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# Hand Gesture–Based Control of Mobile Robot's Freight Ramp

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*Abstract* - **The aim of this paper is to present a novel approach for hand gesture-based control of mobile robot's freight ramp. The research was mainly focused on solving some of the most important problems that current HRI (Human-Robot Interaction) systems fight with. The method is robust and is working in real-time.**

**Keywords: HRI (Human-Robot Interaction), gesture-based control, Robotics, Motion control**

## I. INTRODUCTION

Human-Robot Interaction (HRI) can be considered as one of the most important Computer Vision domains. It has many applications in a variety of fields such as: tele-robotic control, search and rescue, military battle, mine and bomb detection, scientific exploration, entertainment and hospital care. HRI is the study of interactions between people and robots. In HRI based systems, the communication between human operators and robotic systems should be done in the most natural way. Typically, communication is done through hands/head postures and gestures. This type of communication provides an expressive, natural and intuitive way for humans to control robotic systems. One benefit of such a system is that it is a natural way to send geometrical information to the robot, such as: up, down, etc. Gestures may represent a single command, a sequence of commands, a single word, or a phrase and may be static or dynamic. Such a system should be accurate enough to provide the correct classification of hand gestures in a reasonable time.

Human-robot interaction using hand gestures provides a formidable challenge. This is because the environment contains a complex background, dynamic lighting conditions, a deformable hand shape, and real-time execution requirement. There has recently been a growing interest in gesture recognition systems. For example, Stergiopoulou and Papamarkos [1] proposed YCbCr segmentation. Peer et al[2] proposed RGB segmentation, which is more sensitive to light conditions. Ribeiro and Gonzaga [3] proposed different approaches of real time GMM (Gaussian Mixture Method) background subtraction algorithm using video sequences for image segmentation. Kim and Hwang [4] proposed Inter frame change detection segmentation. MacLeant and Herperst [5], proposed skeleton gesture recognition method. The recognition of which finger is raised is not mentioned by MacLeant and Herperst and hole filling algorithm is necessary. Kohonen [6] proposed Self organizing map algorithm for recognition of gesture.

The main objective of this work was the developing of a control system for a robot freight ramp, based on gesture recognition. With that purpose, we decided to use a generic webcam for the image acquisition process, and we have defined a gesture vocabulary for the telerobotic control, using motion detection and gesture recognition algorithm based on histograms, which make it efficient in unconstrained environments, easy to implement and fast enough. Our approach is implemented in a teleoperation client-server internet environment. The paper describes the gesture recognition algorithm and its evaluation.

## II. BRIEF DESCRIPTION OF THE FREIGHT RAMP WORKING PRINCIPLE

Since, this work is focused on the controller development, the details about the conducted research on the ramp mechanics, will not be discussed here. Instead of that, the main working principle of the mobile robot's ramp (Fig. 1) will be described.

As shown on Fig. 1. the robot ramp has two degrees of freedom:

- rotation around the Y axis which can be obtained by one stepper motor
- translation along the Z axis which can be obtained by stepper-based linear actuators

In classic mechanical engineering, linear systems are typically designed using conventional mechanical components to convert rotary into linear motion. Converting rotary to linear motion can be accomplished by several mechanical means using a rotary motor, rack and pinion, belt and pulley, and other mechanical linkages, which require many components to couple and align. Although these methods can be effective, they each carry certain limitations. Conversely, stepper motor-based linear actuators address all these factors and have fewer issues associated with their use. The reason is that rotary-to-linear motion is accomplished in the motor itself, which translates to fewer components, high force output, and increased accuracy.

The ramp has a warning light which is activated whenever the ramp performs a movement and is deactivated when the ramp has finished the last movement. This light can be used as a visual feedback for the operator. The ramp is equipped with a sensor, which measures the angle between 90° ... -10°. In open position the angle is 5°. In closed position the angle is 90°.

