Design and Development of Human Following Robot

[1]Muhammad Sarmad Hassan, [2]Mafaz Wali Khan, [3]Ali Fahim Khan
Department of Electrical Engineering
Institute of Space Technology, Pakistan
[1]sarmadhassan@hotmail.com
[2]mafazwali01@yahoo.com
[3]alifahimkhan@gmail.com

Abstract*—For a robot that performs autonomously, the communication between the person and the robot is the most important factor. A significant awareness has been observed regarding the usage of such a technology. This research has a trivial involvement in the development of such robots. A robot that functions fully autonomously should not only complete the jobs that are desired of them but also somehow establish a connection between themselves and the person operating them. A lot of research has been done of these kinds of robot and a lot of work still needs to be done. In order for a robot to communicate and interact with the person, it should also be capable of following that particular person. Keeping this in mind, there should be a capacity in the robot to get information from the surroundings while persuing the required object. The primary goal of our work was to design and fabricate a robot that not only tracks the target but also moves towards it while doing the tracking. In order to make things simpler, a unique handmade tag was placed on the person that the robot needs to follow. The main hindrance in this kind of work is that the detection of the target is a sensitive thing to carry out. The object has to be unique for the robot to recognize it and carry out the objective. The simple tag removes this problem of uniqueness and makes the task fairly easy. A small camera records the video and the processor processes it to extract the desired information from it. Protecting the robot from collision with the object is another problem that needs to be tackled so in order to do this, a sensor is used. All the processing is carried out by the microprocessor while the control of the motors is carried out by the controller.

***Keywords* — Human following, human tracking, visual imaging, human robot interaction, laser range scanners, image tag, envelope detection, service robots, depth image mapping, thermal conductivity.**

I. INTRODUCTION

Robotic technology has increased appreciably in past couple of years. Such innovations were only a dream for some people a couple of years back. But in this rapid moving world, now there is a need of robot such as “A Human Following Robot” that can interact and co-exist with them. [1]

To perform this task accurately, robot needs a mechanism that enables it to visualize the person and act accordingly [2] [3]. The robot must be intelligent enough to follow a person in the crowded areas, vivid environment and in indoors and outdoors places [4].

The image processing carried out to get the information about the surroundings visually is a very important thing. The following points should be carefully noted while doing the processing.

- The luminosity conditions should be very stable and should not fluctuate.
- The ranges should be set properly for the desired environment on which to perform the tracking.
- The target should not be very far from the visual sensor as the distance matters a lot.
- We should avoid the use of such colors around the robot that matches with that of the target. Otherwise the robot would get confused.

Typically human following robots are equipped with several different diverse combination of sensors i.e. light detection and ranging sensor, radio frequency identification module (RFID), laser ranger finder (LFR), infrared (IR) sensing modules, thermal imaging sensors, camera, wireless transmitter/receiver etc. for recognition and locating the target. All the sensors and modules work in unison to detect and follow the target.

The capability of a robot to track and follow a moving object can be used for several purposes.

- To help humans.
- To create ease for people.
- Can be used for defense purpose.

In this paper, we presented a method of a human following robot based on tag identification and detection by using a camera. Intelligent tracking of specified target is carried out by the use of different sensors and modules [5] i.e. ultrasonic sensor, magnetometer, infrared sensors and camera. An intelligent decision is being made by the robot control unit based on the information obtained from the above sensors and modules, hence finding and tracking the particular object by avoiding the obstacles and without collision with the target.

II. RELATED WORK

So far a lot of research has been done on the kinds of robot that fall into the category of the "Assisting Robots". People have used different logics and alog's to implement their design. All of their primary focus has entirely been on the design of robots that follows the target.

Laser sensor is used by Burgard in his tour guide robot for human tracking [6]. LRF was incorporated by D. Schulz to perform the 'following'. Using the above mentioned process, they performed the information linking for the detection[7]. Nicola, Husing used a technique for pointing out the different styles of movement by using LRF. This information was fused with the information obtained by the camera [8]. Depth imaging was used by Songmin Jia to carry out the detection. The model of a person was determined using the depth imaging [9]. The particular style of clothing was used by Mehrez Kristou. He used a multidirectional camera. LRF was also incorporated by him in the design [10]. A research was conducted by Wilhelm with the focus on the color of the particular person's skin. Information from different sensors was also used by him in the research[11].

