Real-time Signal Light Detection

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Abstract

One of most important issue in research for unmanned ground vehicle is detecting signal lights at crossroads. This paper presents new algorithm for signal light detection. It has high detection rate with real time and fast processing at low price. Experimental environment is built in real vehicle and real urban road. , and we shall show that the proposed algorithm realizes driving with reliability in unmanned ground vehicle.

Keywords: Light Detection, Real-time Signal, Unmanned Vehicle

1. Introduction

Car driving itself without human is a dream of people. There are many studies about Intelligent Transport System (ITS) and Unmanned Ground Vehicle (UGV). Interest on unmanned vehicle is increasing. One of important issue in UGV is detection of signal light. Which is necessary when car is on the crossroads and intersection? RF(Radio Frequency) system is a perfect system for safety crossing, but, for using RF system, all of the intersection or crossroads must have RF receiver and sender, and all the cars should have RF terminal. All of intersection should be changed. This method requires lots of cost. Vision system is chipper than RF approach. Therefore, vision detection system for signal lights detection should be developed.

Also, signal light detection provides help to safety driving. There are many accidents in crossroads and crosswalk. Such accidents are caused by careless drivers. Signal light detection system can support driver to notice about signal light [4].

In this paper we present a new vision algorithm for signal light detection which has real time processing with high detection rate while using low price camera. Using this algorithm, reliability and safety for UGV and drivers will be increasing.

2. Related Works

There have been a lot of studies about unmanned vehicles and signal light detection. Popular one is a contest by DARPA (The Defense Advanced Research Projects Agency)[1]. DARPA open 'Grand Challenge' in 2004, 2005 and 2007. In this contest, cars drive with no driver. Driving environment is dirt road in desert. In 2004, no teams arrived at goal. In 2005, Stanford University Team, led by S. Thrun, won with the car named 'Stanley' equipped with many sensors[2]. However, limitation was 'Stanley' is made for driving in the dirt load. Detection of signboard and signal light in urban road is excepted. In 2007, there are many changes in rule of contest. Urban Challenge was opened. Urban Environment was made artificially. In 2007, difficulty is high, because of very complex urban environment. Team in
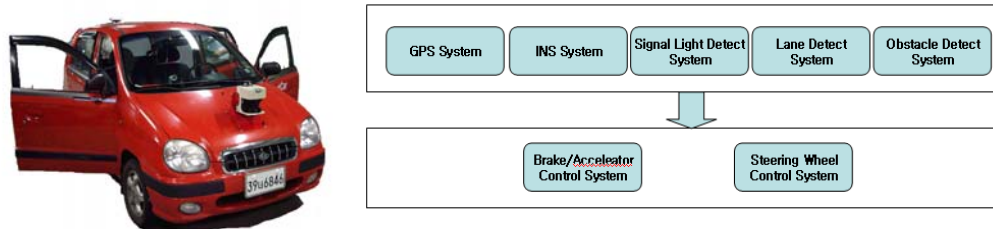
Figure 1. Test UGV and System Architecture..

Canegi Melon University won in 2007. In this contest, car must detect signboard and signal lights. Urban challenge use environment under control for contest, therefore, good condition for UGV.

In 1998, real-time stereo vision system for generic obstacle and lane detection was developed by Massimo Bertozzi and Alberto Broggi[3]. But this system detect only lane on the road and obstacle. This system is for cruising in normal road.

There are many researches for signal light detection. First, there is study based on color tracking by Mahipa. R. Yelal *et al*[4]. This research is about real-time tracking of signal light. But, limitation is only simulation by using 'Matlab', and, condition of sample image is excellent. Backgound of signal lights is clean sky and, no experiment in real urban road.

Another study for signal light detection is using 'Fuzzy AI' by Yun-Chung Chung et al[5]. They use position of light, and processes with 'Fuzzy Map'. Using position, it can detect red, yellow and green signal. But time for processing is 0.5~1 sec per frame. Therefore, it does not support real-time processing.

There is another research built in real car by Lampros Tsinas and Volker Graefe[6]. In this case, they use HSI color map for signal light detection. That takes 20ms. That is fast, and experiment in real road, but limitation is that algorithm can not divide light from cars and another from signal lights. It makes a lot of errors in detection. Therefore, other light sources, they are not signal lights, can be detected in this research. It is a serious error.