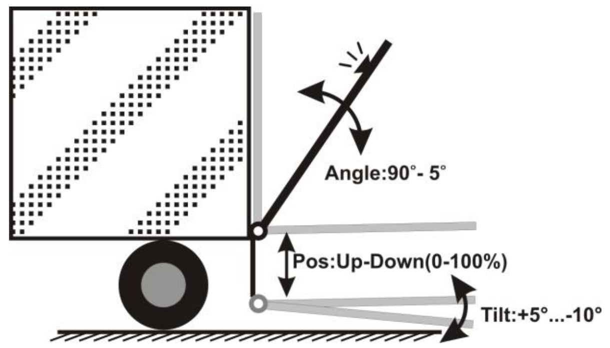


Fig 1. Freight ramp working principle

Another position sensor is used to calculate the vertical position (pos) as a value between 0 ... 100%. If the lift is up the position is 100%. If the lift is down the position is 0%. It is only possible to operate the lift upwards / downwards if the door is fully opened. If the door is open the tilt can be adjusted between +5° and -10° with the resolution of 3°. Adjusting the tilt is only possible if the door is fully open.

The diagram presented on Fig. 2. shows the state diagram for the fright ramp. This diagram is created with Visual Paradigm CASE tool.

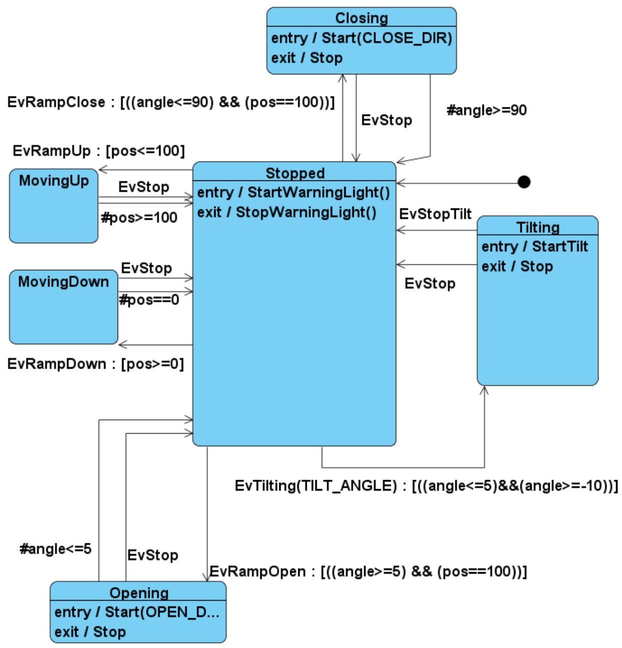


Fig 2. State diagram for the fright ramp

## III. Control System Architecture

To control a robot's ramp movement, the operator evokes a gesture from gesture vocabulary. The user performs his hand gestures in front of a web cam, which captures a video stream. The motion detection is performed and hand gesture is classified using the algorithm described in following. Recognized gesture is sent to the robot for execution, unrecognized gestures are ignored.

Each recognized gesture is sent through the TCP/IP communication protocol to a distant robot PC server. The server can be connected through the same application interface both to the real robot and the robot simulator. The server is also connected to one USB camera, which continually capture the robot or robot simulator movements. Captured video is sent to the client using the FTP protocol.

The hand gesture recognition system flow diagram is shown in Fig. 3. Upon presentation of the robotic scene in the user interface, a gesture G is selected from a gesture vocabulary {G1, G2, …., G12}. A vision system detects a gesture from the video stream and converts it into a command, which is sent to the robot PC server. After the robot executes the command, camera view of the robot is transmitted back to the operator.

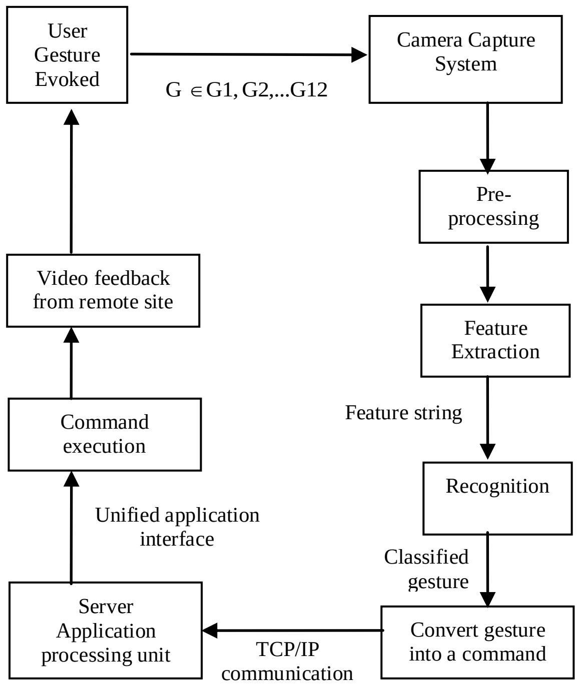


Fig 3. Gesture recognition system flow diagram

## IV. Hand Gesture Language

A vocabulary of 12 static gesture poses (Fig. 4) was designed for robot freight ramp control tasks. The first two gestures control the ramp opening and closing. Next two gestures move the ramp up and down. Stop hand gesture stops any action the ramp performs moving the system into the Stopped position. StopTilt gesture stops any tilt movement the ramp performs and takes the ramp into the Stopped position. All other hand gestures control the tilt angle of the ramp.