Some other research work was also conducted in this regard, Depth imaging was used by Calisi and the target was persued by designing a special algorithm[12]. Ess and Leibe carried out the same work. They did a lot of work on object tracking and detection. The biggest advantage of their method was that their algorithm worked in complex environments as well[13] [14]. Stereo visiion was also carried out by Y. Salih in order to perform the detection[15]. This method enabled him to persue the required target with an effective manner. The combination of different sensors were used by R. Munoz to .get the information about the target to be tracked. In addition to using different sensors, he also used stereo vision to get an accurate information.[16]. The data of the sensors combined with the information from the camera proved to be very helpful in carrying out the task[17].

Different algorithms are being developed by the researchers for the detection purposes. Laser was used in one research to find the style of the moving legs [18] [19][20] and camera was used to detect a particular object or a person[3] [21]. A very simple technique was also used by a research. In this technique, the person used distance sensors on the robot and the person. These sensors emitted radio waves and were detected by the sensors on the person to be followed. This way the robot followed the required target[22].

III. SYSTEM COMPONENTS

Our system consists of a three wheel robotic vehicle mounted with a separate microprocessor and control unit along with different sensors and modules i.e. ultrasonic sensor, magnetometer, infrared sensors, and camera.

The camera height is vertically self-adjusting and is initially mounted on robot at a height of 4 ft. from ground to enhance the visual capability and effectiveness.

This robotic vehicle is controlled by the user by means of an identification tag.

IV. METHODOLOGY

A systematic research methodology is adopted keeping in mind the ultimate goal of a fully functional and autonomous human following robot.

A decentralized top down approach is used for this project. The project is divided in to five modules. Each module is independent from one another. Different phases were carried out step by step, starting from basic sensor testing and proceeding towards obstacle avoidance, object detection, object tracking and data transmission.

Due to the decentralized approach, all modules and sensors act independently. Data obtained by different sensors and modules is collectively analyzed and an intelligent decision on the basis of information obtained is made that instruct the robot to follow a particular direction. Two separate units are used i.e. microprocessor and a controller. The processing is carried out by microprocessor and the information obtained by the sensors is controlled by a controller i.e. Arduino board. A serial communication between microprocessor and controller is established to exchange the visual sensing information.

This approach was most suitable because if there is a fault in any one of the modules then it would not affect the entire system. Hence this provides the best possible results by maintaining accuracy.

Human tracking, obstacle avoidance, maintaining a specific distance from the object and establishing a communication link between microprocessor and controller are the main aspects of this project.

V. IMPLEMENTATION

The implementation of human interactive robot seems to be an easy task but there are some problems related to it. For example, detection of a particular tag. Similarly the tag needs to be unique so that it should not be merged into colors in a vivid environment. So we have designed a novel algorithm to overcome this problem.

There are several features of the project such as the mechanical structure, design of circuits, tag detection and intelligent tracking system.

The implementation of human interactive robot is as follows.

A. *Design of a custom Tag:*

In order to make the target distinctive and unambiguous, a tag was designed in particular. This tag had four different colors in box arrangement. The whole research is based on the fact that the target has to be specific to the robot. The robot should only detect that target and not some other target. All these colors enable the robot to detect the person by tracking the tag. This tag is placed on the person that needs to be pursued. Once the tag is put on the person the robot detects the colors and recognizes the target through the detection.

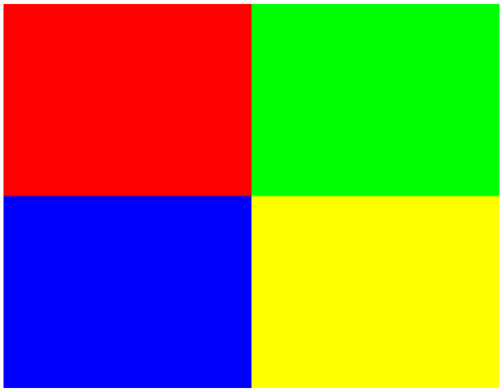

Fig. 1. Custom Tag

B. *Design of Mechanical Structure:*

The mechanical structure of the robot is comprised of two layers base and it consist of two wheel differential drive system and a free wheel. It is designed keeping in view that the camera on robot has to be mounted over a certain height from the ground. The height of this camera is adjustable according to height of a person so that better visual information can be obtained. So initially the height of the camera is set up to 4 ft.