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3. System Architecture

This signal detection algorithm is developed by part of 'Intelligent Vehicle Central Control System'. This project is developed for base technology of unmanned vehicle for real urban road.
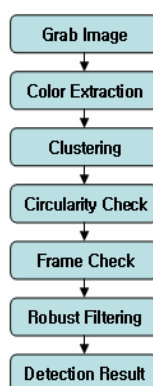
Figure 2. Architecture for signal light detection

Architecture of Intelligent vehicle is in figure 1. All data from each sensor are parsed by each correspondence system. GPS system can track position of car in macroscopic. INS System can detect microscopic position for control car. Lane detection system can detect lane of road. Therefore, car can follow lane in general road. Obstacle detection system detects obstacle in front of car. Finally, signal light detection system detects signal light. Therefore, car can stop and go at crossroads. Each system is connected with steering wheel control system and brake / accelerator control system.

Signal detect system consists of several steps. First, extract candidate pixels of signal light from grabbed image, and cluster extraction result for separating each object. To determine the object is signal light or not, applying 'circularity check' for each object. Looking around the object, find frame of signal light. Finally, remove noise and increase reliability by 'robust filtering'.

4. Algorithm

4.1. Color Extraction

Color extraction step extracts candidate pixels that may come from signal light from grabbed image. This step selects candidate pixels, using statistical processing. Average value of red, green, blue and value of standard deviation are determined for each sample image of signal light. Select pixels within range that is determined from average value and standard deviation and constant.

Pixels of signal lights are extracted from grabbed image in figure 3. Also, pixel from no signal lights are extracted from image, but probability of extracted light pixel is higher than that of extracting error pixel. Generally, error pixels are noise. Its probability is low.

4.2. Clustering

Clustering step is to recognize set of pixel for each object corresponding to the lights source by centroid clustering from grabbed images. We can know centroid position, size, and standard deviation about position to this step.

For clustering steps, this algorithm uses 'K-means centroid clustering'. 'K-means centroid clustering' is introduced by MacQueen in 1967[7]. To get good result, K-means centorid clustering can be run many times recursively, but running one time also get good result in this algorithm.

Using K-means centroid clustering, there are two criteria for detection. First thing is about size of object. K-means centroid clustering can recognize object that have smaller size than threshold. Therefore, if threshold has a size of signal lights, large objects that is not signal light, but have same color are rejected.

Second, some small clusters are regard as a object. In K-means centroid clustering, If there are clusters which have distance to each other is less than threshold range, they are regard as an object. In signal light detection, that criterion is critical. Two of light sources that is far from car can be detected as a light source. In generally, numbers of lane in road are more than one. Therefore, there are two or more of signal lights. These clusters can be detected as an object, but, they will be rejected in 'circularity check' steps. Figure 4 shows result of clustering. In figure 3, there are two signal lights. In figure 4, clustering step detects objects
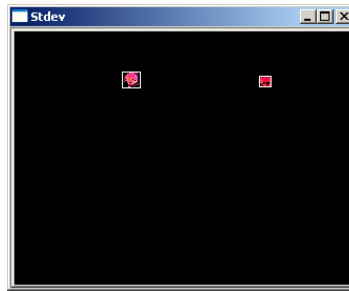

Figure 4. Result of clustering

successfully. The object is drawn by white square.

4.3. Circularity Check

Object that has a shape of circle is detected in this step. There are many lights sources that have color like signal light. For example, they are rear light of car, signboard of buildings and etc. These objects are rejected in circularity check. There are many algorithms for circularity measurement. One of popular algorithm is introduced by Haralick[8]. Eq. (1) is circularity

Figure 3. Grabbed Image (Left) and Result of color

measurement by Haralick. If the circularity measure C for the object is high, it is close to circle.

$$C = \frac{\mu}{\sigma}$$

$$= \frac{\frac{1}{K}\sum_{K=0}^{K-1}\left\|(r_k,c_k)-(\bar{r},\bar{c})\right\|}{\left(\frac{1}{K}\sum_{K=0}^{K-1}\left[\left\|(r_k,c_k)-(\bar{r},\bar{c})\right\|-\mu\right]^2\right)^{1/2}} \quad (1)$$
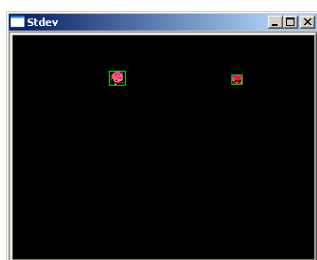

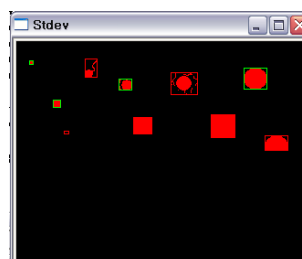Figure 5. Result of circularity check of sample grabbed image

Figure 6. Result of circularity check for some sample figures

In this implementation, we do not use Haralick's circularity measurement, but, similarly, this circularity check uses standard deviation. This algorithm uses a virtual circle using standard deviation. Calculate standard deviation using pixels out of virtual circle. If that value is less than threshold, consider that object as circle.