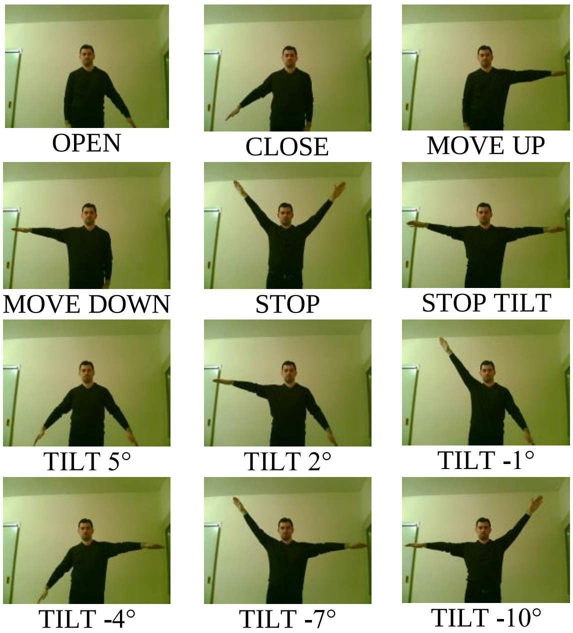


Fig. 4. Hand gesture vocabulary

Fig. 5. Background scene

Fig. 6. Background scene with an operator's hand gestures

## V. MOTION DETECTION AND OBJECT EXTRACTION

In order to be able to apply gesture control over the freight ramp, first the algorithm should be able to recognize the hands gesture. Therefore, the human's body, which demonstrates some gesture should be extracted first, from the grabbed frames and then an appropriate moment when the actual gesture recognition should be done, must be found.

Motion detection approach applied in our algorithm is not bound to any specific video stream format/protocol. Instead of this, it just analyze consequent video frames, which makes them free from any video processing routines and makes them applicable to any video stream format.

Human's body extraction task is using motion detection approach based on background modeling. This approach based on finding difference between current video frame and a frame representing background. It tries to use simple techniques of modeling scene's background and updating it through time to get into account scene's changes. Suppose that from time to time the scene may have some minor changes, like minor changes of light condition, some movements of small objects or even a small object has appeared and stayed on the scene. To take these changes into account, we are going to apply adaptive background modeling approach which tends to decrease the differences between two given images.

This kind of modeling approach gives the ability of more precise highlighting of motion regions and makes the algorithm adaptive to unconstrained dynamic scenes. So, without loss of generality, for the object extraction task, it can be assumed, that the very first frame of a video stream does not contain any moving objects, but just contains a background scene (Fig. 5).

Having these two images, the background and the image with an object (Fig. 6), we may apply a differentiation operation on these two images (source and overlay images) of the same size and pixel format, which will produce an image, where each pixel equals to absolute difference between corresponding pixels from provided images.

To take these changes into account, we are going to apply adaptive background modeling approach which tends to decrease the differences between two given images. The reference image is constantly updated with newly arriving image using the following formula:

$$\forall x, \forall y \; R_t(x,y) = \frac{N-1}{N} \cdot R_{t-1}(x,y) + \frac{1}{N} I(x,y) \tag{1}$$

With R standing for the reference image and I for the newly arrived frame. The formula calculates a running average over all frames, with a weighting that decreases exponentially over time. For setups in front of a wall or white board, we found that the user practically never rests with his hand in the same position for more than 10 seconds, which implies a value of about 500 for N.