The software design of the mechanical structure is shown below.

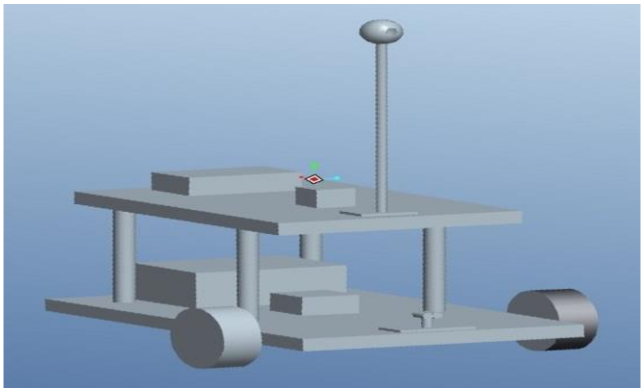

Fig. 2. Software Design of Mechanical Structure

C. *Design of Relay Based Motor Driver Module:*

A relay based motor driver module is designed to control the differential drive of the robotic platform. The advantage of this relay based module is that it can easily drive the high torques motors that require large fluxes. Hence it can easily handle heavy loads.

D. *Image Processing Algorithm:*

A novel algorithm to process the real time video is used to detect and follow the unique tag. We have used a computer vision camera for recognizing the tag at the back of person and an OpenCV python Platform to develop this algorithm.

In this algorithm, a tag having the four color are used. The algorithm is designed in a way that the tag is only detected when the four colors are all together and it that particular order. Once the tag is detected, the centroid of the common region of four colors is found to get the center coordinates of the tag. These center coordinates are then serially transmitted to control unit for further processing and to make an intelligent decision by fusing it with information obtained by the other sensors and modules.

VI. SYSTEM DESIGN

The system design consists of separate processing and control unit. The processing unit only makes use of a camera and is linked with the control unit to serially transmit the visual information after bulk processing. The control unit is serially linked with the processor and it makes use of several sensors and modules i.e. ultrasonic sensor, magnetometer and infrared sensors.

The above sensors and camera works in unison with each other and helps the robot in its operation and to navigate its path by avoiding the obstacles and maintaining a specific distance from the object. The decision is made on the basis of information obtained from all above sensors.

The generalized system design incorporating different sensors and modules is show below.

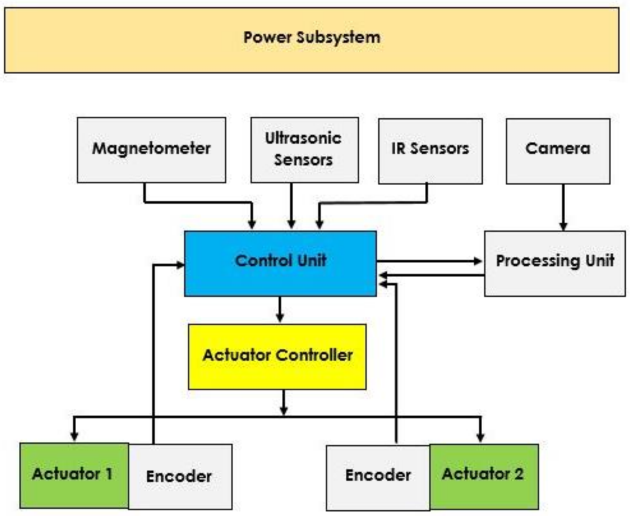

Fig. 3. System Design

Looking at the working of the above system, the first phase is the detection of a tag by means of a camera and carrying out the substantial processing in the processing unit. The processor that we have used is Raspberry Pi single board computer. After the detection of tag next phase is to establish a serial communication between the processor and control unit. We have used Arduino as a control unit. In this phase center point coordinates of tag are serially transmitted to Arduino for further processing.