Figure 5 shows result of circularity check of sample grabbed image. Circularity of object is higher than threshold. Therefore, they are recognized as circle.

Figure 6 is result of circularity check for some sample figures. If object has high circularity, color of square around object will be green. If object has low circularity, color of square around object will be red. In this figure, some shapes have various type of noise, and some shapes are not circle. But some of them is recognized as circle.

There are some features in this circularity measurement algorithm. First, this algorithm has insensitivity to noise. In experiment, this research uses low price camera. It makes many noises. This algorithm considers object if it has low standard deviation than threshold. That means, if threshold is high, noise will be ignored.

Second, if object has small size, this algorithm is insensitive to shape. In figure 6, small square is considered as a circle. If distance from signal lights to car is long, there are many noises. Therefore, object may be not regard as a circle. Therefore, our algorithm is good for detection.

Pseudo Code of this algorithm is below:

For all pixels in the each object

If (distance from center < (standard deviation of x position + standard deviation of y position from center to each pixel in object)){

Get average of square of distance for each pixel,

Get average of distance for each pixel.

}

If ((average of square of distance)-(square of average of distance) > threshold)

{Consider this object circle.}

4.4. Frame Check

This step scans neighborhood of object, and whether object is a signal light or not. Circularity check distinguishes object that has circular form light source, but, there are many light source that have shape likes signal light. Some cars have tail light with circular form. Some of signboards have red circle. They have to be rejected.

If object has a red color, scan right side of object, otherwise scan left side of object. Size is set by that of object. If they have low brightness, object is considered as signal light.

Figure 7 shows result of frame check. In this sample image, there are red signal light. Therefore, 'frame check' step watches right side of object. If this object is signal light, its right side will be dark. If object is signboard or rear light of car, brightness of right side is high. Therefore, they are rejected.
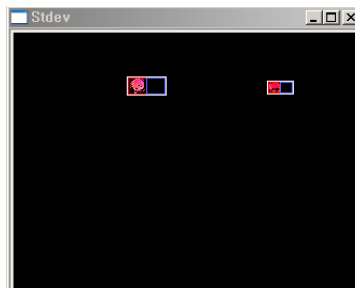

Figure 7. Result of frame

4.5. Robust Filtering

For improving quality, 'Robust Filtering' is applied to result. Grabbed image has many noises. Robust filtering reduces noise. Because of noise, result is cracked. Therefore quality of result of 'frame check' is low. It may tell there is a signal light even if there is not. Even if there is signal light, it may tell there is not. But, in case of signal light, result of only few frames may tell there is not. Also, even if there is not signal light, result of few frames show there is. Therefore, if there are many frames with signal light in last several frames, we consider at this moment there is signal light. If there are only few frames in last frames with signal light, consider there is not signal light.
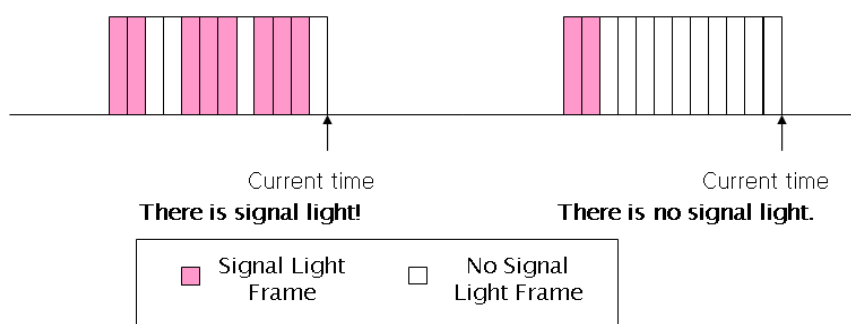
Figure 8. Algorithm of robust filtering

4.6. Priority policy

This algorithm has policy for priority between objects, if many objects are detected in same time. It is related with size, position, color, and shape.

First priority is related with size and position. Depending on view point, Camera can see numbers of signal lights. In this case, a near signal light from car has priority. For example, depending on position, camera can watch signal light on the next crossroads.

Second, priority is related with color. In Korea, there are many lights sources in one signal light frame. In this case, red signal light has priority. In figure 9, there is example of this case in left image of third row. In this image, turn left is allowed, but go straight is not allowed.

Third, priority is related on shape. Signal light for 'turn left allowed' has shape of '←'. In this algorithm, only circular figure is allowed. And, any other figure is rejected. Naturally, signal light for 'turn left allowed' is ignored.

