LAPORAN TAHUNAN

PENELITIAN HIBAH KOMPETENSI

Sistem Pemandu Pengemudi Berbasis Kamera Embeded

Tahun ke-1 dari rencana 3 tahun

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RINGKASAN

Keamanan dan kenyamanan berkendara merupakan salah satu aspek penting yang harus diperhatikan oleh industri otomotif. Sebuah sistem yang mampu memberikan peringatan dini pada pengemudi akan membantu mencegah terjadinya kecelakaan. Sistem pemandu pengemudi (Driver assistance system) merupakan sistem yang dikembangkan untuk menyediakan fungsi tersebut.

Sistem pemandu pengemudi berbasis kamera merupakan sistem yang berkembang cukup pesat, seiring dengan perkembangan teknologi di bidang teknik pengolahan citra digital dan sistem komputer. Penelitian ini bertujuan untuk mengembangkan sistem pemandu pengemudi berbasis kamera yang mampu mendeteksi kelelahan dan konsentrasi/pandangan mata pengemudi, rambu-rambu lalu lintas, dan marka jalan, serta objek atau kendaraan yang berada di depan.

Pada peneltian di tahun pertama, dikembangkan sistem pendeteksi kelelahan pengemudi menggunakan kamera embeded yang dipasang di ruang kemudi kendaraan. Sebuah sistem komputer embeded digunakan sebagai pengolah utama dalam proses pendeteksian berbasis kamera tersebut. Dengan menggunakan sistem embeded ini, implementasi sistem di kendaraan dapat dilakukan dengan mudah dan murah.

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Malang, November 2016

Penulis

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BAB I

PENDAHULUAN

1.1. Latar Belakang

Sistem pemandu pengemudi (*Driver Assistant System: DAS*) merupakan suatu sistem yang berfungsi membantu pengemudi dalam mengemudikan kendaraan untuk menghindari terjadinya kecelakaan. Di awal perkembangannya, sistem ini bertujuan untuk menjaga kestabilan dinamika kendaraan. Kemudian dikembangkan untuk memberikan informasi, peringatan dan kenyamanan bagi pengemudi. Dan di masa mendatang merupakan pengemudi otomasis (K. Bengler, dkk., 2014).

Sistem berbasis sensor kamera merupakan salah satu sistem yang berkembang cukup pesat. Beberapa kelebihan dari sistem kamera ini adalah: a) Pemasangan kamera tidak mengganggu pengemudi/pergerakan pengemudi ; b) Sistem kamera dapat dilakukan dengan mudah; c) Tersedianya berbagai jenis kamera yang cukup banyak di pasaran; d) Semakin mudah dan murah sistem komputer atau sistem embeded yang mendukung aplikasi berbasis kamera.

Sistem pemandu pengemudi merupakan sistem yang kompleks dan terus berkembang seiring dengan perkembangan teknologi informasi dan komunikasi. Penelitian yang sedang dan akan dikembangan oleh pengusul meliputi sistem yang mampu memantau kondisi di dalam dan di luar kendaraan (mobil). Kondisi di dalam kendaraan yang dipantau adalah perilaku pengemudi seperti tingkat kelelahan pengemudi (*driver fatigue*) dan tingkat konsentrasi pengemudi (*driver awareness*). Perilaku pengemudi tersebut dibaca melalui sensor kamera yang dipasang di dalam kendaraaan.

Kondisi di luar kendaraan yang dipantau meliputi rambu-rambu lalu lintas, marka jalan dan kendaraan lain di jalan. Kondisi ini dibaca oleh kamera yang di pasang di depan atau ruang kemudi kendaraan. Kedua macam inforrmasi tersebut (di luar dan di dalam kendaraan) akan diolah untuk memberikan informasi dan peringatan dini pada pengemudi.

Algoritma pendeteksian perilaku pengemudi dan kondisi jalan raya merupakan topik penelitian yang cukup instensif dilakukan para peneliti. Sebagian besar penelitian tersebut masih menggunakan komputer PC sebagai pengolah utama. Penelitian yang menggunakan sistem embeded relatif masih sedikit. Pada penelitian ini peneliti mengusulkan pemakaian kamera embeded untuk mengimplementasikan sistem pemandu pengemudi. Dengan kamera embeded ini, sistem pemandu pengemudi dapat diimplementasikan dan diterapkan di kendaraan dengan mudah.

1.2. Perumusan Masalah

Masalah penelitian pad atahun pertama adalah bagaimana merancang metode pendeteksian kelelahan menggunakan kamera dengan algoritma yang efisien, sehingga dapat diimplementasikan pada system embedded.

1.3. Luaran Penelitian

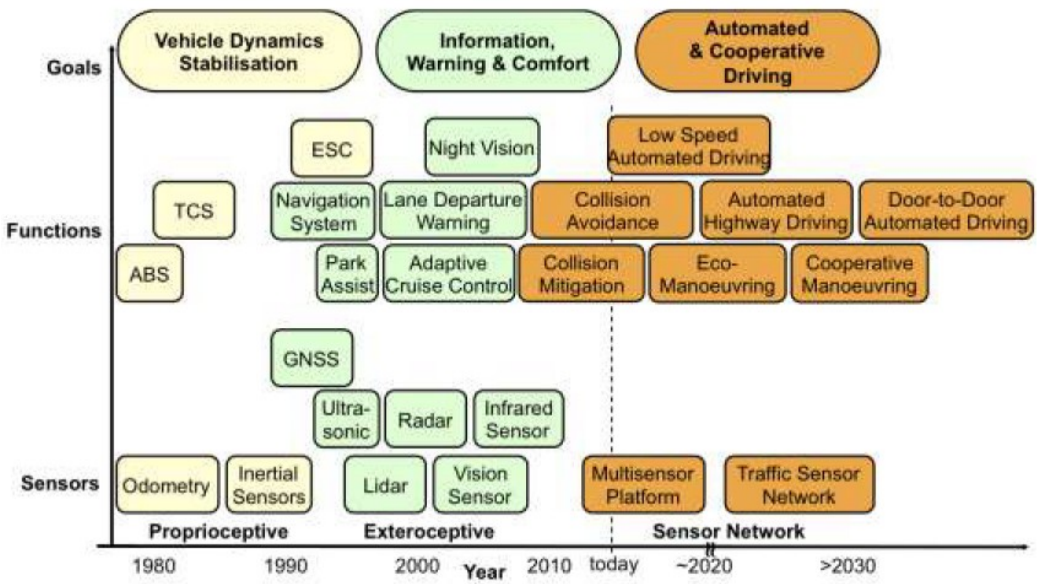
Luaran yang diharapkan pada tahun pertama adalah:

- Prototipe sistem deteksi kelelahan pengemudi berbasis kamera
- Artikel ilmiah yang diseminarkan di Seminar Internasional (terindek IEEExplore/Scopus)
- Artikel ilmiah yang dipublikasikan di Jurnal Internasional (terindek Scopus)

BAB II

TINJAUAN PUSTAKA

Evolusi perkembangan teknologi sistem pemandu pengemudi diperlihatkan pada Gambar 2-1. Di era saat ini, sistem pemandu pengemudi bertujuan untuk menyediakan informasi, peringatan dan kenyamanan bagi pengemudi. Seperti terlihat pada gambar, salah satu fungsi sistem pemandu pengemudi adalah untuk pencegahan kecelakaaan/tabrakan. Berbagai sensor yang digunakan meliputi sensor infra merah, ultrasonik, radar, laser, dan kamera. Di masa mendatang teknologi jaringan sensor yang menggabungkan berbagai jenis sensor kendaraaan dan sensor jaringan lalu lintas akan menjadi pilihan teknologi sensor untuk sistem pemandu pengemudi.



Gambar 2-1. Evolusi perkembangan sistem pemandu pengemudi (K. Bengler, dkk., 2014)

Sistem pemandu pengemudi berbasis kamera merupakan salah satu sistem yang banyak dikembangkan oleh para peneliti. Beberapa keunggulan dari sistem berbasis kamera ini adalah (I. Buciu, A. Gascadi, C. Grava, 2010): a) Memungkinkan untuk mengklasifikasi suatu objek; b) Dapat mendeteksi bentuk dan ukuran objek; c) Harga relatif lebih murah. Sedangkan kelemahannya adalah: a) Sulit digunakan pada situasi di mana pandangan kamera tidak jelas; b) Sulit digunakan juka kondisi intensitas cahaya bervariasi cukup besar (terang dan gelap).

Sistem pemandu pengemudi pada umumnya terdiri dari (I. Buciu, A. Gascadi, C. Grava, 2010):

1. Pemantauan kondisi lalu lintas;
2. Pemantauan kondisi/perilaku pengemudi;
3. Pemantauan kondisi kendaraan;
4. Komunikasi interaktif dengan pengemudi;
5. Pengendalian kendaraan;
6. Sistem pemikiran (*reasoning system*).

Pemantauan kondisi lalu lintas meliputi pemantauan rambu lalu lintas, marka jalan, kendaraan di depan, penyeberang jalan, objek lainnya (bangunan, pohon, dll). Pemantauan kondisi pengendara meliputi pemantauan gerakan kepala, kelelahan, konsentrasi pengemudi. Pemantauan kondisi kendaraan memberikan informasi tentang bahan bakar, tekanan ban, kecepatan kendaraan, dll. Komunikasi interaktif dengan pengemudi dapat berupu informasi dari GPS (*Global Positioning System*) sebagai alat bantu navigasi kendaraan. Pengendalian kendaraan berfungsi untuk sistem pengemudi semi-otomatis. Dan sistem pemikiran dapat digunakan untuk membantu pengambilan keputusan ketika mengemudi.

Penelitian tentang sistem deteksi rambu lalu lintas sudah banyak dilakukan para peneliti (A. Mogelmose, M.M. Trivedi, T.B. Moeslund, 2012). Pada umumnya sistem deteksi rambu lalu lintas dibagi menjadi tiga tahapan, yaitu: segmentasi, ektraksi fitur dan deteksi. Pada proses segmentasi, umumnya digunakan deteksi warna objek menggunakan berbagai macam format warna, seperti RGB dan HSV. Pengusul berhasil mengembangkan metode deteksi baru berdasarkan warna menggunakan diagram kromasitas RGB untuk memisahkan warna merah rambu lalu lintas (A. Soetedjo, K. Yamada, 2007), warna biru rambu petunjuk lalu lintas (A. Soetedjo, K. Yamada, F. Y. Limpraptono, 2009; A. Soetedjo, K.Yamada, F. Y. Limpraptono, 2010).

Teknik deteksi tersebut di atas digunakan untuk menentukan lokasi rambu lalu lintas pada gambar yang diambil kamera. Langkah selanjutnya adalah proses klasifikasi atau pengenalan rambu atau objek yang dideteksi tersebut. Berbagai metode dikembangkan para peneliti untuk proses pengenalan rambu lalu lintas, seperti klasifikasi menggunakan SVM (*Support Vector Machine*) yang dikembangkan oleh (J. Greenhalgh, M. Mirmehdi, 2012). Salah satu kelemahan metode ini adalah dibutuhkan data yang cukup besar untuk proses pelatihannya. Pengusul telah mengembangkan metode klasifikasi tanpa data pelatihan dengan teknik partisi (A. Soetedjo, K. Yamada, 2005). Metode ini cukup efektif untuk mengkasifikasi rambu lalu lintas dengan algoritma yang sederhana. Implementasi teknik ini masih menggunakan simulasi menggunakan program MATLAB. Implementasi secara waktu nyata akan dilakukan pada penelitian yang diusulkan. Sedangkan teknik SVM yang dikembangkan oleh (J. Greenhalgh, M. Mirmehdi, 2012) sudah diuji secara waktu nyata menggunakan perangkat lunak OpenCV yang dijalankan pada komputer Intel Core i5 dan dapat memproses 20 *fps* (*frame per second*).

Sistem deteksi perilaku pengemudi menggunakan kamera dikembangkan para peneliti dengan mendeteksi wajah pengemudi. Parameter penting yang dideteksi adalah kelelahan dan konsentrasi pengemudi. Sistem deteksi menggunakan kamera ini memiliki kelebihan dibanding dengan metode yang menggunakan sensor bioelektrik dan sensor gerakan kemudi (*steering*) seperti terlihat pada Tabel 2.1 (M.H. Sigari, M.R. Pourshahabi, M. Soryani, M. Fathy, 2014).

Tabel 2.1. Perbandingan teknik deteksi kelelahan pengemudi (M.H. Sigari, M.R. Pourshahabi, M. Soryani, M. Fathy, 2014).

	Approaches based on Bioelectric Signals	Approaches based on Steering Motion	Approaches based on Driver Face Monitoring
Fatigue Detection	Yes	Yes	Yes
Distraction Detection	No	Yes	Yes
Accuracy	Very Good	Good	Moderate
Simplicity	Difficult	Relatively Easy	Easy
Detection Speed	Very Fast	Slow	Fast

Penelitian tentang deteksi kelelahan pengemudi menggunakan kamera dikembangkan oleh pengusul dengan mendeteksi lama membuka dan menutupnya mata (A. Soetedjo, F. Yudi Limpraptono, 2009). Metode yang dikembangkan ini menggunakan pemisahan warna kulit (A. Soetedjo, K. Yamada, 2008) yang cukup efektif untuk mendeteksi fitur wajah. Metode yang dikembangkan tersebut masih diimplementasikan pada komputer PC dengan perangkat lunak MATLAB. Beberapa peneliti telah mengimplementasikan sistem deteksi kelelahan pada sistem embeded menggunakan Raspberry Pi (D. Sarkar, A. Chowdhury, 2014) atau Beagebone (V. Krishnasree, N. Balaji, P.S Rao, 2014).

Sistem pemandu pengemudi untuk mendeteksi marka jalan dan kendaraan di depan dikembangkan oleh (J.F. Liu, Y.F. Su, M.K. Ko, P.N. Yu, 2008). Pada sistem ini, sebuah kamera digunakan untuk menangkap gambar jalan di depan kendaraan. Untuk mendeteksi marka jalan dilakukan dengan transformasi warna yang memisahkan marka dengan jalan. Posisi kendaraan di jalur didetksi menggunakan berdasarkan geometri jalan. Kendaraan di depan dideteksi menggunakan deteksi tepi *Sobel* untuk mengekstrak batas kendaraan. Perbandingan panjang dan lebar kendaraan digunakan untuk memvalidasi objek sebagai kendaraan atau bukan. Selanjutnya jarak antar kendaraan dihitung dan digunakan untuk memberikan peringatan pada pengemudi jika jaraknya terlalu dekat.