Next phase is to interface modules and necessary sensors with the control unit. For this purpose, we used ultrasonic sensor, magnetometer and IR sensors for the proper functioning of robot.

We used ultrasonic sensor for obstacle avoidance and to maintain a specific distance for the object. The ultrasonic sensor works accurately works accurately with in a range of 4 meters. Ultrasonic sensors operate by calculating the times differences. [23].

$$Distance\ from\ object = \frac{High\ level\ time * Speed\ of\ sound\ in\ air}{2}$$

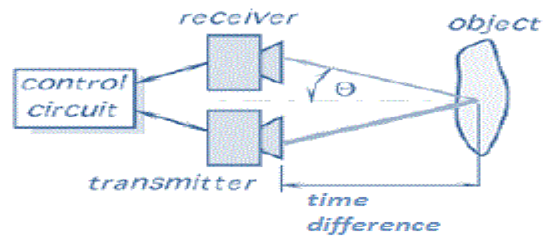

Fig. 4. Ultrasonic Sensor Principle

This ultrasonic sensor is placed at the top of robot along with the camera module to maintain accuracy in measuring distance between the robot and target object.

The flow chart to maintain specific distance from target is shown below.

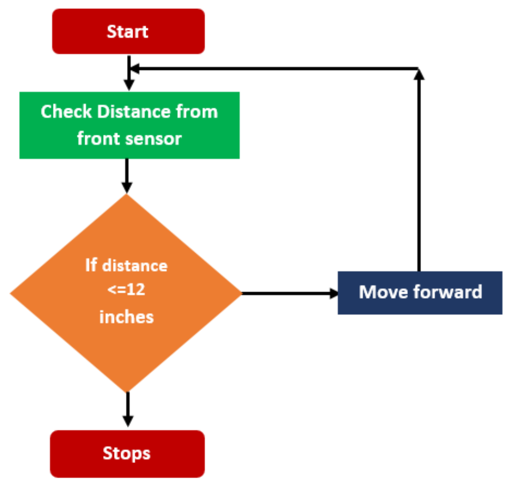

Fig. 5: Flow Chart of Maintaining Specific Distance

After ultrasonic sensor we interfaced the magnetometer to get the orientation of robot in x-y-z coordinates. This module determines the orientation of robot and tells heading direction of robot. This heading direction is used to determine the tilt of robot from its original position. [24]. On the basis of information obtained from this module, the control unit determines that how much direction change is required to be back on track again by after avoiding the obstacle.

After interfacing of above sensors, the next most important part of this system design is to interface the encoders to wheel calculate the distance travelled by the robot to eliminate any further error in the robotic movement due to displacement. For this purpose we attached two slot sensors on top of the encoder's right beside the wheels. The slot sensor has IR transmitter and a photodiode mounted on it and facing each other. The light emitted by the IR LED is blocked because of alternating slots of the encoder disc. This causes the logic level of the photo diode to change and is detected by the controller [25].

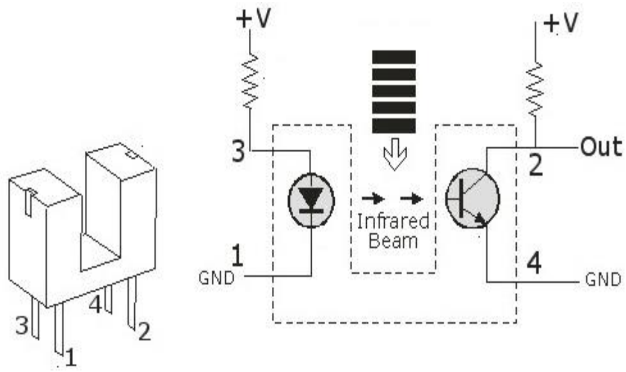

Fig. 6. IR Slot Sensor

The distance is obtained by the number of counts recorded in memory of the controller and is used for distance calculations by using the following formula.

$$Distance\ Travelled = \frac{Wheel\ Circumference}{Counts\ Per\ Revolution}$$

Final phase is consisted of fusing all the information obtained by the sensors and modules in the control unit. Hence, control unit makes an intelligent decision to change the direction of robot and to get back on its track again and to follow the target having tag on basis of information obtained for all sensors and modules i.e. serially received coordinates from processor, distance information from ultrasonic sensor, heading direction from magnetometer, and distance calculation from the IR sensor.

