3.2 Vision System for Object Recognition

Ana Brandusa Pavel and Catalin Buiu discusses about an embedded artificial vision system for an autonomous robot which is capable of finding objects, identifying them if they are known to the robot or store them in an object library if perceived for the first time [20]. Object detection was done by various electronic devices/components of which CMOS active pixel image sensors graps its attention and popularity. An image sensor is a device that converts an optical image into an electronic signal. The CMOS sensors are main part of technology in digital imaging. The acquisition system requires a photosensitive matrix arrangement from the image sensor as first light sensitive element. The photosensitive device provides an electrical output proportional to the luminous intensity that obtains from the input. The resolution can be determined by the total number of elements used in the photosensitive system. An analog-to-digital converter (ADC) is required for sampling and discretizing the electric signal generated by the photosensitive elements to store in the memory. The number of bits used to store the data of the image defines the resolution of the image.

The objects can be identified with various genres like pattern, geometric dimensions, length, color etc. The first step to recognize the object of a static image from the CMOS image sensor is pattern recognition. The vision assistant was used for the pattern (object) recognition.

An image A (size WxH) and image P (size wxh), is the result of the image M (size (W-w+1) x (H-h+1)), where each pixel M(x, y) indicates the probability that the rectangle [x,y]-[x+w-1,y+h-1] of A contains the Pattern. By using the above equations the vision assistant carries out the pattern matching algorithm and identifies the desired object in the image.

$$M(x,y)=\sum_{a=0}^{w}\sum_{b=0}^{h}\left(P(a,b)-A(x+a,y+b)\right)^2$$

The image M is defined by the difference function between the segments of the image:

3.3 Robot Arm Modeling

To express the performance of a physical system in many circumstances an analytical model is used. Analytical study of the motion of a robot manipulator is called robot kinematics. Modeling, analysis and implementation of serial robot arm implicates the study of its kinematic behavior. Modeling of robot kinematics was divided into two problems one is forward kinematics and second is inverse kinematics. The problem of solving the cartesian position and orientation of a mechanism which gives the knowledge of the kinematic structure and joint coordinates is called forward kinematics. The problem of computing the joint variables through the position and orientation of robot's end-effector is called inverse kinematics (IK) [16]. Many researchers have evaluated and executed these problems in different scenarios using different tools and devices.

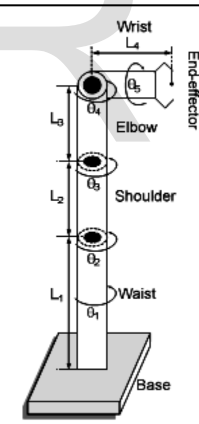

Fig. 4. Kinematic Model of Robot

The detailed design principles of many components of robot for example manipulators, end effectors are dealt in the text books [6], [7], [8]. Raza Ul Islam and associates designed and developed the forward and inverse kinematic model for a vertical articulated robot arm to simulate the industrial applications like pick and place, sorting and other object manipulation tasks using image processing techniques to make the robot autonomous [9].

3.3.1 Forward Kinematic Model

Kinematic problem of a serial robot arm was carried out by using two methods they are, Denavit-Hartenberg (DH) convention and Dual Quaternion approach. DH convention is the classic method used to determine the position and orientation of the end effector of the robot in robotics community arm where homogeneous transformation matrix is adopted for calculations and Dual Quaternion algebra was composed of 8 components to represent the posture of a rigid body by a minimal form using general algebra methods [23].

The two approaches are organized for modeling serial manipulators. Dual quaternion gives the rotation and translation in a compressed form of transformation vector, simultaneously and the orientation of a body is represented nine elements in homogenous transformations, the dual quaternions reduce the number of elements to four [24]. Though quaternion constitutes an enhanced technique, it was not used as much as DH method in robotics community. DH method has become the standard method for describing robot kinematics. Hence, DH conventional method is proposed to use for robot arm modeling.

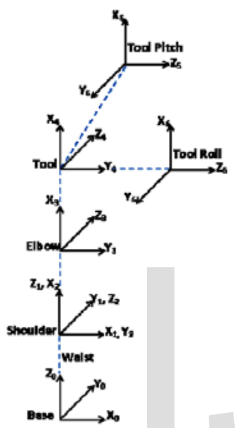

Fig. 5. Orthonormal Coordinate System.