BAB III
TUJUAN DAN MANFAAT PENELITIAN

3.1 Tujuan Penelitian

Penelitian ini bertujuan untuk mengembangkan algoritma dan membuat prototipe sistem pemandu pengemudi berbasis kamera embeded. Beberapa aspek yang menjadi titik berat penelitan adalah: a) Kesederhanaan dan kehandalan algoritma pendeteksian; dan b) Kelayakan sistem untuk dapat diimplementasikan di kendarann dengan mudah dan murah.

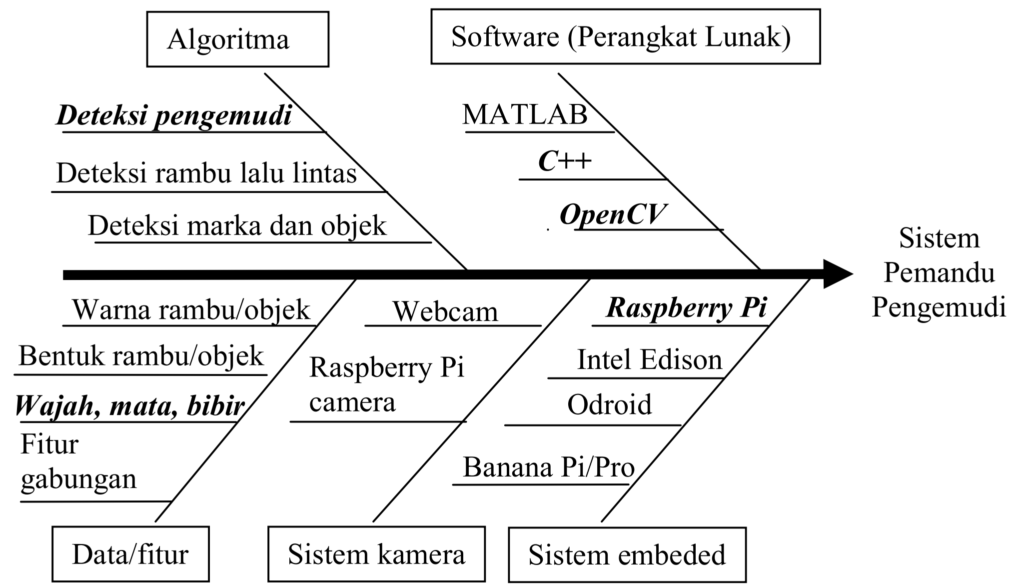
3.2 Manfaat Penelitian

Penelitian yang diusulkan diharapkan dapat menghasilkan prototipe system pemandu pengemudi yang handal dan dapat dipasang di kendaraan secara mudah dan murah. Sistem yang dikembangkan berbasis kamera embeded menggunakan Raspberry Pi kamera dengan pengolah utama modul Raspberry Pi. Sistem yang dirancang ini cukup kecil ukurannya, sehingga memungkinkan untuk dipasang di kendaraan tanpa memerlukan modifikasi yang rumit. Selain itu, Raspberry Pi adalah sistem yang bersifat *Open source*, sehingga pengembangan sistem dapat dilakukan dengan mudah. Tantangan terbesar dari sistem yang dirancang adalah pengembangan metode pendeteksian yang cukup handal dengan proses komputasi yang cepat, sehingga dapat diaplikasikan pada sistem embeded seperti Raspberry Pi.

Hasil penelitian ini diharapkan dapat membantu masyarakat khususnya pengendara mobil untuk memanfaatkan sistem pemandu pengemudi yang mampu memberikan informasi dan peringatan pengemudi untuk menghindari terjadinya kecelakaan. Sistem yang dirancang diharapkan juga dapat digunakan oleh industri otomatif dalam pembuatan dan pengembangan kendaraaan yang dilengkapi dengan tambahan fitur pengaman penghindar atau peringantan dini pencegahan kecelakaan.

BAB IV
METODE PENELITIAN

Metode penelitian yang dilakukan digambarkan dengan diagram tulang ikan seperti terlihat pada Gambar 4-1. Untuk mencapai tujuan akhir penelitian berupa prototipe sistem pemandu pengemudi, diperlukan lima komponen utama yang terdiri dari: algoritma pendeteksian, perangkat lunak, penentuan data/fitur pendeteksian, sistem kamera, dan sistem embeded dimana algoritma akan diimplementasikan.



Gambar 4-1. Diagram tulang ikan penelitian sistem pemandu pengemudi.

Algoritma yang dibuat merupakan teknik-teknik dalam bidang pengolahan citra dan pengenalan pola yang digunakan untuk mendeteksi objek berdasarkan fitur-fitur tertentu. Pada penelitian yang diusulkan terdapat tiga macam objek yang akan dididetekasi, yaitu:

1. Perilaku pengemudi berdasar fitur wajah, mata dan bibir
2. Rambu-rambu lalu lintas berdasar fitur bentuk rambu dan warna rambu
3. Marka jalan dan objek di depan kendaraan berdasarkan fitur dan warna objek.

Dari hasil eksperimen menggunakan masing-masing fitur, selanjutnya akan dilakukan pengembangkan untuk menggabungkan fitur-fitur dengan menggunakan pendekatan gabungan fitur (*data fusion*).

Metode penelitian pada tahun pertama adalah mengembangkan sistem pendeteksi kelelahan dan konsentrasi/pandangan pengemudi. Untuk mengembangkan sistem ini, dilakukan perancangan sistem untuk mendeteksi wajah dan mata. Deteksi kelelahan ditentukan berdasarkan lamanya mata menutup.

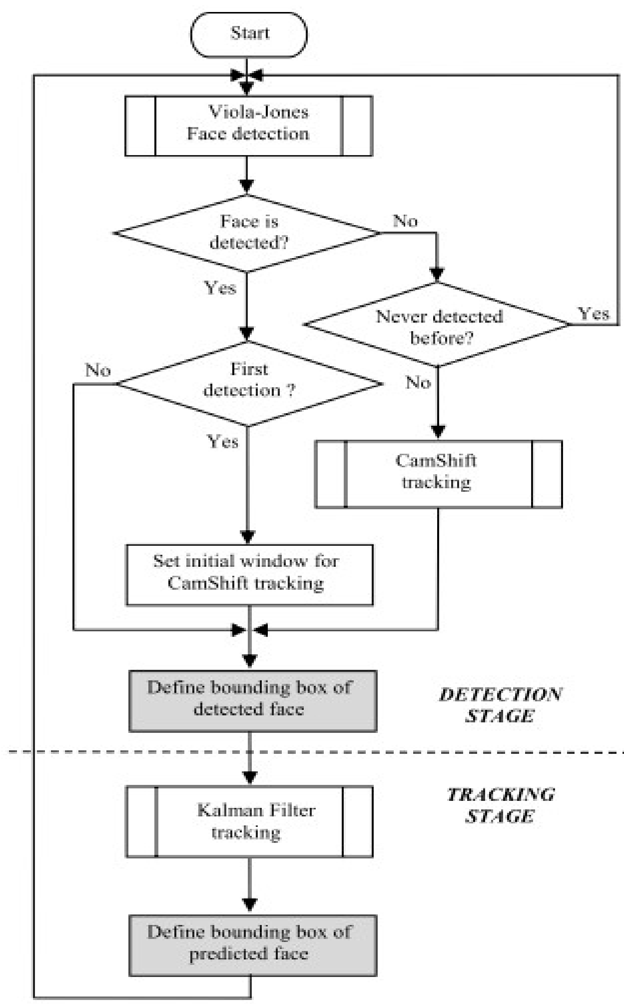
Algoritma yang dirancang diimplementasikan pada sistem embeded menggunakan nodul Raspberry Pi dan Raspicam (Raspberry Pi camera).

BAB V
HASIL DAN PEMBAHASAN

5.1 Sistem Deteksi dan Pelacakan Wajah

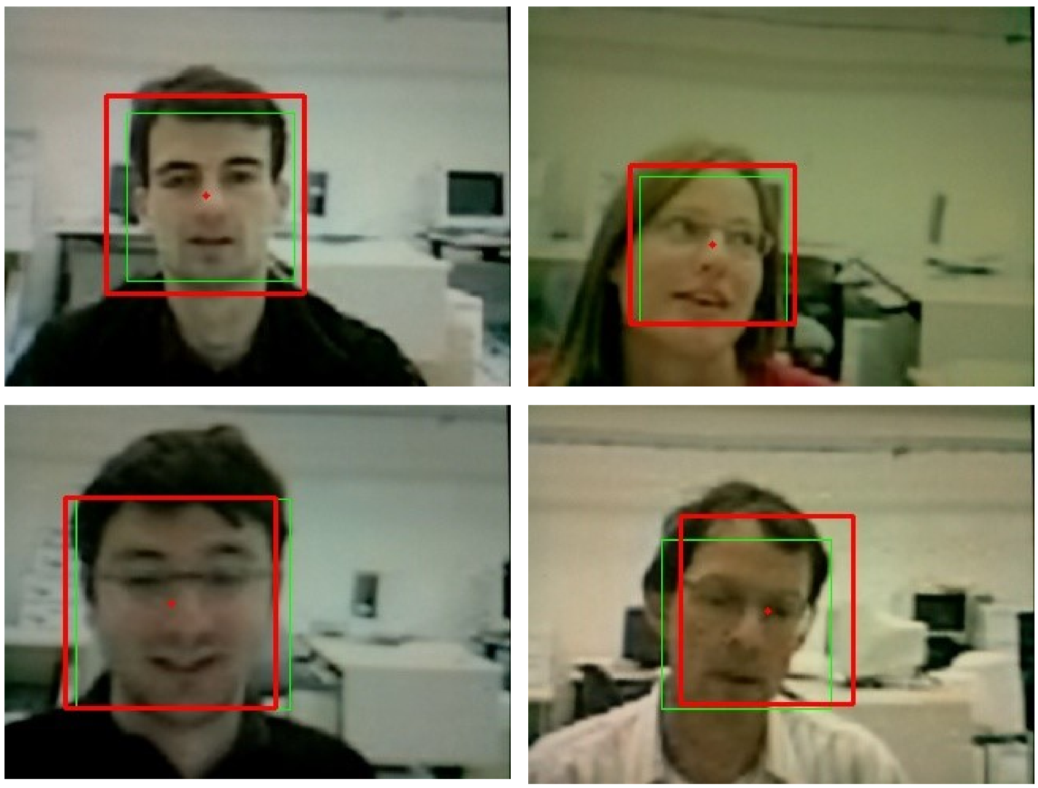
Sistem deteksi dan pelacakan wajah digunakan sebagai proses awal untuk mempersempit lokasi pencaraian mata. Setelah wajah dideteksi, maka proses deteksi mata hanya dilakukan pada area di wajah tersebut. Cara ini akan mempercepat proses pendeteksian mata.

Sistem deteksi wajah yang dikembangkan meggunakan metode Viola Jones yang banyak digunakan oleh para peneliti. Pada penelitian ini, dikembangkan metode baru yang merupakan penggabungan dari beberapa metode yang ada. Algoritma yang dikembangkan diperlihatkan pada Gambar 5-1.



Gambar 5-1. Diagram alir sistem deteksi wajah.

Algoritma yang dikembangkan sudah diuji untuk mendeteksi berbagai macam wajah yang direkam dengan video seperti terlihat pada Gambar 5-2. Seperti terlihat pada gambar, posisi wajah yang dideteksi digambarkan dengan kotak berwarna hijau, sedangkan posisi hasil pelacakan digambarkan dengan kotak berwarna merah. Hasil pengujian dengan berbagai video diperlihatkan pada Tabel 5-1, dimana VJ adalah metode Viola-Jones, VJ-CS adalah gabungan metode Viola-Jones dan Camshift, VJ=KF adalah gabungan antara metode Viola-Jones dan Kalman filter, PM adalah metode yang diusulkan/dikembangkan penulis dalam penelitian ini.



Gambar 5-2. Contoh hasil pengujian deteksi wajah.

Tabel 5.1 Hasil pengujian deteksi wajah

Video No.	**Methods**			
	VJ	***VJ-CS***	***VJ-KF***	***PM***
1	76.1%	82.4%	79.8%	99.3%
2	100%	81.0%	92.3%	100%
3	87.3%	21.6%	89.0%	93.8%
4	95.8%	83.3%	95.7%	100%
Average	**89.8%**	**67.1%**	**89.2%**	**98.3%**

Berdasarkan hasil pengujian pada Tabel 5.1, diperoleh bahwa metode yang dikembangkan memiliki tingkat keberhasilan pendeteksian wajah yang paling tinggi, yaitu 98,3%. Hasil ini menunjukkan bahwa metode gabungan yang diusulkan cukup efektif dalam mendeteksi wajah.

Hasil pengujian kecepatan komputasi deteksi wajah diperlihatkan pada Tabel 5.2. Dari tabel tersebut diperoleh bahwa kecepatan komputasi tercepat adalah ketika menggunakan metode VJ-CS, yaitu 14,25 *fps* (*frame per second*). Tetapi metode ini menghasilkan tingkat keberhasilan pendeteksian yang rendah, yaitu hanya 67,1%. Sedangkan metode yang diusulkan memiliki kecepatan komputasi yang relatif cepat (urutan kedua), yaitu 7,09 fps.

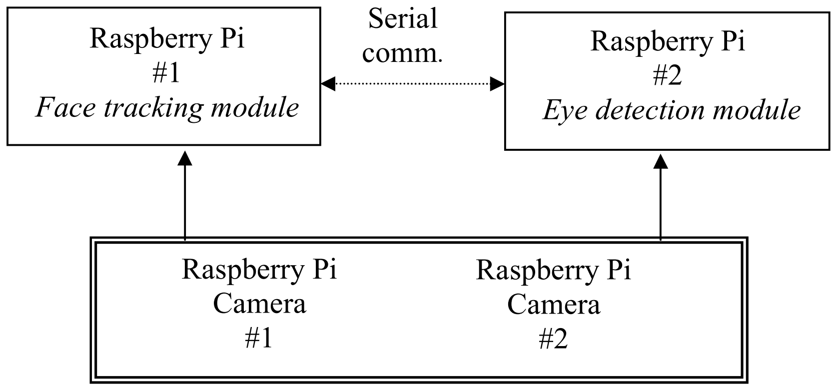
Berdasarkan hasil-hasil di atas, dapat disimpulkan bahwa metode yang diusulkan merupakan metode yang optimal dari sisi tingkat keberhasilan pendeteksian dan kecepatan komputasi.