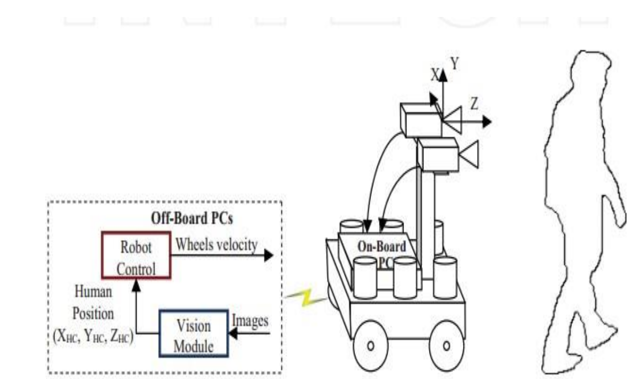

Fig. 7. Human Following Robotic System.

The system is designed in such a way that it intelligently makes use of the information obtained from different sensors and modules. Different sensors are incorporated in the system to make it able to respond to diverse situations.

VII. EXPERIMENTS AND RESULTS

Different experiments were conducted and the performance of the human following robot was tested. Each experiment that was performed took about 10 to 15 minutes. On the basis of results obtained from these tests and experiments, we made the necessary changes in the processing and control algorithm.

First test was performed on the ultrasonic sensor. It was noted that sensor was working accurately with in a range of 4 meters. Then we performed the test to check that weather the robot maintains a specific distance with target object. Initially the we set the stopping of robot to 8 inches. It was observed that robot collided with the object as the distance between robot and target object approaches to 8 inches. This problem behind this was that the stopping distance was small enough and robot was not stopping quickly because of its load on board. So we increased the distance to 12 inches. Then we again verified the routine.

The next test was performed on the magnetometer module. This module gave us the heading direction of the robot with respect to some reference. But we observed that there was some offset error in that heading direction. On observation we found that this was due to the wrong placement of the magnetometer module. This module was interfering with the magnetic field of the electronic components due to which we were getting the offset error. So we changed its placement and set it up at bottom layer and in the center of the robotic structure. Now we had the heading degree without any offset error.

Then the next experiment was to test the detection of tag. We observed that in certain lightning conditions the tag was not detecting properly. So we adjusted the hue, saturation and value of all the four colors as color thresholding in HSV varies by the lighting conditions. So after changing the threshold value we observed that this time the processor was detecting the Tag properly.

Results are shown below.

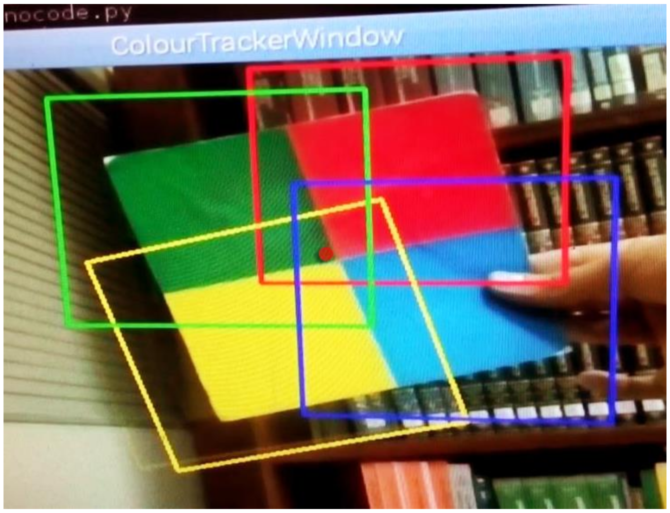

Fig. 8. Tag Detection

Then we check the serial communication between Arduino and Raspberry pi. We observed that when the tag was not infront of camera the processor transmitted a null value for both coordinates and some value when tag was in front of camera. Hence, processor was correctly transmitting the coordinates to control unit.

Results are shown below.