The main problem with this type of reference image updating is that dark, non-moving objects, such as the body are added to the reference image. If the user moves his/her hand into regions with dark objects in the reference image, there is not sufficient contrast between foreground and background to detect a difference. For this reason, we can update dark regions slowly, but light regions instantly. The value N in formula (1) is calculated as in Eq. 2.

$$\forall x, \forall y\ N(x,y) = \begin{cases} 1\ for\ I_{t-1}(x,y) - I_t(x,y) \le 0 \\ \approx 500\ for\ I_{t-1}(x,y) - I_t(x,y) > 0 \end{cases} \quad (2)$$

With this modification, the algorithm provides the maximum contrast between foreground and background at any time.

This kind of modeling approach gives the ability of more precise highlighting of motion regions and makes the algorithm adaptive to unconstrained dynamic scenes.

On the difference image it is possible to see absolute difference between two images where whiter areas show the areas of higher difference and black areas show the areas of no difference. On this image, some "thresholding" will be done by classification of each pixel as significant change (most probably caused by moving object) or as non significant change. After removing noise from the "thresholded" difference image the stand alone pixels, which could be caused by noisy camera and other circumstances, will be removed, so the resulting image should depict only more or less significant areas of changes (motion areas) (Fig. 7).

Before we get such image from the video stream, a lot of other mid frames should be processed, which may have many other different objects, which are far from being human body. To get rid of the false objects, all objects in the image will be examined and their size will be checked. Only the objects which are big enough and which satisfies some constrains relative to the human body proportions will be potentially considered as human body.

In order to pass to the hands gesture recognition task, the algorithm must be sure that the detected object is not performing some movement and has stopped for a while, showing a particular gesture. In this particular case we are interested in not motion detection, but detection of motion absence.

To catch the moment when the object has stopped, a motion detector, which is based on between frames difference, is used. The motion detector checks the amount of changes between two consequent video frames (the current and the previous one) and depending on this makes a decision if there is or no motion detected.

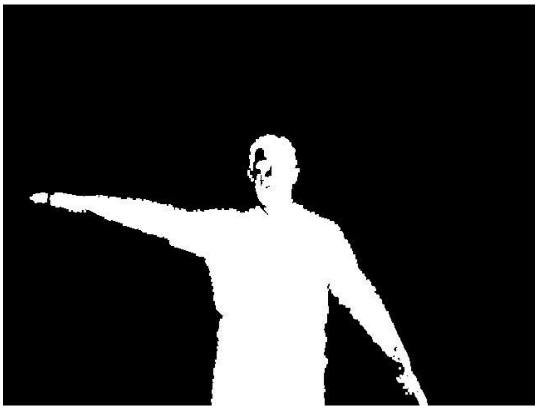

Fig. 7. Image with quite recognizable human's body

If the absence of motion is present in a sequence of consecutive frames which is longer than some predefined threshold value, the gesture recognition should be performed.

## VI. Hands Gesture Recognition

The algorithm for hand gesture recognition assumes that target object occupies the entire image. It takes into consideration human's body proportions and is based on histogram analysis, and presents two advantages: implementation simplicity and execution quickness.

The core idea of this algorithm is based on analyzing two kinds of object's histograms: horizontal and vertical histograms (Fig. 8).

Analyzing the horizontal histogram, one can observe that the hands' areas have relatively small values on the histogram, and the torso area is represented by a peak of high values. Taking into account some simple relative proportions of humans' body, we may say that human hand's thickness can never exceed 30% percent of human's body height So, applying simple thresholding to the horizontal histogram, we can easily classify hands' areas and torso area, and determine their length.

Considering some statistical assumptions about body proportions, we can determine if the hand is raised or not. If the hand is not raised it's width on horizontal histogram will not exceed some threshold value of torso's width. Both experimentally and analytically can be proven that in most cases the threshold value of 30% gives satisfactory results. Otherwise it can be considered that the hand is raised somehow.

When the hand is raised it can be raised in three different positions: raised diagonally down, raised straight or raised diagonally up. In order to determine the exact hand's position when it is raised, the vertical histogram of the hands objects only (Fig. 9), will be analyzed.