Tabel 5.2 Hasil pengujian kecepatan komputasi deteksi wajah

Video No.	**Methods**			
	VJ	***VJ-CS***	***VJ-KF***	***PM***
1	3,05 fps	14,47 fps	5,56 fps	6,77 fps
2	3,00 fps	13,70 fps	6,55 fps	7,17 fps
3	2,95 fps	14,54 fps	6,87 fps	6,70 fps
4	3,01 fps	14,30 fps	7,24 fps	7,72 fps
Average	**3,00 fps**	**14,25 fps**	**6,56 fps**	**7,09 fps**

5.2 Sistem Deteksi Mata dengan Dual Kamera

Sistem deteksi kelelahan yang dikembangkan menggunakan informasi membuka dan menutup mata sebagai indicator kelelahan/mengantuk. Untuk mendeteksi mata digunakan dua buah kamera yang masing-masing terhubung ke Raspberry Pi sebagai pengolah utama. Teknik ini digunakan untuk mempercepat proses pendeteksian dengan memanfaatkan fitur kamera dan sistem prosesor yang murah. Arsitektur sistem deteksi mata dieprlihatkan pada gambar 5-3. Sedangkan prototipe sistem tersebut terlihat pada Gambar 5-4.

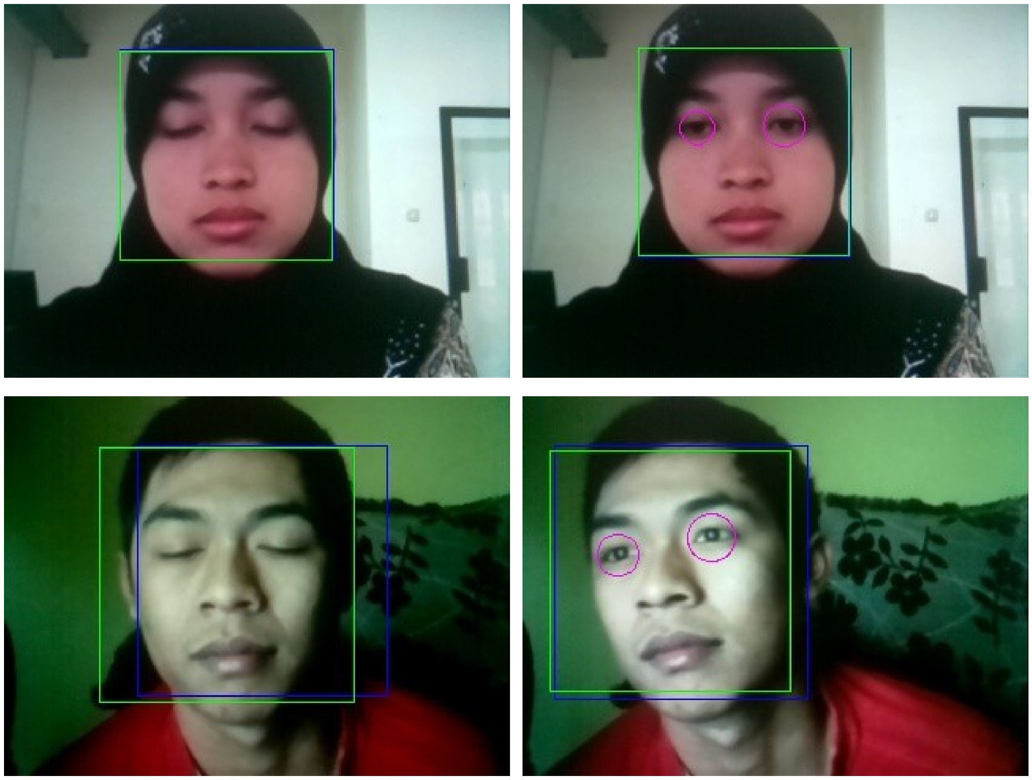


Gambar 5-3. Arsitektur sistem deteksi mata

Gambar 5-4. Prototipe sistem deteksi mata

Beberapa contoh hasil deteksi mata diperlihatkan pada Gambar 5-5, dimana hasil deteksi mata ketika terbuka ditandai dengan lingkaran warna merah. Hasil pengujian sistem deteksi mata dengan dua kamera diperlihatkan pada Tabel 5.3 yang terdiri dari tiga metode. Metode-1 adalah metode di mana area pencarian deteksi mata tidak diperkecil. Metode-2 adalah metode di mana area pencarian deteksi mata diperkecil sehingga tinggi area pencarian menjadi 80 piksel. Sedangkan Metode-3 adalah metode di mana area pencarian deteksi mata diperkecil 0,875 kali.

Dari hasil pengujian pada Tabel 5.3 diperoleh bahwa kecepatan komputasi tercepat dicapai dengan Metode-3, yaitu 11,594 fps, tetapi dengan tingkat keberhasilan pendektian yang rendah, yaitu 81,8%. Sedangkan metode yang optimal dari sisi kecepatan komputasi dan tingkat keberhasilan dicapai dengan Metode-2, yaitu tingkat keberhasilan pendeteksian 88,9% dan kecepatan komputasi 6,061 fps.



Gambar 5-5. Contoh hasil deteksi mata tertutup (kiri) dan terbuka (kanan).

Tabel 5.3 Hasil pengujian sistem deteksi mata dengan dua kamera

Metode	**True detection (%)**	**Frame rate (fps)**
Metode-1	89,0	4,609
Metode-2	88,9	6,061
Metode-3	81,8	11,594

5.3 Luaran Yang Dicapai

Luaran yang sudah dicapai adalah:

- Prototipe sistem deteksi kelelahan pengemudi berbasis kamera
- Artikel ilmiah dengan judul "Implementation of Face Detection and Tracking on A Low Cost Embedded System Using Fusion Technique" yang sudah dipublikasikan pada seminar Internasional IEEE-ICCSE (The 11th International Conference on Computer Science & Education) 2016 di Nagoya, Jepang, 22 s/d 25 Agustus 2016: Terindek IEEExplore.

- Artikel ilmiah dengan judul “Implementation of Eye Detection Using Dual Camera on the Embedded System” yang dikirimkan (sedang dalam proses revisi) ke *International Journal of Innovative Computing, Information and Control* (Terindek SCOPUS, Q1).
- Draft Paten dengan judul “Sistem Deteksi Mata Menggunakan Dua Kamera Berbasis Cahaya Inframerah”

BAB VI
RENCANA TAHAPAN BERIKUTNYA

Rencana tahap berikutnya (Tahun-2) adalah:

1. Perancangan sistem pengenalan rambu lalu lintas
   a. Pengembangan dan penyempurnaan algoritma pendeteksi rambu lalu lintas
   b. Pengembangan dan penyempurnaan algoritma pengenalan rambu lalu lintas
   c. Pengumpulan/survey data video rambu-rambu lalu lintas
   d. Perancangan konfigurasi sistem embeded untuk pengenalan rambu lalu lintas
2. Implementasi sistem pengenalan rambu lalu lintas
   a. Pembuatan program pengolahan citra dan pengenalan pola untuk pendeteksian rambu lalu lintas pada sistem embeded
   b. Pembuatan program pengolahan citra dan pengenalan pola untuk pengenalan rambu lalu lintas
   c. Perakitan dan pembuatan prototipe alat pendeteksi dan pengenalan rambu lalu lintas berbasis sistem embeded
   d. Implementasi prototipe alat pendeteksi dan pengenalan rambu lintas untuk pengujian di laboratorium
3. Pengujian sistem pengenalan rambu lalu lintas
   a. Pengujian algoritma pendeteksian rambu lalu lintas menggunakan video
   b. Pengujian algoritma pengenalan rambu lalu lintas menggunakan video
   c. Pengujian prototipe (sistem embeded) alat pendeteksi dan pengenalan rambu lalu lintas menggunakan video
   d. Pengujian prototipe (sistem embeded) alat pendeteksi dan pengenalan rambu lalu lintas menggunakan simulator

BAB VII
KESIMPULAN DAN SARAN

7.1 Kesimpulan

1. Algoritma deteksi wajah yang dikembangkan dengan menggabungkan dengan berbagai teknik yang ada mampu memberikan hasil pendeteksian yang lebih baik dibanding dengan teknik yang sudah ada.
2. Sistem pendeteksi kelelahan yang dikembangkan dengan menggunakan dua buah kamera mampu mempercepat proses deteksi, dan dapat diimplementasikan pada perangkat keras yang sederhana.

7.2 Saran

1. Untuk menyempurnakan sistem pendeteksian wajah dan mata, dapat dikembangkan sistem deteksi wajah/mata pada kondisi gelap.
2. Prototipe dapat dikembangkan untuk diimplementasikan pada kondisi sebenarnya.

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A.Soetedjo, A.Mahmudi, M.I. Ashari, Y.I. Nakhoda, 2013*, Camera-Based Shooting Simulator Using Color Thresholding Techniques*, Proceedings of International Conference on Instrumentation, Control and Automation (ICA 2013), Bali.

A. Soetedjo, A. Mahmudi, M.I. Ashari, Y.I. Nakhoda, 2014, *Detecting Laser Spot in Shooting Simulator Using an Embedded Camera*, International Journal on Smart Sensing and Intelligent Systems, Vol. 7, No. 1.

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A. Soetedjo, A. Mahmudi, M.I. Ashari, Y.I. Nakhoda, 2014, *Raspberry Pi Based Laser Spot Detection*, Proceedings of International Conference on Electrical Engineering and Computer Science (ICEECS), Bali.

A. Soetedjo, A. Mahmudi, M.I. Ashari, Y.I. Nakhoda, 2015, *Low Cost Shooting Simulator Based on a Single Board Computer*, American Journal of Applied Sciences. (in press)

D. Sarkar, A. Chowdhury, 2014, *A Real Time Embedded System Application for Driver Drowsiness and Alcoholic Intoxication Detection*, International Journal of Engineering Trends and Technology, Vol. 10, No. 9, pp. 461-465.

I. Buciu, A. Gascadi, C. Grava, 2010, *Vision based Approaches for Driver Assitance Systems,* Proceedings of the 11th WSEAS International Conference on Automation and Informatics, Iasi, Romania.

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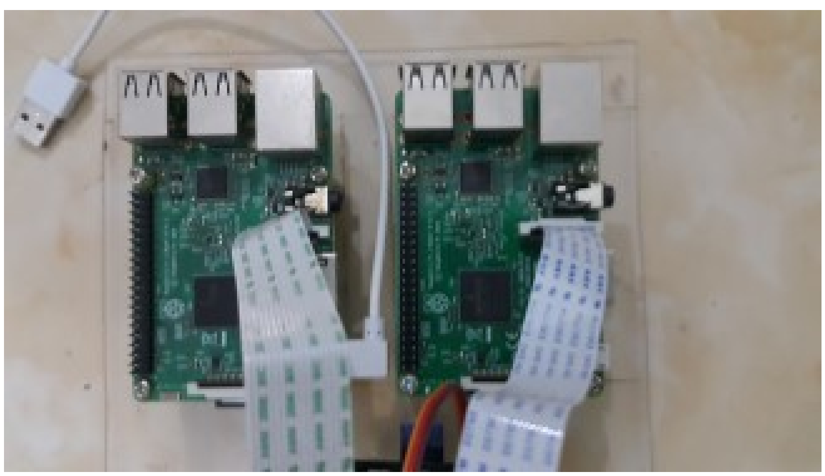
V. Krishnasree, N. Balaji, P.S Rao, 2014, *A Real Time Improved Driver Fatigue Monitoring System*, WSEAS Transactions on Signal Processing, Vol. 10, pp. 146-155.

LAMPIRAN 1

Foto-foto prototipe Sistem Deteksi Kelelahan



LAMPIRAN 2

BIODATA KETUA PENELITI

A. Identitas Diri

1	Nama Lengkap (dengan gelar)	Dr. Eng. Aryuanto Soetedjo, ST, MT
2	Jabatan Fungsional	Lektor
3	Jabatan Struktural	Kepala Laboratorium
4	NIP/NIK/Identitas lainnya	1030800417
5	NIDN	0425017102
6	Tempat dan Tanggal Lahir	Sragen, 25 Januari 1971
7	Alamat Rumah	Perum Bumi Mondoroko Raya Blok AG-30, Singosari Malang
8	Nomor Telepon/Faks/HP	0341-450612/081220629329
9	Alamat Kantor	Jl. Raya Karanglo Karangploso Km 2.
10	Nomor Telepon/Faks	0341-417636/0341417634
11	Alamat e-mail	aryuanto@gmail.com
12	Lulusan yang Telah Dihasilkan	S1= 50 orang: S2= orang; S3= orang
13. Mata Kuliah yg Diampu		1. Dasar Sistem Kendali
		2. Robotika
		3. Pengendalian Dalam Industri
		4. Pengolahan Citra Digital

B. Riwayat Pendidikan

	S1	**S2**	**S3**
Nama Perguruan Tinggi	ITB Bandung	ITB Bandung	NUT, Jepang
Bidang Ilmu	Teknik Elektro	Teknik Elektro	Teknik Elektro
Tahun Masuk-Lulus	1989 - 1993	1999 - 2002	2003 - 2006
Judul Skripsi/Thesis/Desertasi	Perancangan Manipulator 2 DOF Berbasis PC	Perancangan Kendali Logika Fuzzy Untuk Pengendali Lampu Lalu Lintas di Persimpangan Lewat Jenuh	A Study on Fast and Robust Algorithm for Traffic Sign Recognition System
Nama Pembimbing Promotor	Kuspriyanto, Ir., Dr.	Bambang Riyanto, Ir., Dr.	Koichi Yamada, Prof.