A 6DOF robot arm modeling was discussed as an example in the present work. The basic kinematic model of the robotic arm is shown in Figure 4. DH mechanism works with quadruple (1), which represents twist angle, link length, link offset and joint angle respectively. The pictorial representation of DH convention method of the manipulator in an orthonormal coordinate system is shown in Figure 5.

$$\{\alpha_{i-1}, a_{i-1}, d_i, \theta_i\} \tag{1}$$

By means of the general form of the transformation matrix for each link (expressing joint *i* in its previous neighboring joint *i-1*) derived in [6], the equivalent transformation matrices for each link of the robotic arm have been written. Depending on the compound transformation property, the end-effector of the robot with respect to its base can be evaluated by multiplying the individual transformation matrices to get the overall matrix.

$$ {}^{0}_{6}T = \begin{pmatrix} C_1C_5S_{234} + S_1S_5 & -C_1S_{234}S_5 + S_1C_5 & C_1C_{234} & C_1A \\ -S_1C_5C_{234} - C_1S_5 & S_1C_{234}C_5 + C_1C_5 & S_1C_{234} & S_1A \\ C_{234}C_5 & -C_{234}S_5 & -S_{234} & B \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{2}$$

Where

$$A = L_2S_2 + L_3S_{23} + L_4C_{234}$$

$$B = L_1 + L_2C_2 + L + C_{23} - L_4S_{234}$$

Equation (2) represents the resultant matrix in which the 3X3 matrix comprising of first three rows and first three columns is the rotation and the last column gives the position (x,y,z) of the robot end effector w.r.t. its base.

3.3.2 Inverse Kinematic Model

The practical robotic systems found its standard applications by implementing IK model. IK model calculates the joint angles to the desired position and orientation. Analytical method was followed to develop IK model. This method determines the correct joint angles for any object in the workspace of the robot arm. The first four joint angles i.e. waist (θ_1), shoulder (θ_2), elbow (θ_3) and tool pitch (θ_4) calculated using this method while tool roll (θ_5) is straight away given by the desired orientation for object manipulation.

Since transformation encompasses rotation as well as translation, the general form of the transformation matrix from tool to base is given by (3).

$$ {}^{Base}_{Tool}T = \begin{pmatrix} n_x & ox & a_x & p_x \\ n_y & oy & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{3}$$

Where the first 3x3 matrix and (P_x, P_y, P_z) representing the rotation and the translation of end-effector w.r.t base of the robot in an IK problem.

$$\theta_1 = A\tan 2(p_x, p_y) \tag{4}$$

$$s_{234} = c_1a_x + s_1a_y$$

$$c_{234} = a_z$$

$$\theta_{234} = A\tan 2(s_{234}, c_{234})$$

$$c_3 = \frac{(c_1p_x + s_1p_y + l_4s_{234})^2 + (\mathrm{p_z} - l_1 + l_4\,\mathrm{c}_{234})^2 - l_2^{\,2} - l_3^{\,2}}{2l_2l_3}$$

$$s_3 = \pm\sqrt{1 - c_3^{\,2}}$$

$$\theta_3 = A\tan 2(s_3, c_3) \tag{5}$$

$$c_2 = \frac{(c_1p_x + s_1p_y + l_4s_{234})(c_3l_3 + l_2) - (p_z - l_1 + l_4c_{234})s_3l_3}{(c_3l_3 + l_2)^2 + s_3^{\,2}l_3^{\,2}}$$

$$s_2 = -\frac{(c_1 p_x + s_1 p_y + l_4 s_{234}) s_3 l_3 + (p_z - l_1 + l_4 c_{234})(c_3 l_3 + l_2)}{(c_3 l_3 + l_2)^2 + s_3^{\ 2} l_3^{\ 2}}$$

$$\theta_2 = A\tan 2(s_2, c_2) \quad (6)$$

$$\theta_4 = \theta_{234} - \theta_2 - \theta_3 \quad (7)$$

Equations (4), (5), (6) and (7) give the joint angles θ_1, θ_3, θ_2 and θ_4 respectively for IK model, after intensive mathematical computations. These equations express the required joint angles in terms of given coefficients of (3).