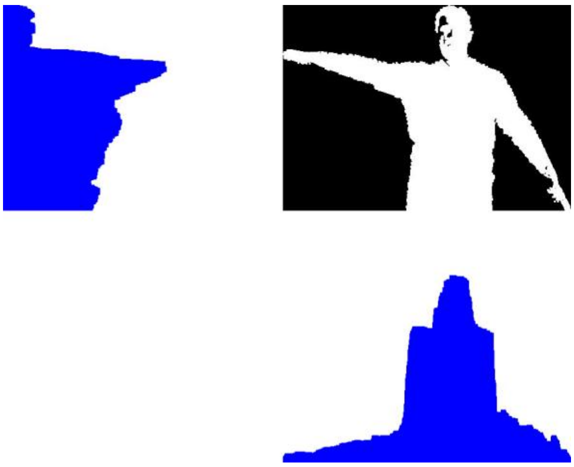

Fig. 8. Horizontal and vertical histogram of the detected human's body

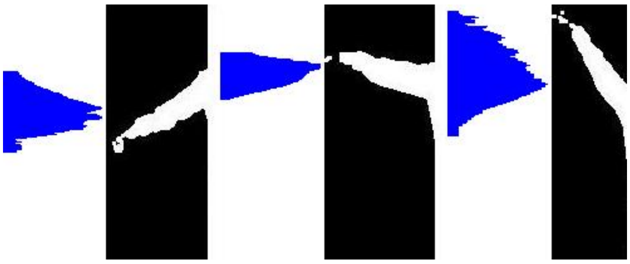

Fig. 9. Vertical filtered histograms of the raised hand.

In most of the cases it is quite easy to recognize the gesture, but in some cases the histograms may be cluttered with noise, which may be caused by light conditions and shadows. Therefore two additional preprocessing steps of filtering will be performed, on the vertical histogram:

**-** removing the low values from the histogram, which are lower then some threshold percentage value of maximum histogram's value. This will remove some artifacts caused by the shadows.

**-** removing all peaks, which are not the highest peak. This will remove the strong shadows and other artifacts caused by the environment changing conditions.

After these preprocessing steps exact hand position will be determined, taking into consideration one more assumption about body proportions, length of the hand is much bigger than its width.

Therefore, one may observe that in the case of straight raised hand its histogram should have quite high, but thin peak, the peak for the diagonally up hand is shifted to the top of vertical histogram, but the peak of the diagonally down hand is shifted more to the center (Fig. 9).

## VII. Experimental results

In order to evaluate the performances of the developed control algorithm, a physics-based robot simulator using ODE libraries[7] has been developed. The simulator and server application are deployed on PC with AMD Athlon 64 Processor on 2.4GHz with 1GB of RAM, NVIDIA GeForce FX5500 with 256MB memory and Windows XP operating system. Gesture recognition client application is implemented in C# language and is deployed on HP Pavilion dv62000 with Intel Core 2 Duo Processor on 2.2GHz with 2GB RAM, it has built in WebCam with 1.3 Megapixels resolution. Both computers are connected on (8 Mbps) Internet connection.

The performances of the developed control method were tested in two different conditions:

1. with sample images grabbed from static scenes in which the lighting and the distances from the camera were approximately constant.
2. in unconstrained scenes with changes of lighting and different distances from the camera.

TABLE I
Hand Gesture Detection Rates

| Gesture | Static scene detection rate (%) | Unconstrained scene detection rate (%) |
|---|---|---|
| OPEN | 93.2% | 89.7% |
| CLOSE | 91.5% | 90.4% |
| MOVE UP | 94.9% | 91.8% |
| MOVE DOWN | 95.1% | 92.2% |
| TILT -4° | 94.6% | 91.3% |
| TILT -7° | 95.3% | 93.2% |
| TILT -10° | 95.1% | 92.8% |

The accuracy was measured for 18 untrained users (9 males, 9 females with different body sizes) in both cases. Each user tried all command gestures 95 times in front of the camera watching the monitor.

In order to reduce the operator's cognitive load, information about each recognized gesture is presented with correspondent visual and audio message, and the lists of all future possible gestures are presented graphically. For each command issued via gesture, a button alternative exists. In the case of unrecognized gestures, the system outputs "No gesture detected" message.

Table 1 shows the rates of successfully performed actions by the robot simulator. The results are average of all users.

## VIII. Conclusion and future work

This paper presents a fast, robust and accurate method for hand gestures recognition under unconstrained scenes. Due to its advantages, the method can be extended and used in various Computer Vision applications. Experimental results show satisfactory recognition percentage of the gestures.

The failure of the system to recognize some gesture is mainly due to the very changeable lighting conditions and moving objects (persons) entering the scene, operator's failure to move the hand to the proper posture. It must be emphasize that after a short experience operators get used to the system.

Future work will be focused on recognition of more complicated gestures and development of the ramp mechanism.

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