C. Pengalaman Penelitian Dalam 5 Tahun Terakhir

(Bukan Skripsi, Tesis maupun Disertasi)

No	Tahun	Judul Penelitian	Pendanaan	
			Sumber*	Jml(Juta Rp)
1	2015	Implementasi SCADA Pada Sistem Integrasi Pembangkit Energi Terbarukan Dan Teknologi Smart Grid	DP2M-DIKTI Hibah Penelitian Unggulan PT	Rp. 60.500.000

2	2014	Aplikasi Sistem Embeded Pada Simulator Menembak Senjata Ringan (Tahun-2)	DP2M-DIKTI Hibah Penelitian Strategis Nasional	Rp. 96.500.000
3	2013	Aplikasi Sistem Embeded Pada Simulator Menembak Senjata Ringan (Tahun-1)	DP2M-DIKTI Hibah Penelitian Strategis Nasional	Rp. 80.000.000
4	2011	Sistem SCADA Untuk Optimalisasi Pembangkit Energi terbarukan	LP2M - ITN Malang	Rp. 10.000.000
5	2011	Pengembangan Laboratorium Jarak Jauh Untuk Menunjang Proses Pembelajaran Berbasis KBK di Jurusan Teknik Elektro ITN Malang	LP2M - ITN Malang	Rp. 8.000.000
6	2010	Rancang Bangun Sistem Teknologi Hybrid Dalam Pengembangan Potensi Energi Terbarukan Skala Kecil Untuk Memenuhi Kebutuhan Energi di Daerah Terpencil	DP2M-DIKTI Hibah Penelitian Strategis Nasional	Rp. 70.000.000

**Tuliskan sumber pendanaan : PDM, SKW, Pemula, Fundamental, Hibah Bersaing, Hibah Pekerti, Hibah Pascasarjana, Hikom, Stranas, Kerjasama Luar Negeri dan Publikasi Internasional, RAPID, Unggulan Stranas, atau sumber lainnya.*

D. Pengalaman Pengabdian Kepada Masyarakat Dalam 5 Tahun Terakhir

No	Tahun	Judul Pengabdian Kepada Masyarakat	Pendanaan	
			Sumber*	Jml(Juta Rp)
1	2014	Pelatihan Pemanfaatan Komputer Untuk Pembuatan Program Aplikasi SCADA pada Siswa SMK	LP2M - ITN Malang	Rp. 5.000.000
2	2013	IbM Pemanfaatan Alat Pengendali Suhu dan Kelembaban Untuk Proses Fermentasi Tempe	DP2M-DIKTI	Rp. 40.000.000
3	2010	Pelatihan PLC		

**Tuliskan sumber pendanaan : Penerapan IPTEKS-SOSBUD, Vucer Multitahun, UJI, Sibermas atau sumber lainnya.*

E. Pengalaman Penulisan Artikel Ilmiah Dalam Jurnal Dalam 5 Tahun Terakhir

No	Judul Artikel Ilmiah	Volume/Nomor/Tahun	Nama Jurnal
1	Low Cost Shooting Simulator Based on a Single Board Compute	In press	American Journal of Applied Sciences
2	Web-SCADA for Monitoring and Controlling Hybrid Wind-PV Power	Vol. 12, No. 2, 2014	TELKOMNIKA Indonesian Journal of

	System		Electrical Engineering
3	Detecting Laser Spot in Shooting Simulator Using an Embedded Camera	Vol. 7, No. 1, 2014	International Journal on Smart Sensing and Intelligent Systems
4	Photodiode Array for Detecting Laser Pointer Applied in Shooting SImulato	Vol. 151, No. 4, 2013	Sensors and Transducers Journa
5	Combining Web SCADA Software and Matlab-Simulink for Studying Wind-PV-Battery Power Systems	Vol. 10, No. 2, 2012	International Journal of Computer Science Issues (IJCSI)
6	Modeling of Maximum Power Point Tracking Controller for Solar Power System	Vol. 10, No. 3, 2012	TELKOMNIKA Indonesian Journal of Electrical Engineering
7	Eye Detection Based-on Color and Shape Features	Vol. 3, No. 5, 2012	International Journal of Advanced Computer Science and Applications
8	Experimental Study on Lip and Smile Detection	Vol. 4, No. 2, 2011	Jurnal Ilmu Komputer dan Informasi
9	Devoloping of Low Cost Vision-Based Shooting Range Simulator	Vol. 11, No. 2, 2011	International Journal of Computer Science and Network Security
10	Segmentation of Road Guidance Sign Symbols and Characters Based on Normalized RGB Chromaticity Diagram	Vol. 3, No. 3, 2010	International Journal of Computer Applications

F. Pengalaman Penyampaian Makalah Secara Oral Pada Pertemuan/Seminar Ilmiah Dalam 5 Tahun Terakhir.

No	Nama Pertemuan Ilmiah/Seminar	Judul Artikel Ilmiah	Waktu dan Tempat
1	International Conference on Electrical Engineering and Computer Science (ICEECS)	Raspberry Pi Based Laser Spot Detection	24-25 November 2014, Bali

2	International Conference on Technology, Informatics, Management, Engineering & Environment (TIME-E) 2014	Implementation of Sensor on the Gun System Using Embedded Camera for Shooting Training	19-21 Agustus 2014, Bandung
3	International Conference on Instrumentation, Control and Automation (ICA 2013)	Camera-Based Shooting Simulator Using Color Thresholding Techniques	28 – 30 Agustus 2013. Bali
4	International Symposium on Electrical and Computer Engineering 2013 (QIR2013)	Development of Data Acquisition System for Hybrid Power Plant	25 – 28 Juni 2013, Yogyakarta
5	Seminar Internasional MICEEI	Implementation of MPPT Controller for PV System based on AVR Microcontrolle	Unhas Makassar, 2012
6	Seminar Nasional TEKNOIN 2012	Supervisory Control for Hybrid Power System Using Smart Relay	UII Yogyakarta, 2012
7	International Conference on Information Technology and Electrical Engineering (CITEE2012)	Remote Laboratory Over the Internet for DC Motor Experiment	UGM, Yogyakarta, Indonesia, 2012
8	International Conference on Electrical Engineering and Informatics (ICEEI 2011)	Modeling of Wind Energy System with MPPT Control	17 – 19 Juli 2011, ITB Bandung
9	International Conference on Electrical Engineering and Informatics (ICEEI 2011)	Development of a Cost-Effective Shooting Simulator Using Laser Pointer	17 – 19 Juli 2011, ITB Bandung
10	Seminar Nasional Energi Baru Terbarukan dan Konservasi Energi	Pemodelan Sistem Pembangkit Listrik Hibrid Angin dan Surya	26 April 2011, Politeknik Negeri Jember
11	The 6th	Lip Detection Based on	28 September

	International Conference on Information & Communication Technology and System (ICTS 2010)	Normalized RGB Chromaticity Diagram	2010, ITS Surabaya

G. Pengalaman Penulisan Buku dalam 5 Tahun Terakhir

No	Judul Buku	Tahun	Jumlah Halaman	Penerbit
1				
2				
3				

H. Pengalaman Perolehan HKI Dalam 5-10 Tahun Terakhir

No	Judul /Tema HKI	Tahun	Jenis	Nomor P/ID
1				
2				
3				

I. Pengalaman Merumuskan Kebijakan Publik/Rekayasa Sosial Lainnya Dalam 5 Tahun Terakhir.

No	Judul /Tema / Jenis Rekayasa Soaial Lainnya yang Telah Diterapkan	Tahun	Tempat Penerapan	Respon Masyarakat
1				
2				
3				

J. Penghargaan yang Pernah Diraih dalam 10 tahun Terakhir (dari pemerintah, asosiasi atau institusi lainnya)

No	Jenis Penghargaan	Institusi Pemberi Penghargaan	Tahun
1	Peserta Dosen Berprestasi Tingkat Kopertis 7 Jawa Timur	Kopertis 7 Jawa Timur	2013
2	Piagam Penghargaan Sebagai Pembimbing Kontes Robot Indonesia (KRI) 2012	Direktorat Jenderal Pendidikan Tinggi	2012
3	Piagam Penghargaan Sebagai Pembimbing Kompetisi Muatan Roket Indonesia (KOMURINDO) 2012	Direktorat Jenderal Pendidikan Tinggi	2012
4	Piagram Penghargaan Sebagai Pembimbing PIMNAS 2012	Direktorat Jenderal Pendidikan Tinggi	2012
5	Piagam Penghargaan Sebagai Pembimbing Kompetisi	Institut Teknologi Nasional Malang	2011

	Muatan Roket Indonesia (KOMURINDO) 2011 (Lolos Tingkat Nasional)		
6	Piagam Penghargaan Sebagai Pembimbing Kontes Robot Indonesia (KRI) 2011	Direktorat Jenderal Pendidikan Tinggi	2011
7	Piagam Penghargaan Sebagai Pembimbing Kompetisi Roket Indonesia (KORINDO) 2010 (Lolos Tingkat Nasional)	Institut Teknologi Nasional Malang	2010
8	Piagam Penghargaan Sebagai Pembimbing Tim Kontes Robot Indonesia (KRI) 2010	Institut Teknologi Nasional Malang	2010
9	Piagam Penghargaan Sebagai Pembimbing Kompetisi Roket Indonesia (KORINDO) 2010	Direktorat Jenderal Pendidikan Tinggi	2010
10	Piagam Penghargaan Sebagai Pembimbing Kontes Robot Indonesia (KRI) 2010	Direktorat Jenderal Pendidikan Tinggi	2010

Semua data yang saya isikan dan tercantum dalam biodata ini adalah benar dan dapat dipertanggungjawabkan secara hukum. Apabila di kemudian hari terdapat dijumpai ketidaksesuaian dengan kenyataan, saya sanggup menerima resikonya.

Malang, 20 Nopember 2016
Ketua Peneliti,

(Dr. Eng. Aryuanto Soetedjo, ST, MT)
NIP.P. 1030800417

BIODATA ANGGOTA PENELITI

a. Identitas Diri

1	Nama Lengkap (dengangelar)	Dr. Eng. I KomangSomawirata, ST, MT
2	JabatanFungsional	Lektor
3	JabatanStruktural	Sek.Prodi Teknik Elektro S1
4	NIP/NIK?identitaslainnya	103.0100.361
5	NIDN	0717067401
6	TempatdanTanggalLahir	Jembrana, 17 Juni 1974
7	AlamatRumah	Jl. Ontoseno II/73 - Malang
8	NomorTelepon/Faks/HP	0341-367233
9	Alamat Kantor	Jl. Raya Karanglo Karangploso Km 2.
10	NomorTelepon/Faks	0341-417636/0341417634
11	Alamat e-mail	kmgsomawirata@yahoo.com
12	Lulusan yang TelahDihasilkan	S1= orang: S2= orang; S3= orang
13. Mata KuliahygDiampu		1. Pengolahan Citra Digital
		2. Sistem Embedded
		3. ArsitekturSistemKomputer

B. RiwayatPendidikan

	S1	S2	S3
Nama PerguruanTinggi	ITN Malang	Universitas Brawijaya Malang	Kumamoto University
BidangIlmu	T. Elektronika	T. Elektro	Computer Science and Electrical Engineering
TahunMasuk-Lulus	1992 – 1997	2006-2008	2011-2014
JudulSkripsi/Thesis/Desertasi	Perencanaan dan Pembuatan Alat Ukur Jumlah gram perak dalam satu liter larutan perak nitrat	Pembesaran Citra Digital dengan Metode Hybrid	A Study of Image Enlargement MethodBased on Window Kernel
Nama Pembimbing Promotor	Ir. Moefadol	Dr. Ir. Sudaryanto Ir. Julius ,MT	Prof. Keiichi UCHIMURA

C. Pengalaman Penelitian Dalam 5 Tahun Terakhir

(Bukan Skripsi, Tesis maupun Disertasi)

No	Tahun	JudulPenelitian	Pendanaan	
			Sumber*	Jml(JutaRp)
1				
2				
3				

**Tuliskansumberpendanaan : PDM, SKW, Pemula, Fundamental, HibahBersaing, HibahPekerti, HibahPascasarjana, Hikom, Stranas, KerjasamaLuarNegeridanPublikasiInternasional, RAPID, UnggulanStranas, atausumberlainnya.*

D. Pengalaman Pengabdian Kepada Masyarakat Dalam 5 Tahun Terakhir

No	Tahun	JudulPengabdianKepadaMasyarakat	Pendanaan	
			Sumber*	Jml(JutaRp)
1				

**Tuliskansumberpendanaan :Penerapan IPTEKS-SOSBUD, VucerMultitahun, UJI, Sibermasatausumberlainnya.*

E. Pengalaman Penulisan Artikel Ilmiah Dalam Jurnal Dalam 5 Tahun Terakhir

No	JudulArtikelIlmiah	Volume/Nomor/Tahun	Nama Jurnal
1	Image Enlargement Using Pyramid Window Kernel Based on Local Image Data	vol. 9, no. 12, pp. 4863-4874, 2013	International Journal of Innovative Computing , Information and Control (IJICIC)
2	Image Enlargement Based on Proportional Salient Feature	vol. 3, no. 3, pp. 1-6, December 2013	Journal on Computing (JoC)
3			
4			
5			
6			

F. PengalamanPenyampaianMakalahSecara Oral PadaPertemuan/Seminar IlmiahDalam 5 TahunTerakhir.

No	Nama PertemuanIlmiah/Seminar	JudulArtikelIlmiah	WaktudanTempat
1	International conference IEEE-ICSPCC	Image Enlargement Using Adaptive Manipulation Interpolation Kernel Based on Local Image Data	August 2012, Hong Kong
2	International conference ICAST	Image Enlargement with Shift Pixel and Edge Reconstruction based on Local Image Data	Seoul-Korea, October 2012
3	International conference IWAIT	Image Enlargement by Adaptive Kernel with Edge Guide Reconstruction Based on Local Image Data	January 2013, Nagoya-Japan
4	International Conference on Quality Control by Artificial Vision (QCAV)	Nonlinear Interpolation Based on Curve Weighting for Image Up-Scaling	June 2013, Fukuoka
5	International Conference on Intelligent System and Image Processing (ICISIP)	Image Enlargement Based on the Different Scale	September 2013, Kitakyushu-Japan

		Factors for Slice Region	
	International student Conference Advanced Science and Technology (ICAST)	Image Sequences Enlargement Based on Salient Feature Aware	December 2013, Kumamoto University
	International conference International Workshop on Advanced Image Technology (IWAIT)	Image Enlargement in Different Ratio Based on the Non Salient Feature Enlarged	January 2014, Thailan
	IEICE-Technical Report	Image Enlargement in Different Ratio with Edge Region and Salient Feature Aware	February 2014, Hokaido-Japan

G. Pengalaman Penulisan Buku dalam 5 Tahun Terakhir

No	JudulBuku	Tahun	JumlahHalaman	Penerbit
1				
2				
3				

H. Pengalaman Perolehan HKI Dalam 5-10 Tahun Terakhir

No	Judul /Tema HKI	Tahun	Jenis	Nomor P/ID
1				
2				
3				
4				

II. Pengalaman Merumuskan Kebijakan Publik/Rekayasa Sosial Lainnya Dalam 5 Tahun Terakhir.

No	Judul /Tema / JenisRekayasaSoaialLainnya yang TelahDiterapkan	Tahun	TempatPenerapan	ResponMasyarakat
1				
2				
3				
4				

J. Penghargaan yang PernahDiraihdalam 10 tahunTerakhir (daripemerintah, asosiasiatauinstitusilainnya)

No	JenisPenghargaan	InstitusiPemberiPenghargaan	Tahun
1			
2			
3			
4			

5			

Semua data yang saya isikan dan tercantum dalam biodata ini adalah benar dan dapat dipertanggungjawabkan secara hukum. Apabila di kemudian hari terdapat dijumpai ketidaksesuaian dengan kenyataan, saya sanggup menerima resikonya.