3.4 Wireless Embedded Based Control

In recent years, advancement of electronics, embedded wireless technology has given rise to a large number of emerging industrial applilcations. The design aspect of an embedded control system comprises of four features, i.e., system structure, functions, hardware, and software design. System structure represents the overall system design concepts and required physical components. Functions are number of input and output parameters used to measure and control. The physical components integration for an application gives the hardware design and the source code which performs the required task along with the hardware is called the software design. The detailed description of system structure and fuctions were discussed in the earlier sections.

To develop the embedded robot control a controller based on the combination of advanced RISC microprocessor (ARM) is required [18]. Depending upon the combination of advanced RISC microprocessor (ARM), DSP and ARM-Linux, a WiFi based robot arm control system was designed in [19]. MoGuan proved that ARM processor with the features of multi-parameter execution, multi-level monitoring and networking, it is suitable for a wide range of network applications [27].

Several embedded systems are equipped with wireless technology such as Bluetooth, WiFi, and Zigbee etc. Wireless technologies like Bluetooth and IrDA standards deliver the capability to fortify the local wireless network and it sommunicates with a device in a range of about 10 meters and supports both voice and data communications with broadband of 1MBPS as in [28]. WiFi or WLAN (Wireless Local Area Networks) is a wireless network based on a series of specifications from the Institute of Electrical and Electronics Engineers (IEEE) called 802.11. The unlicensed radio frequency in the range of 2.4GHz is using by WiFi. There are several versions of WiFi for different applications:

- 802.11a (offering transmission speeds of 24mbps to 54mbps).
- 802.11b (6mbps to 11mbps) and 802.11g (24mbps to 54 mbps).
- 802.11n (50mbps to 100mbps).

As per the IEEE 802.15.4 standard for low data rates, wireless Personal Area Networks (PAN) is extensively considered as one of the technology for wireless sensor networks [29]. As of now ZigBee is the widespread among these. ZigBee is used to create a personal area network which is built from small, low-power digital radios for high level communication. It consumes low power, data transmission vary from 20 KBPS in 868 MHz frequency band to 250 KBPS in 2.4Ghz frequency band and covers the distance over 100 meters.

Although there are various wireless technologies that are used to control the robot manipulator, but each technology have the advantages and disadvantages. Bluetooth technology implementation cost on small scale is inexpensive. But developer for this application face a bound rate problem which is both microcontroller and Bluetooth devices are running at different bound rate. WiFi admittance needs high data rates (to enable large amounts of data to be uploaded and downloaded) and is able to accept minor connection delays. ZigBee specification is proposed for the present work because of its simplicity and less expensive over other WPANs, such as Bluetooth or WiFi.

4 Development Methodology

The development of the present work can be scheduled in segments as described below. Primarily system modelling could be done, followed by controller design in software develepemnt tool. Confirmation by simulation is approved at each and every phase. Next, the embedded control system is implemented and finally the complete system is validated and tested by experimentations.

4.1 Segment – I

- Abstract design of embedded system and modeling of robot arm.
- Graphical user interface design for interaction.
- Integration of robot manipulator with the embedded control and vision systems.

4.2 Segment – II

- Understanding of embedded control for wireless networking robot manipulators and integration of the systems.
- Experimental examination and verification of user interface systems through testing.

5 Experimental Verification

The following steps need to be planned to estimate the total system performance.

- Direct and inverse kinematics problems.
- Study of different controllers and the effects of control parameters on individual robot manipulators.
- Experiments on vision systems to identify the object.
- Experiments of different wireless technologies to choose one for the application.
- Experiments on wireless networking with the Vision system.
- Experiments on wireless embedded control of robot arm.

6 Conclusion

The present work when implemented provide good research knowledge on vision systems, robot arm modeling, wireless technologies and emebedded based control. The hardware and software implementation provides an easier access to exercise robot manipulation using the functionalities and programming abilities of the real robots for mounting different industrial applications. Therefore, this paper provides an overview for a researcher interested in the field of embedded systems and robotics with the status, and a broad review of accessible literature and an outline on the basic module functionalities.

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