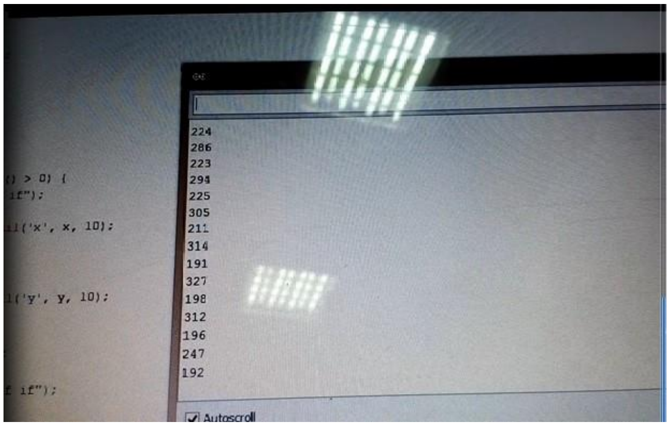

Fig. 9. Serial Communication between Arduino and Raspberry Pi

Final test was performed on the differential drive system to check whether the robot intelligently follow the person or not. We observed that the results produced were very satisfying. The robot was perfectly following the person wherever it goes. We just adjusted its speed at the end.

Hence the objective of implementing a good Human-Robot interaction was achieved by fast processing of the visual input combined with the proper handling of the information from the sensors.

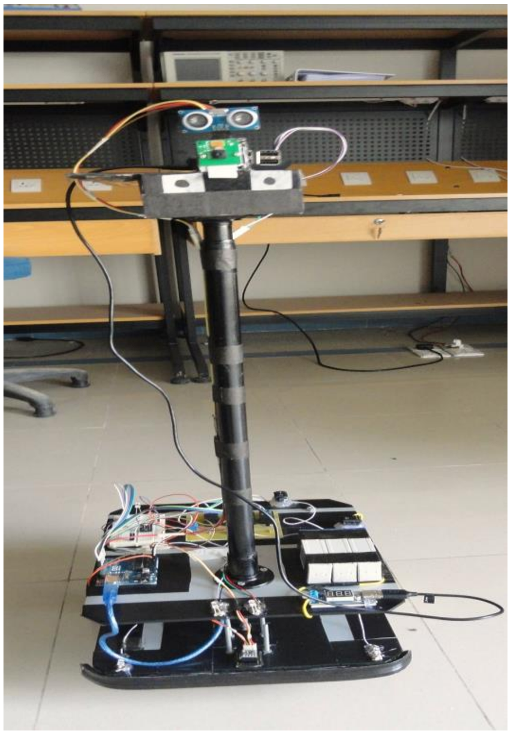

Fig. 10. Human Follower Robot

VIII. APPLICATIONS

Looking deeply into environment or our surroundings, we will be able interpret that "YES" there is a need of such robot that can assist humans and can serve them. Such a robot can be used for many purposes. With a few changings, the robot can act as a human companion as well.

Some other applications of this robot are

- Can assist in carrying loads for people working in hospitals, libraries, airports, etc.
- Can service people at shopping centers or public areas.
- Can assist elderly people, special children and babies.
- Can follow a particular Vehicle.

IX. FUTURE WORK

There are many interesting applications of this research in different fields whether military or medical. A wireless communication functionality can be added in the robot to make it more versatile and control it from a large distance. This capability of a robot could also be used for military purposes. By mounting a real time video recorder on top of the camera, we can monitor the surroundings by just sitting in our rooms. We can also add some modifications in the algorithm and the structure as well to fit it for any other purpose. E-g a vehicle follower.

Similarly it can assist the public in shopping malls. So there it can act as a luggage carrier, hence no need to carry up the weights or to pull that. Using this algorithm the robot will automatically follow that person.

X. CONCLUSION

A successful implementation of a person follower robot is illustrated in this research. This robot does not only have the detection capability but also the tracking and following ability as well. The tracking is basically performed on the tag and the human is followed on the basis of that detection. It was also kept in mind that the 'following' capability of the robot should be as efficient as possible. The tests were performed on the different conditions to pin point the mistakes in the algorithm and correct them. The different sensors that were integrated with the robot added an additional advantage.

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