Malang, 20 Nopember 3026
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LAMPIRAN 3

DRAFT PATEN

Deskripsi

SISTEM DETEKSI MATA MENGGUNAKAN DUA KAMERA BERBASIS CAHAYA INFRA MERAH

Bidang Teknik Invensi

Invensi ini berkaitan dengan metode deteksi mata menggunakan kamera. Selain kamera, sistem deteksi juga dilengkapi dengan sinar infra merah untuk menerangi wajah. Sistem deteksi memanfaatkan karakteristik lensa mata yang akan memantulkan cahaya infra merah. Perbedaan intensitas pada wajah yang disinari infra merah dengan tidak disinari digunakan oleh kamera untuk mendeteksi lokasi mata.

Latar Belakang Invensi

Sistem deteksi mata banyak digunakan untuk berbagai aplikasi, seperti mendeteksi kelelahan pengemudi, sebagai sistem sensor untuk menggerakan atau mengendalikan peralatan berdasarkan gerakan mata.

Selain itu, deteksi mata sering digunakan sebagai langkah awal untuk mendeteksi wajah dan fitur-fitur lainya. Karena mata mempunyai karakteristik yang unik dibandingkan dengan komponen lain di wajah seperti hidung, mulut atau telinga, maka deteksi mata sering digunakan untuk deteksi awal.

Masalah utama yang harus dipecahkan untuk mendeteksi mata adalah perubahan cahaya yang terjadi di sekililing mata atau wajah. Berbgai metoda sudah dikembangkan untuk mendeksi mata. Salah satu metode yang cukup efektif adalah dengan menggunakan cahaya infra merah untuk menerangi wajah dan membaca image wajah untuk mencari lokasi mata.

Uraian Singkat Invensi

Sistem yang menjadi invensi ini menggunakan dua kamera untuk mendeteksi mata. Satu kamera merupakan kamera biasa, sedangkan satu kamera lainnya merupakan kamera yang dilengkapi dengan filter infra merah. Sebuah modul berisi LED infra merah digunakan untuk menerangi wajah secara bergantian dengan periode tertentu. Sistem komputer pada kedua kamera akan membandingkan dan mengolah image yang diterima untuk mendeteksi lokasi mata di wajah yang disinari cahaya infra merah.

Uraian Singkat Gambar

Untuk mempermudah pemahaman mengenai inti invensi ini, selanjutnya akan diuraikan perwujudan invensi melalui gambar-gambar terlampir.

Gambar 1 adalah konfigurasi peralatan yang digunakan untuk mendeteksi mata.

Uraian Lengkap Invensi

Teknik deteksi mata yang menjadi invensi terdiri dari sistem kamera embeded standar, sistem kamera embeded infra merah, sistem pencahayaan infra merah seperti diperlihatkan pada Gambar 1. Sistem pencahayaan dirancang sehingga memancarkan cahaya infra merah ke wajah dengan periode tertentu. Kedua sistem kamera embeded dapat saling berkomunikasi melalui jaringan Ethernet dengan protokol komunikasi TCP/IP.

Pada sistem ini, kedua kamera menangkap objek yang sama yaitu wajah. Karena wajah disinari cahaya infra merah yang bervariasi secara periodik, maka terdapat perbedaan antara image yang diterima oleh kamera standar dengan kamera infra merah. Hal ini disebabkan karena ketika wajah disinari infra merah, bagian wajah di sekitar mata akan memantulkan cahaya infra merah tersebut. Pantulan cahaya infra merah tersebut hanya dapat ditangkap oleh kamera infra merah.

Karena kedua sistem kamera dapat berkomunikasi, maka gambar yang ditangkap kamera standar dapat dikirimkan ke kamera infra merah. Sistem komputer pada kamera infra merah akan membandingkan kedua gambar tersebut untuk menentukan posisi mata berdasarkan perbedaan intensitas cahaya yang dipantulkan oleh lensa mata ketika disinari cahaya infra merah.

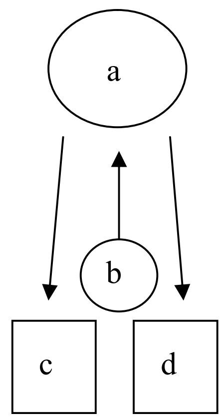
Klaim

1. Dua kamera yang dipasang berdampingan dengan salah satu kamera dilengkapi filter infra merah digunakan untuk mendteksi mata yang disinari cahaya infra merah secara periodik.

Abstrak

SISTEM DETEKSI MATA MENGGUNAKAN DUA KAMERA BERBASIS CAHAYA INFRA MERAH

Invensi ini berkaitan dengan teknik mendeteksi mata menggunakan dua kamera yang dilengkapi dengan pencahayaan infra merah. Teknik deteksi ini mempermudah proses pendeteksian tanpa memerlukan rangkaian elektronika yang komplek jika hanya menggunakan satu kamera. Untuk mendapatkan hasil pendeteksian yang akurat, proses kalibrasi harus dilakukan di saat awal pemasangan kedua kamera pada dudukannya.



a. Wajah
b. Modul pencahayaan infra merah
c. Kamera embeded standar
d. Kamera embeded infra merah

Gambar 1.

LAMPIRAN 4

1. Artikel Ilmiah di Internasional IEEE-ICCSE (The 11th International Conference on Computer Science & Education) 2016 di Nagoya, Jepang, 22 s/d 25 Agustus 2016 : Terindek IEEEXplore/SCOPUS **(*Published*)**

Judul " Implementation of Face Detection and Tracking on A Low Cost Embedded System Using Fusion Technique"

2. Artikel Ilmiah dipublikasikan di *International Journal of Innovative Computing, Information and Control* (*Submitted/under review*)

Judul " Implementation of Eye Detection Using Dual Camera on the Embedded System"

Implementation of Face Detection and Tracking on A Low Cost Embedded System Using Fusion Technique

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***Abstract*—This paper presents the fusion techniques for detecting and tracking the face. The proposed method combines the Viola-Jones method, the CamShift tracking, and the Kalman Filter tracking. The objective is to increase the face detection rate, while reduce the computation cost. The proposed method is implemented on a low cost embedded system based-on the Raspberry Pi module. The experimental results show that the average detection rate of 98.3% is achieved, and it is superior compared to the existing techniques. The proposed system achieves the frame rate of 7.09 fps in the real-time face detection.**

***Index Terms*—Face detection, Viola-Jones, CamShift, Kalman Filter, Raspberry Pi.**

I. INTRODUCTION

Face detection and tracking is an important and popular research topic in the image processing area. An example of the real application that employs the technique is a system for detecting the driver fatigue using the camera systems [1]-[5]. In the system, the driver fatigue is examined from the facial features, such as the eye closure, eye blinking, and mouth openness. The face detection technique is a crucial task for localizing the face area for further process, especially for finding the eyes precisely [1]. Usually, the face tracking is performed after the face detection to improve the performance. By tracking the face, the search area on the next image frame is limited.

Due to the real-time requirement, the driver fatigue detection systems have been implemented using the embedded systems [2]-[5]. The low cost embedded systems using Raspberry Pi module was adopted for real implementation [4], [5].

Many face detection techniques have been proposed by the researchers, namely based on the skin color models [6]-[9] and Haar-like classifier [2]-[5],[8],[10],[11]. In the previous techniques, a face is detected by thresholding the image on a particular color space, such as the normalized RGB [6], the generalized LHS [7], and YCbCr [8],[9]. The latter methods employ the Adaboost learning to detect the face from the Haar-like features called as the Viola-Jones method [12].

In general, the face detection methods based on the Viola-Jones methods offer the better detection rate compared to the skin color model techniques [6[. The computation cost of the Viola-Jones method is relative low. Therefore, this method becomes the most popular method for face detection. However, the method fails to detect the face when the face is occluded by the other objects. To overcome the limitations, the modified version or fusion techniques are proposed by the researchers.

The computation time of face detection from video images could be improved by introducing the tracking technique. By tracking the face in every frame, the search area to find the face in the next frame is localized in the limited area only. Thus it will reduce the computation time.

The CamShift tracking was employed to track the face on the video image once the face was detected [4]. In the system, tracking was used to find the center of face image for judging three conditions, i.e. driver alert condition, drowsiness condition, and out of box condition. The face detection and tracking was implemented on a single board computer equipped with a camera.

The CamShift tracking is a simple and efficient tracking method [13]. It was suitable to track the face for the driver fatigue detection system due to the several reasons [10]: (1) only hands and face are the biggest objects on the captured image; (2) the background of the image is almost stationary. To increase the performance in the varying lighting environment, they proposed to limit the search window of the CamShift method.

Other methods to improve the performance of Camshift tracking are by combining with the Kalman Filter tracking [9], [14]. The Kalman Filter tracks an object by considering the velocity and position of the moving object. It is used to predict the next position of object. The predicted location is then analyzed by the CamShift method for finding the face.

In this paper, we propose a new fusion technique based on the Viola-Jones, the CamShift, and the Kalman Filter techniques for face detection. The main contribution of our proposed method is two folds, i.e.: (1) instead of combine the Viola-Jones and the CamShift techniques in cascade arrangement, we combine them as complimentary or parallel arrangement; (2) the decision output consists of two bounding boxes, namely the detection bounding box and the prediction bounding box. The second contribution could be achieved by the assumption that the proposed face detection is the earlier stage to extract the further features of the face, such as eyes or

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mouth. Our method provides two bounding boxes representing the face that could be further validated by the next stage to find the eyes or mouth.

The proposed technique is simple and fast. Therefore it could be implemented on a low cost Raspberry Pi module equipped with 5 Mega Pixels Raspberry Pi camera to achieve the real-time implementation.

The rest of the paper is organized as follows. Section 2 presents our proposed approach. Section 3 discusses the experimental results. Conclusion is covered in Section 4.

II. Proposed Approach

A. System Overview

The proposed face detection and tracking is illustrated in Fig. 1. The method is divided into two stages: detection stage and tracking stage. In the detection stage, the Viola-Jones face detection technique is combined in parallel with the CamShift tracking. The objective of combining them in parallel fashion is described in the following.

The Viola-Jones method could detect the face effectively. However, it could not detect the occluded face. Further, the detection is affected by the type of classifier which is used during detection. For instance, if the frontal face classifier is used, it could not detect the profile face and vice versa. One solution is by adopting both the frontal face and profile face classifiers. But it consumes the computation time.

The problem of occlusions, in a certain degree, could be solved by employed the CamShift tracking. When a small object occludes the face, the Viola-Jones may fail to detect the face. But the CamShift method could detect the face properly. In some cases, when the skin colored objects distract the face, for instance when a man holds the ears using his hands, then the CamShift method will detect the face wrongly. Fortunately the Viola-Jones could detect the face properly.

Related to the problem of the frontal and profile faces, since both types of the face appear in the same color, they could be detected properly using the CamShift method.

From the above explanation, it is clear that both the Viola-Jones and CamShift techniques are complement each other. To exploit both advantages, it is suggested to combine them in parallel fashion as illustrated in Fig. 1.

The output of detection stage is the detected face region obtained by the Viola Jones or the CamShift techniques. Then the detected region is used by the Kalman Filter tracking to predict the location of the face. The predicted region is assigned as the new search window for searching the face in the next frame.

As stated previously, the proposed approach generates two bounding boxes (gray boxes in Fig. 1) to provide the better face detection as described in the following. When the face is detected by the Viola-Jones method, the detected face region is assigned as the bounding box of detected face. Otherwise, the bounding box is defined from the CamShift tracking. This approach works properly when the conditions as described previously are satisfied.

In some cases, the bounding box defines the wrong face region as explained in the following. Let us assume that in the k^{th} frame, the face is detected by the Viola Jones method. However the Viola-Jones fails to detect the face in the $(k+1)^{th}$ frame. Therefore in the $(k+1)^{th}$ frame, the detected face region is defined by the CamShift method. It could be a wrong position due to the occlusion or lighting changes. Thus the bounding box does not localize the face properly. Fortunately, since the Kalman Filter tracking considers the position and velocity of the face in the previous frame, the predicted region in the $(k+1)^{th}$ frame is still closely to the detected region in kth frame. It leads to propose the approach that generates both bounding boxes, i.e the bounding box defined by the Viola-Jones or the Camshift methods, and the bounding box which is predicted by the Kalman Filter tracking.

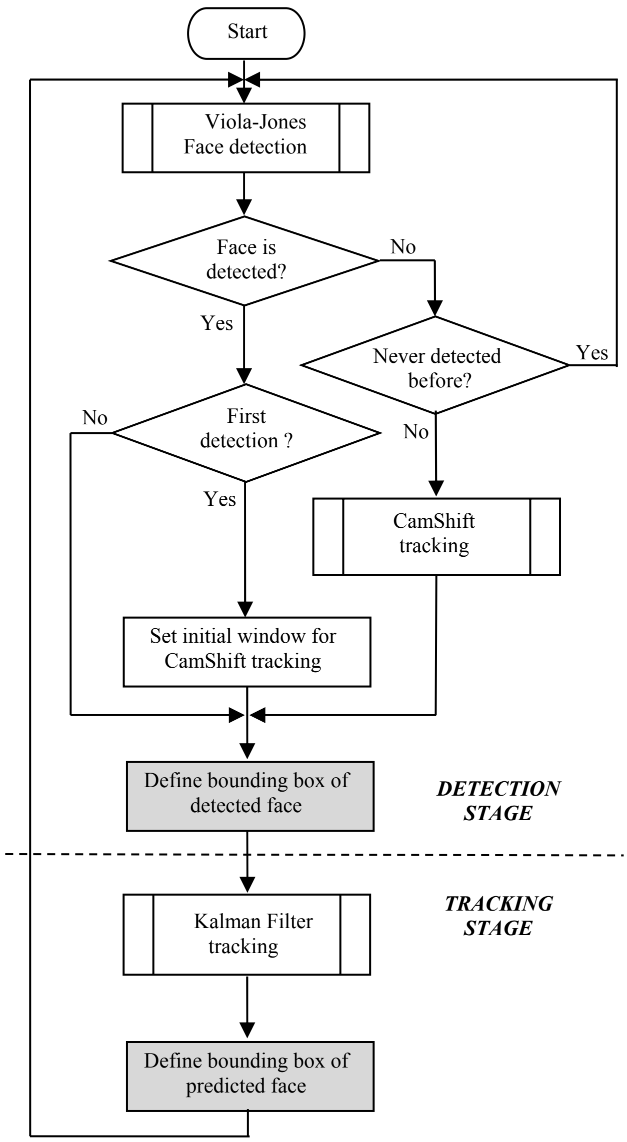


Fig. 1. Proposed face detection and tracking.