5. Experiment and Result

All of computers and other equipments are carried out in real vehicle. Environment is below: First, CCD (Charge coupled device) camera has low price with no special brand. Price is less then $100. ISO and shutter speed cannot be controlled by manual. Size of CCD is 1/4 inches. CCD camera connected with NTSC to image grabber. Also, image grabber has low price. It is connected with USB (Universal Serial Bus) to computer. Computer is 'Mac Mini' made by Apple corp. It has CPU (Central processing unit) of 'Core Duo' with 1.66 GHz and 512MB RAM. Grabbed image has 320x240 of resolution and 30fps of frame rate. Development tool is Visual C++ 6.0, and Open CV library v1.0. Figure 10 shows computers and equipments built in car.

Location is Anam-dong in Seoul. Time is 7:00~11:00 am. Weather was cloudy. Cloudy weather is not a good condition. ISO sensitivity and shutter time of camera is not controllable by manual. Therefore, brightness of image depends on weather and time. If sky is clear and bright, ISO sensitivity becomes down and shutter time becomes fast. Ager becomes good, and noise will be decreasing. Therefore, quality of image is good. The other way, cloudy weather is not a good condition. Color of signal lights goes to 'white hole'. Number of experiment is twice. Courses are different.

Figure 9. Result for some sample images.

Figure 9 shows result of some sample images. Image shows result for various environments. First row shows signal light detection for usual environment. A signal light far from car has small size in first image. And near signal light has big size. Both of signal lights are detected well. Second rows shows signal light detection in complex urban environment. There are many buildings and signboards. But this algorithm works well. Third row shows signal light detection with multiple objects. In left image, there are 'red light' and 'turn left light' at same time. 'Red signal light' has priority by policy. And 'left turn signal' is rejected. In right image, there are red and green signal lights, together. 'Green signal light' has priority in this case. Because of, 'green signal light' is near the vehicle. Therefore, this algorithm decides that this frame is detected green signal light.
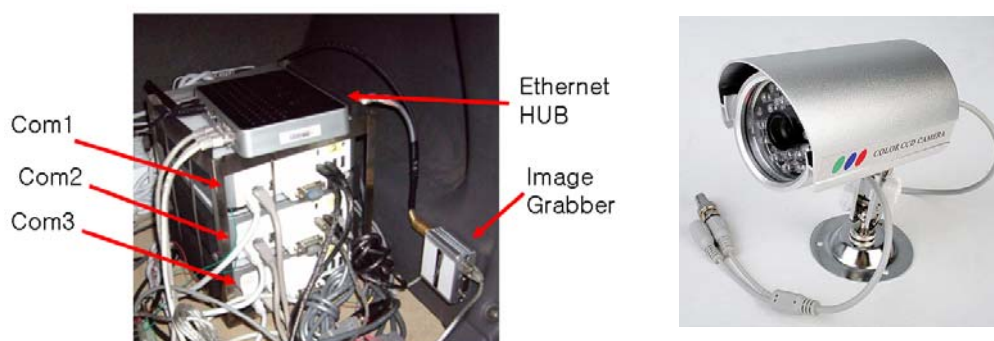
Figure 10. Computers and equipments built in car and camera.

Detection success rate is with 93.9%. 124 of 132 signal lights are successfully detected. And, green and red lights are detected well. In policy, red light has priority, and, signal light with shapes likes 'X' and '←' are not detected.

Table 1. Run time comparison of other algorithm

Method (Year)	Time
This algorithm	7 ms
Yelal's (2006) [4]	108~120 ms
Chung's (2002) [5]	500-1000 ms

Table 1 shows run time comparison of other algorithms. Average of run time is 7ms per frame. This time is faster than any other algorithms in reference. Considering 'Moore's law', this algorithm is faster than other algorithms. And also, this algorithm realizes real-time detection.

6. Conclusion

Technology for unmanned vehicle is rapidly advanced. Peoples are interested in unmanned vehicle. In urban environment, unmanned vehicle should pass crossroads. Therefore, signal light detection is important. There are many research and development for unmanned vehicle. Contest has opened, but, it is artificial and limited. Research for real-time tracking was just simulation. AI based research has slow run time. HSI color map based research has fast run time. But it has low detection rate.

In this paper, we presented the new algorithm for signal light detection. This algorithm has high detection rate. Also, red and green signal lights are detected successfully. Low price camera can be used for this algorithm. Environment is real urban road. Condition for weather is not good, but, detectable. And, all of computers and equipments are built in real vehicle.

Future work will be implementation on real-time embedded system. Also, shape like '←' and 'X' should be detectable. And, detection rate should be increased up to 99%.

Acknowledgement

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