B. Face Detection

In the proposed approach, the Viola-Jones method is considered as the primary detection technique, in the sense that in every frame the face is searched by the Viola-Jones first. When it is failed then the CamShift method will take over. The detected face region obtained by the Viola-Jones in the first time is used by the CamShift method as the target tracking in the successive frames.

Since the Viola-Jones method works on a grayscale image, it is required to convert the captured RGB image to the grayscale image. The CamShift tracking starts to run if the Viola-Jones does not detect the face and the face is already detected for the first time. The RGB image is converted to HSV image before it is processed by the CamShift tracking.

C. Face Tracking

Once the bounding box of face is defined, the face is then tracked by the Kalman Filter tracking. The Kalman Filter tracking is used to predict the face in the next frame. This prediction defines the new search window used by the Viola-Jones method to find the face. By limiting the search window, the computation time is reduced.

The parameters of the Kalman Filter tracking consist of the state vector and the measurement vector. In this work, the state vector consists of the *x*-coordinate of the center position of the face, the *y*-coordinate of the center position of the face region, the velocity in the *x*-direction, the velocity in the y-direction, the width of face region, and the height of face region. While the measurement vector consists of the *x*-coordinate of the center position of the face, the *y*-coordinate of the center position of the face region, the width of face region, and the height of face region.

The Kalman Filter tracking is divided into two processes: the time update (prediction) and the measurement update (correction). The measurement update uses the observation data from the bounding box of detected face obtained by the detection stage.

III. Experimental Results

The proposed system is implemented on a low cost embedded system based on the Raspberry Pi 3 Model B with 1.2 GHz 64-bit quad-core ARMv8 CPU and 1 GB RAM. To capture the video image, the Raspberry Pi camera module is employed. The camera module uses the image sensor Omnivision 5647 and supports image resolution of 2592 x 1944 pixels. In the experiment, the image resolution is set to 320 x 240 pixels to speed up the execution time.

The Raspberry Pi runs under the Raspbian operating system. The proposed algorithm is implemented using C++ language and OpenCV library. To evaluate our proposed algorithm, four methods are compared. The first method is the Viola-Jones only method (**VJ**). The second method is the Viola-Jones method and the CamShift tracking (**VJ-CS**), in which the Viola Jones method is used to detect the face for the first time only. Once the face is detected, the rest detection is performed by the CamShift tracking. The third method is the Viola-Jones method and the Kalman Filter tracking (**VJ-KF**), in which the Kalman Filter is used to predict the face region, while the detected face region obtained by the Viola-Jones method is used to update the Kalman Filter. The fourth method is our proposed method (**PM).**

In the experiments, four methods are tested using the same hardware, i.e. the Raspberry Pi and camera module. Since only one camera module is employed, it is difficult to prepare the tested object (human) that is able to repeat the same movement for every method under testing. Instead, the recorded video is employed, in which it is played back to evaluate every method. Therefore the camera module is placed in front of the computer's monitor that playing the tested video. This arrangement ensures that every method captures the same video images. The tested video images are taken from NRC-IIT Facial Video Database [15]. Four video sets are used for evaluating the methods. The image samples of the four video sets are shown in Fig. 2.

Fig. 2. Image samples of four video sets used in the experiments.

For comparing the four methods, two parameters are evaluated, i.e. the true detection rate and the frame rate. The true detection rate is defined as the number of successful detected face images divided by the total number of images. It is noted here that for PM, the detected face image is considered as successful detection if one or both bounding boxes generated by the algorithm are the face images. The frame rate is the number of captured images in one second, and expressed as frame per second (*fps*).

The experimental results of the detection rates and the frame rates are listed in Table 1 and Table 2 respectively. From Table 1, it is obtained that the highest true face detection rate of 98.3% is achieved by our proposed method. While the lowest face detection rate of 67.1% is achieved by the Viola-Jones method and the CamShift tracking. It is clearly shown from the results that our strategy to combine three methods and to generate two bounding boxes works effectively for detecting the face.

The frame rate of our proposed method is 7.09 fps. It is lower compared to the CamShift method. However, by considering both the detection rate and the frame rate, our proposed method is superior compared to the others.

TABLE I. Result of true detection rates

Video No.	Methods			
	VJ	*VJ-CS*	*VJ-KF*	*PM*
1	76.1%	82.4%	79.8%	99.3%
2	100%	81.0%	92.3%	100%
3	87.3%	21.6%	89.0%	93.8%
4	95.8%	83.3%	95.7%	100%
Average	**89.8%**	**67.1%**	**89.2%**	**98.3%**

TABLE II. Result of frame rates

Video No.	Methods			
	VJ	*VJ-CS*	*VJ-KF*	*PM*
1	3.05 fps	14.47 fps	5.56 fps	6.77 fps
2	3.00 fps	13.70 fps	6.55 fps	7.17 fps
3	2.95 fps	14.54 fps	6.87 fps	6.70 fps
4	3.01 fps	14.30 fps	7.24 fps	7.72 fps
Average	**3.00 fps**	**14.25 fps**	**6.56 fps**	**7.09 fps**

Some image sequences of the detection results are shown in Fig. 3. The detection results of **VJ**, **VJ-CS**, **VJ-KF**, and **PM** are shown in Fig. 3(a), Fig. 3(b), Fig. 3(c), and Fig. 3(d) respectively. The image sequences are taken from video set-1 during the time where the man moves his hands to his face then opens the hands over the face. Since the frame rate of every method is different, the image sequences and the frame numbers are not always the same.

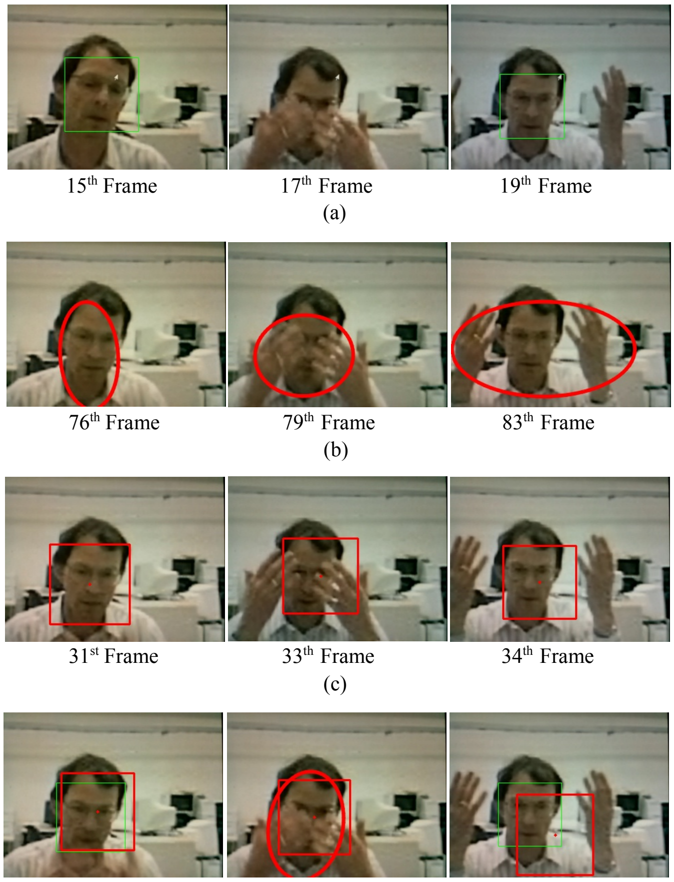
In the figures, the green rectangle represents the bounding box of detected face obtained by the Viola-Jones method. The red rectangle represents the bounding box of predicted face obtained by the Kalman Filter tracking. While the red ellipse represents the detected face obtained by the CamShift method.

From Fig. 3(a), the face is detected in 15th frame. However in 17th frame, the face is occluded by the hand, and the face could not be detected. In 19th frame when the hands move out from the face, the face is detected properly. It is clear that the Viola-Jones method fails to detect the face under occlusions.

From Fig. 3(b), the CamShift method could detect the face in 76th frame. Since the CamShift method works by tracking the color of the face, the neck whose color is similar to the face will be detected as shown in the figure. In 79th frame, the detected face region includes the hands covering the face. In this case, the detected region is still closely to the face region. Thus it is considered as the true face detection. However in 83th frame, the detected region becomes very large following the hand position. It is considered as the false face detection.

From Fig. 3(c), the bounding boxes of predicted face in 31st, 33th, and 34th frames are located properly in the face region. By observing the images, it is clearly shown that the Kalman Filter tracking uses the position and velocity of the face for prediction. In the figures, the man moves his hands but does not move his face. Thus the predicted face is not disturbed by the movement of the hands.

From Fig. 3(d), in 34th frame, both detected and predicted faces are located closely. In 35th frame, since the hands occlude the face, the Viola-Jones method fails to detect the face. Thus the face detection is performed by the CamShift method that yields a larger face region due to the appearing of the hands. Fortunately, the predicted face obtained by the Kalman filter tracking is located on the face region closely. In 38th frame, the predicted face is located wrongly. This wrong tracking is caused by the movement of hands that are now considered in the Kalman Filter tracking due to the fact that in the previous frame (35th frame), the tracked object changes from the face region detected by the Viola-Jones method to the face region detected by the CamShift method. Fortunately, the Viola-Jones method could detect the face properly in 38th frame. Thus according to our strategy, all three images are considered as the true face detection.



15th Frame 17th Frame 19th Frame
(a)
76th Frame 79th Frame 83th Frame
(b)
31st Frame 33th Frame 34th Frame
(c)
34th Frame 35th Frame 38th Frame
(d)

Fig. 3. Some image sequences obtained during the experiments.

IV. Conclusion

The real-time face detection and tracking system is proposed. To achieve the high detection rate, the fusion technique is employed. The method is evaluated and compared to the existing techniques, namely the Viola-Jones method, the combination of the Viola-Jones method and the CamShift method, and the combination of the Viola-Jones method and the Kalman Filter tracking. The detection rate of the proposed method is the best, while the frame rate is the second best.

In future, the method will be extended to improve the execution time. Further, the fusion techniques could be explored more to increase the detection efficiency.

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Implementation of Eye Detection Using Dual Camera on the Embedded System

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ABSTRACT. *This paper presents an implementation of eye detection on the embedded system. Two camera systems based-on the low cost Raspberry Pi modules are employed. To speed up the process, the proposed system implements the face detection technique and the eye detection technique on two camera systems separately. The face detection module detects the bounding box of face and sends the coordinates to the eye detection module via a serial communication. In the eye detection module, the eyes are searched on a limited area defined by the face's bounding box. The popular Viola-Jones object detection is employed on both face and eye detection modules. Several approaches for resizing the eye search area are introduced and validated in the experiments. Two best results determined by the true detection rate and the frame rate are obtained. In the first, the true detection rate of 0.889 and the frame rate of 6.061 fps is achieved. Secondly, the true detection rate of 0.818 and the frame rate of 11.594 fps is achieved.*
Keywords: Face detection, Eye Detection, Viola-Jones, Raspberry Pi, Dual camera

1. **Introduction.** The camera-based systems play significant roles in the recent trend in technology. Many applications adopt the vision systems for replacing the conventional techniques or developing the new techniques. One of them is an application for detecting the driver fatigue as proposed in [1-12]. A typical method developed in [1-8] is by analyzing the eye state (eye is open or close). The combination of eye state and other features are also commonly used, such as the head gesture [9], and the yawning [10-12].

Several methods are employed to detect the eye such as the Haar classifiers method, which is sometimes called as the Viola-Jones method (VJ) [1-4,8,10,14,15], using infrared camera [5,6], the Hough transform for detecting the circle [7], the color segmentation [12,16], and the projection technique [17].

The VJ is the most popular technique for detecting the objects. The technique relies on the integral image, the Adaboost learning algorithm, and the cascade mechanism [18]. In the work of [2], the VJ was employed to extract the eye region from the face image. Then the shape of eye was calculated to determine the open or close eye. The optimal sampling ratio and the minimal object size of the eye detection using the VJ was discussed in [3].To limit the search area, the VJ was applied on a defined region based on the face area [4].

The VJ sometimes fails to detect eyes due the similar characteristic of other objects on the face such as eyebrows, nostrils, and mouth. To overcome this problem, the geometric features of the eye were calculated after the detection process [10]. The other method is by introducing the new rectangle features [14].

Another approach to detect eye is using infrared camera. The basic principle of the technique is that the eye (pupil) reflects the infrared light to produce the bright pupil effect. The drawback of this method is that the infrared illuminator should be placed along the center of camera axis [5]. The practical implementation is by placing a few infrared illuminators on the concentric ring surrounds the camera. The method proposed in [6] utilized the infrared illuminator in the different way. The infrared illuminator was used to make the brighter face image compared to the background. The eye was detected by comparing the difference image obtaining by subtracting two succeeding frames.

Since the iris of eye forms the circle, the shape detection method using the Hough transform was employed to detect the eye [7]. The Hough transform was applied on the edge image of the search region defined on the face. The eye state is determined by measuring the intersection of the edge image and the obtained circle image.

The eye-map calculated from the chrominance and luminance components of YCbCr color space was constructed to detect the eye [12]. The open eye is determined when the area of binary image obtained from the eye-map is larger than a threshold. The white color segmentation based on the normalized RGB chromaticity diagram was employed to detect the while sclera of eye [16]. Then the ellipse fitting method was applied to obtain the precise boundary of eye.

The position of eye could be found by projecting the edge image of the face [17]. The complexity feature which is calculated based on the numbers of edges and areas was used to find the accurate face location.

To be implemented in the real implementation, the algorithm of eye detection system should be fast enough. Moreover for the driver fatigue detection system, it should be implemented on the embedded platform for easy installation on the car. Almost all the works described previously implemented the algorithms using the USB camera or Webcam and personal computer or laptop. Only a few of them implemented it on the embedded platform based on the Tiny4412 [3].

This paper deals with the real-time implementation of eye detection on the embedded system. To speed up the computation time, two embedded camera system based on the Raspberry Pi single board computer is developed. It takes advantages of the low cost and the small size of the Raspberry Pi module compared to the previous work of [3]. Similar to the previous works, our method performs the face detection first to limit the eye search area. However the face detection and the eye detection are executed separately on two camera systems. The VJ is employed for both detection methods. Since the methods are executed on the different processor simultaneously, the overall computation time for detecting the eye could be decreased.

The rest of paper is organized as follows. Section 2 describes the proposed system. It covers the method and implementation of the system. Section 3 presents the experimental results. Conclusion is covered in Section 4.

2. **Proposed System.**

2.1. **System Overview.** In the eye detection process, it is common to limit the eye search area to increase the eye detection speed and accuracy. The search area is defined based on the detected face area. Thus the face detection process is carried out first before the eye detection. Unfortunately, it contributes most of the computational burden.

To overcome the problem, we propose the dual camera system, in which the face detection and the eye detection run separately. The system architecture is illustrated in Figure 1, where the face detection runs on the face detection module, while the eye detection runs on the eye detection module. The system consists of five components: a face detection processing unit, an eye detection processing unit, a face detection camera unit, an eye detection camera unit, and a camera frame. Two camera units are attached side by side on the camera frame.

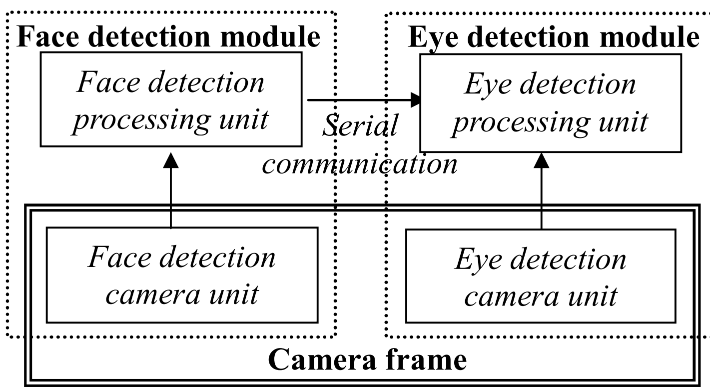

FIGURE 1. Configuration of dual camera system.

A serial communication is employed to communicate the face detection processing unit and the eye detection processing unit. It is a simple communication for sending the coordinate of detected face from the face detection module to the eye detection module. Since two camera units are arranged in a fixed position on the camera frame, the coordinate transformation between both cameras could be calculated easily.

The proposed system works as follows. Both face detection camera and eye detection camera capture the image continuously. At first the face detection module searches the face from captured image. Once the face is detected, it sends the coordinates of face's bounding box to the eye detection module. Upon receiving the coordinates, the eye detection module crops the captured image on the face area and starts the eye detection process.

2.2. **Detection Method.**

2.2.1. *Transformation of camera's coordinate.* As described previously, the eye detection process is carried out on the eye detection module. The module gets the coordinate of detected face from the face detection module. The eye search area is bounded on the face area only. This approach decreases the eye detection time effectively. However, it requires two image processing modules to be implemented. Fortunately, we could employ the low cost image processing hardware to fulfill this requirement as described in the next section.

As shown in Figure 1, since both camera units are installed on a planar frame side by side, the face coordinates detected by the face detection module are different with the one detected by the eye detection module. To transform the face coordinates on the face detection module into the eye detection module, we adopt a simple practical method as follows.

It is noted here that the proposed system is intended to detect the driver eye for calculating the driver fatigue. It is also assumed that the modules could be installed on a proper position in such way that only one face (the driver) is appeared on the camera. Figure 2 depicts the model of dual camera system, where I_{fm} and I_{em} are the image planes of face detection and eye detection cameras respectively, W_{obj} is the line denotes the width of face object, O_{fm} and O_{em} are the optical center of face detection and eye detection cameras respectively, TL and TR are the points on left side and right side of face object respectively, tl_{fm} and tl_{em} are the image points of TL on face detection and eye detection cameras respectively, tr_{fm} and tr_{em} are the image points of TR on face detection and eye detection cameras respectively.

The installation of camera modules should ensure that the image points of face object lie inside the image planes I_{fm} and I_{em}. From the model shown in Figure 2 and the cameras arrangement in Figure 1, it is clear that the coordinate transformation between the image points on the face detection and eye detection cameras involves the displacement in x-coordinate only. The displacement value is found experimentally in the calibration process that is done once during the hardware installation.

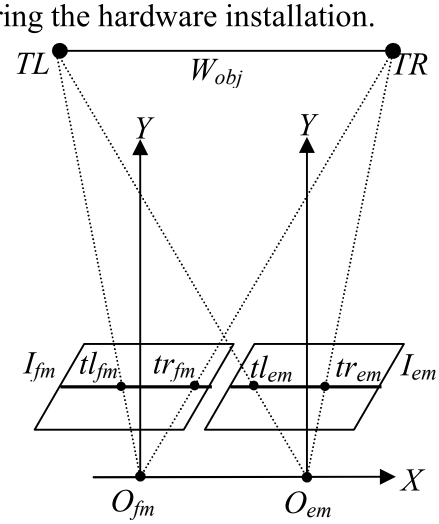

FIGURE 2. Dual camera model.

The calibration process is done by implementing the face detection algorithm on both face detection and eye detection modules. Then run them simultaneously to detect the face. Since both modules use the same hardware, the detected face will be the same, in the sense that the bounding box of detected face obtained by the face detection module occupies the same area with the one obtained by the eye detection module. However the coordinates of the bounding box on each module are different. By subtracting the x-coordinate of the bounding box (could be one point on the corner of bounding box) on the face detection module by the one on the eye detection module, the displacement value could be obtained.

2.2.2. *Eye detection.* The face detection module is employed to provide the bounding box of face to the eye detection module. The bounding box is defined by the coordinates of four corners. The coordinates are sent out when the face is detected. This bounding box is used by the eye detection module to determine the eye search area.

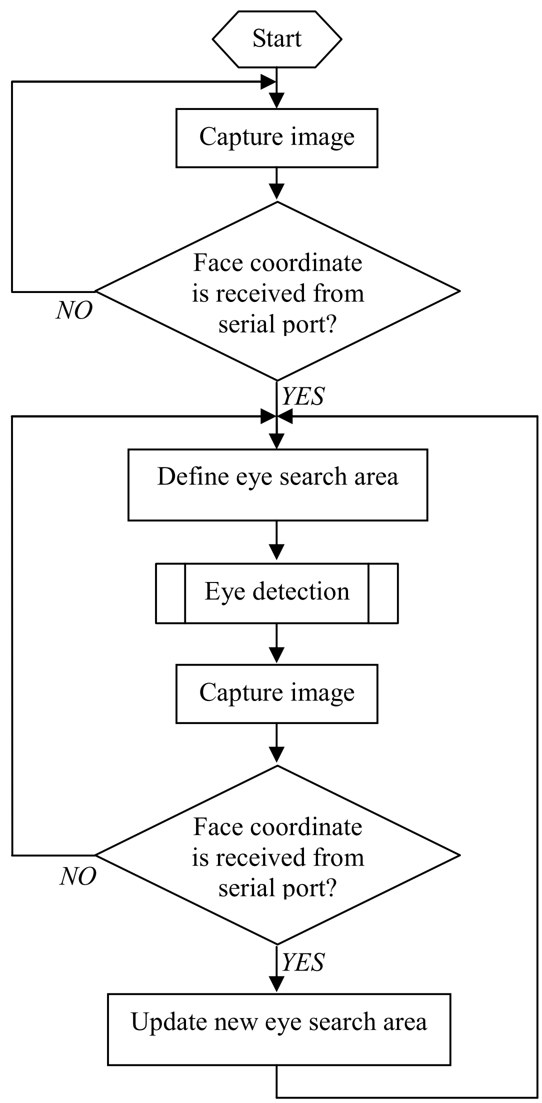

FIGURE 3. Eye detection method.

As stated previously that the eye detection conducted in the research deals with the fatigue detection, in which it should distinguish the open and close eye for determining the fatigue. Thus the eye detection discussed here represents the open eye detection. It means that when the eye is closed, the algorithm should not detect it as the eye.

The proposed eye detection method is depicted in Figure 3. The algorithm starts when it receives the coordinates of face's bounding box from the face detection module. Once the bounding box is received, it is used to define the eye search area until the new update is received. The eye detection module could execute the eye detection algorithm freely, without having to wait the data (coordinates of face's bounding box) sent by the face detection module. Therefore the computation time of eye detection module could be decreased, and it is not affected by the computation time of face detection module. This approach works well when the human face does not move rapidly.

2.2.3. *Image resizing.* Our proposed method employs the VJ for detecting face and eye on the face detection and the eye detection modules respectively. Since the performance of the VJ is affected by image size as discussed in [3], our goal is to find the optimal value of image size (search area) as discussed in the following.

The relationship among image rescaling, frame rate and detection rate is discussed in [3]. Rescaling image to a smaller one increases the frame rate. However, it reduces the detection rate accordingly. In addition, the optimal scale factor should consider the minimum object size allowed by the VJ, which is usually set to 20 x 20 pixels, or 30 x 30 pixels.

As stated earlier, the computation time of face detection module does not affect the computation time of eye detection module. However when the face detection process is slow, the coordinates of bounding box sent to the eye detection module are updated slowly. It may lead to the wrong eye detection, especially when the face moves rapidly. In this work, we deal with the slow or moderate face movement, thus the problem could be minimized.

In the eye detection module, the VJ is applied on the search area which is defined by the face's bounding box. The image resizing discussed in the following refers to this search area, not the whole captured image. We propose three methods for resizing the search area. In the first method, search area is defined according to (1) to (4), where *sa_top*, *sa_left*, *sa_width*, and *sa_height* are the top border, the left border, the width, and the height of search area respectively; *fb_top, fb_left, fb_width,* and *fb_height* are the top border, the left border, the width, and the height of face's bounding box. This method considers that the eye is located on two thirds upper part of the face as expressed by (4).

$$sa\_top = fb\_top \quad (1)$$

$$sa\_left = fb\_left \quad (2)$$

$$sa\_width = fb\_width \quad (3)$$

$$sa\_height = fb\_height \times 0.67 \quad (4)$$

In the second method, the search area is defined in the similar way, but it is rescaled down so that the new search area has a fixed height. It is expressed by (5) to (8), where the height of search area (*sa_height*) is defined in advance; β is the scaling factor, which is calculated during detection process. In this method, *sa_height* is defined by considering the minimum eye size allowed by the VJ.

$$\beta = sa\_height/(fb\_height \times 0.67) \quad (5)$$
$$sa\_width = fb\_width \times \beta \quad (6)$$
$$sa\_top = fb\_top \times \beta \quad (7)$$
$$sa\_left = fb\_left \times \beta \quad (8)$$

The third method limits the search area on a narrow size defined by (9) to (12), where α is a scaling factor ($\alpha < 1$), which is defined in advance. The aim of the method is to reduce the execution time significantly by reducing the search area in the limited size only, and by rescaling down the image.

$$sa\_width = fb\_width \times \alpha \quad (9)$$
$$sa\_height = 0.33 \times fb\_height \times \alpha \quad (10)$$
$$sa\_top = (fb\_top + (0.25 \times fb\_height)) \times \alpha \quad (11)$$
$$sa\_left = fb\_left \times \alpha \quad (12)$$

2.3. **Implementation.**

2.3.1. *Hardware implementation*. The proposed method is implemented on the low cost embedded camera systems, namely the Raspberry Pi [19] based camera systems. Both the face detection processing unit and the eye detection processing unit are implemented on the Raspberry Pi Type 3 Model B modules. The module has a 1.2GHz 64-bit quad-core ARMv8 CPU, 1GB RAM, 40 GPIO pins, Camera Serial Interface (CSI), microSD card storage. The price of each module is about US$ 35. The board dimension is 85.6mm x 56mm x 21mm.

Both the face detection camera unit and the eye detection camera unit are implemented on the Raspberry Pi camera. The camera has the OmniVision OV5647 image sensor, the sensor resolution of 2592 x 1944 pixels, the horizontal field of view of 53.50^0, the vertical field of view of 41.41^0. The camera dimension is 25mm x 24mm x 9mm. The price of each camera module is about US$ 25. The camera is connected to the Raspberry Pi module via the CSI connector. From a few experiments, and refers to the previous work proposed in [8], the resolution of 320 x 240 pixels is chosen as the optimal resolution used in this experiment. The prototype of hardware system is depicted in Figure 4.

The serial communication between the face detection module and the eye detection module is performed via the UART (Universal asynchronous receiver/transmitter) on the GPIO (General purpose input/output) pins. The communication parameters are:

- Data bits: 8 bits,
- Baud rate: 9600 bps,

- Parity: none,
- Stop bits: 1 bit,
- Flow control: none.

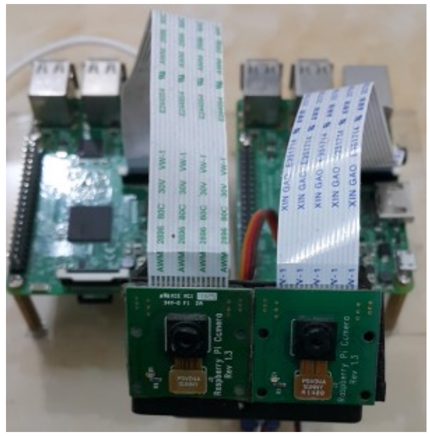

FIGURE 4. Prototype of hardware system.

2.3.2. *Software implementation*. The Raspberry Pi used in the research runs on the Raspbian operating system [20]. It is a Debian-based operating system for the Raspberry Pi. The proposed algorithm is implemented using C++. The OpenCV library [21] is adopted to handle the image processing tasks.

The OpenCV provides useful libraries used in the experiments, such as capturing the image from the camera, manipulating the image, and performing the VJ method for face detection and eye detection. The important parameters used in the implementation of the VJ method are:

- Haar classifier: the xml file of the Haar classifier for object detection. The classifiers [22]: "haarcascade_frontalface_alt.xml" and "haarcascade_eye_tree_eyeglasses.xml" are employed for the face detection and the eye detection respectively.
- Scale factor: the scale of image resizing each image scale. The default of 1.1 is used in the experiments.
- Minimum size: the minimum size of object allowed by the algorithm. In the experiments, the minimum sizes of 50 x 50 pixels and 20 x 20 pixels are used for the face detection and the eye detection respectively.

The serial communication protocol between the face detection module and the eye detection module is implemented in a simple fashion. The data flows in one direction only, i.e. from the face detection module to the eye detection module. The data consists of 13 bytes in ASCII format. The first byte is the character "S" for indicating the start of data packet. The 2^{nd}, 3^{rd}, and 4^{th} bytes are three digits of the *x*-coordinate of face's bounding box; the 5^{th}, 6^{th}, 7^{th} bytes are three digits of the *y*-coordinate of face's bounding box; the 8^{th}, 9^{th}, 10^{th} bytes are three digits of the width of face's bounding box; the 11^{th}, 12^{th}, 13^{th} bytes are the three digits of the height of face's bounding box.

3. **Experimental Results.** To validate our methods, three approaches are evaluated. The first approach (*Approach-1*) called as the **OCam** is the common or existing method, where the face detection and the eye detection are carried out on one camera system. At first, the face detection is employed to find the face's bounding box. Then the eye detection is applied on the bounding box. In this scenario, the camera resolution is set to 320 x 240 pixels.

The second and third approaches (*Approach-2* and *Approach-3*) deal with the proposed dual camera system. Both approaches differ in the face detection module, where the camera resolution of 320 x 240 pixels is used in *Approach-2*, while the camera resolution of 160 x 120 pixels is used in *Approach-3*. In both approaches, the eye detection modules use the same camera resolution, i.e. 320 x 240 pixels.

In *Approach-2* and *Approach-3*, three methods described in Section 2.2.3 are evaluated. The fixed height (*sa_height*) in (5) is set to 80 pixels, and α is set to 0.875 in (9) to (12). To simplify the explanation, they are called as **DCamA1**, **DCamA2**, and **DCamA3** for the first, second, and third methods of *Approach-2* respectively. While for *Approach-3*, they are called as **DCamB1**, **DCamB2**, and **DCamB3** respectively.

To provide a fair comparison, the object (and the movement) captured by the camera should be the same for all approaches. Unfortunately, it is difficult to ask the peoples for acting with the same pose and movement repeatedly. Therefore, we record them in the video and play back the video on the computer monitor. The camera system under test is placed in front of the computer monitor. Using this arrangement, it is ensured that all approaches capture the same image during testing.

There are seven video images used in the experiments as depicted in Figure 5. The images in Figure 5, from left to right, illustrate the sample image frames of tested Video-1 to Video-7 respectively. In all videos, the peoples open and close their eyes in a certain interval. The faces do not move (or only move slightly) in Video-1, Video-4, Video-5, Video-6, and Video-7. While in Video-2 and Video-3, the faces move from left to right and front to back.

FIGURE 5. Sample images of the tested videos.

During experiments, three parameters are evaluated, i.e. a) true detection rate (**TD**), b) false detection rate (**FD**), and c) frame rate (**FR**). The true detection rate is defined as the numbers of eyes (open eyes) detected by the algorithm divided by the numbers of eyes (open eyes) counted manually in the video. The false detection rate is defined as the numbers of non-eye objects (including close eyes) detected by the algorithm divided by the numbers of eyes (open eyes) counted manually in the video. The frame rate is the total numbers of processed image frames of the video in one second, and expressed in fps (frame per second). It is noted here that the number of eye in an image is considered as one.

Therefore the eye is detected when only one eye (left or right) is detected, or both eyes are detected. The experimental results of three approaches, i.e. **OCam**, **DCamA1/A2/A3**, and **DCamB1/B2/B3** using seven tested videos are discussed in the following.

3.1. **One Camera System.** The detection results of one camera system (**OCam**) are listed in Table 1. The results show that the average true detection rate is high, while the average false detection rate is very low. It shows that the VJ could detect the eyes effectively. However, since the system (one Raspberry Pi) should compute both the face detection and the eye detection, the frame rate is very low, about 2.562 fps.

TABLE 1. Detection results of the one camera system: **OCam**

Video No.	TD	FD	FR (fps)
Video-1	0.864	0	2.599
Video-2	0.827	0.013	2.762
Video-3	0.841	0.182	2.417
Video-4	0.792	0	2.780
Video-5	0.826	0	2.5
Video-6	0.952	0	2.552
Video-7	0.9	0	2.321
Average	**0.857**	**0.028**	**2.562**

FIGURE 6. Typical images of detection results in the **OCam.**

The typical image detection results are depicted in Figure 6, where images in the first, second, and third rows represent the true detection, no detection, and the false detection respectively. In the figures, the green rectangle represents the detected face in the current frame, the blue rectangle represents the detected face in the previous frame, while the red circle represents the detected eye.

As shown in the first row, both eyes are detected successfully. However the eyes are not detected as shown in the second row. From the observation it is found that in a few transition conditions from the open state to the eye state or vice versa, the eyes are sometimes failed to be detected. In the third row, the nose and the close eyes are detected. Thus it produces the false detection.

3.2. **Dual Camera System.** The detection results of dual camera system are given in Table 2, 3, and 4, where the results of **DCamA1** and **DCamB1** (first method of *Approach-2* and *Approach-3*) are listed in Table 2, the results of **DCamA2** and **DCamB2** (second method of *Approach-2* and *Approach-3*) are listed in Table 3, and the results of **DCamA3** and **DCamB3** (third method of *Approach-2* and *Approach-3*) are listed in Table 4.

It is obtained from Table 2 and 3 that the average true detection rates of dual camera system (first method and second method) are little bit higher than the one of single camera system. However the average frame rates of dual camera system (first method and second method) are about two times and three times faster than single camera system respectively. From Table 4, it is obtained that the average frame rate of dual camera system (third method) is almost five times faster than the single camera system, but the average true detection rates is rather lower than the single camera system.

The results show that the proposed dual camera systems achieve the faster computation time significantly compared to the single camera system, while the true detection rates do not differ significantly. The false detection rates for all approaches are very low and almost the same.

TABLE 2. Detection results of **DCamA1** and **DCamB1**

Video No.	**TD**		**FD**		**FR (fps)**	
	DCamA1	**DCamB1**	**DCamA1**	**DCamB1**	**DCamA1**	**DCamB1**
Video-1	0.750	0.789	0	0.000	4.771	4.554
Video-2	0.894	0.866	0	0.000	6.976	6.189
Video-3	0.816	0.461	0.053	0.029	4.174	4.837
Video-4	0.970	1.000	0.152	0.188	3.684	3.714
Video-5	0.850	0.800	0.075	0.050	4.848	4.618
Video-6	0.972	0.969	0.028	0.000	4.087	4.091
Video-7	0.975	1.000	0.025	0.000	3.723	3.360
Average	**0.890**	**0.841**	**0.047**	**0.038**	**4.609**	**4.481**

TABLE 3. Detection results of **DCamA2** and **DCamB2**

Video No.	TD		FD		FR (fps)	
	DCamA2	DCamB2	DCamA2	DCamB2	DCamA2	DCamB2
Video-1	0.646	0.667	0.000	0.000	6.078	6.024
Video-2	0.929	0.908	0.000	0.000	6.228	6.306
Video-3	0.845	0.791	0.036	0.045	6.337	6.428
Video-4	1.000	0.980	0.059	0.100	5.841	5.771
Video-5	0.918	0.827	0.020	0.019	6.471	6.517
Video-6	0.957	1.000	0.000	0.021	5.439	5.439
Video-7	0.924	0.970	0.000	0.000	6.029	5.980
Average	**0.889**	**0.877**	**0.017**	**0.027**	**6.061**	**6.066**

TABLE 4. Detection results of **DCamA3** and **DCamB3**

Video No.	TD		FD		FR (fps)	
	DCamA3	DCamB3	DCamA3	DCamB3	DCamA3	DCamB3
Video-1	0.747	0.526	0.000	0.000	12.149	11.592
Video-2	0.488	0.593	0.000	0.000	16.686	14.009
Video-3	0.680	0.803	0.051	0.014	10.938	10.522
Video-4	0.881	0.847	0.000	0.000	9.991	9.936
Video-5	0.952	0.912	0.036	0.000	11.312	10.720
Video-6	0.976	0.989	0.000	0.000	11.434	11.536
Video-7	1.000	0.989	0.000	0.000	8.651	9.026
Average	**0.818**	**0.809**	**0.012**	**0.02**	**11.594**	**11.049**

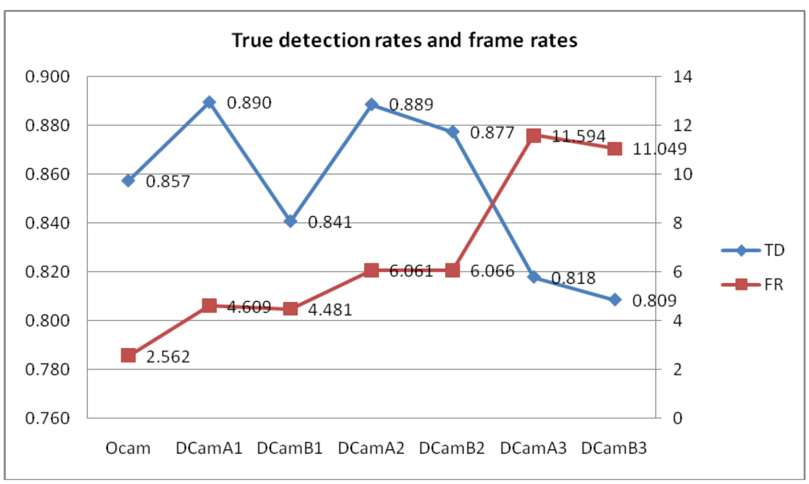

FIGURE 7. Comparison of true detection rates and frame rates.

The comparison of true detection rates and frame rates for all approaches/methods are shown in Figure 7. Observing the figure, **DCamA2** and **DCamA3** could be selected as two best methods, where if the fast frame rate becomes the main criteria, then the best method is **DCamA3**. Meanwhile if the moderate frame rate is sufficient, then the best method is **DCamA2**.

It is observed from the experiments that decreasing the true detection rates in *Approaches-3* is caused by narrowing the search area as expressed in (10). In some images, especially for moving face, it yields the wrong search area. Further it could be understood by comparing **DCamA3** and **DCamB3** for moving faces (Video-2 and Video-3) as given in Table 4. From the table, it is obtained that the true detection rates of **DCamB3** are higher than **DCamA3**. It means that by speeding up the face detection module (*Approach-3***: DCamB3**), the search area defined in the eye detection module locates the eyes better than *Approach-2*: **DCamA3**, especially in the case of moving face.

The impact of *Approach-3* is also observed from the result in Table 2 for moving face (Video-2), where the true detection rate of *Approach-2*: **DCamA1** is 0.816, while the one of *Approach-3*: **DCamB1** is 0.461. In this case, the frame rate of face detection module in *Approach-3* increases (higher than *Approach-2*), while the frame rate of eye detection modules in both approaches are almost similar. Since the face moves in some large movements, the face's coordinate sent by the face detection module in *Approach-3* may yield the wrong eye search area defined by the eye detection module, due to the slower frame rate of the eye detection module. Therefore the eyes could not be detected properly as indicated by decreasing the true detection rate.

The strategies to increase the frame rate (by resizing the search area) work as expected. Resizing image of the second method (Table 3) increases the average frame rate to 6.066 fps, while the average true detection rate is almost similar to the first method (dual camera: no resizing image). Resizing and narrowing the search area of the third method (Table 4) could improve the average frame rate to 11.594 fps, however the average true detection rate reduces to 0.818.

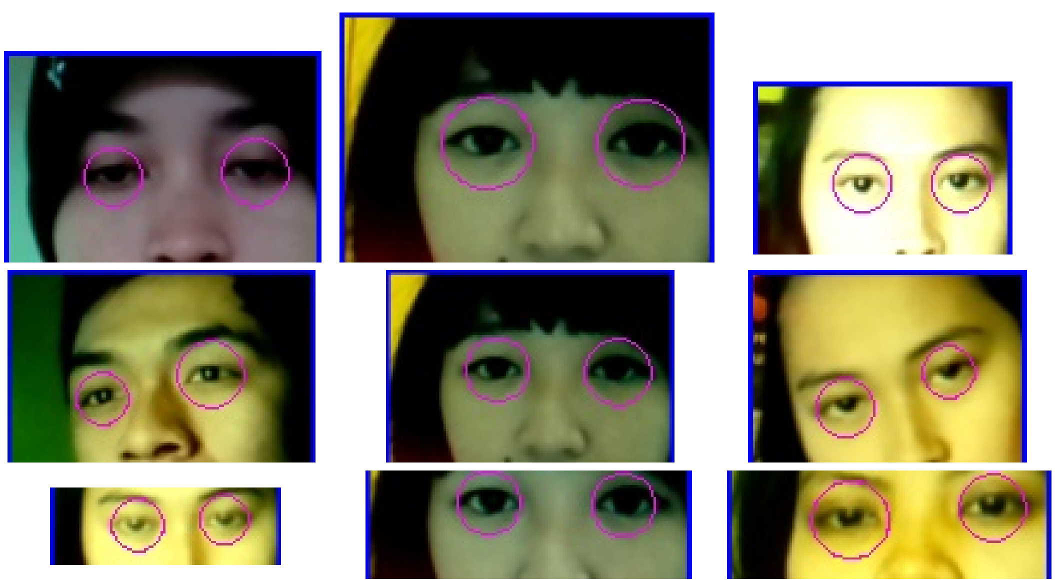

FIGURE 8. Typical images of true detection results in the dual camera system**.**

The typical images of true eye detection results of the dual camera system are shown in Figure 8, where images in the first, second, and third rows represent the results of the first method (**DCamA1/B1**), the second method (**DCamA2/B2**), and the third method (**DCamA3/B3**) respectively. As shown in the figure, the images are resized proportionally to indicate the resizing methods accordingly. The sizes of images in the first row follow the sizes of detected faces. In the second row, the heights of images are the same, i.e. 80 pixels. In the third row, the sizes of images are limited on the surrounding area of eye location.

4. **Conclusions.** The implementation of eye detection using dual camera system has been presented in the paper. The proposed method aims to increase the computation speed of the VJ detection method by processing the face detection and the eye detection in parallel fashion on the dual camera system. The effectiveness of proposed method has been validated in the experiments, where the frame rate of 11.594 and the true detection rate of 0.818 could be achieved. The results suggest that the method could be implemented for the real-time application. In future, the system will be extended to implement the tracking systems and the other object detection techniques.

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