Klaus WÜST, Michael KREUTZER
UNIVERSITY OF APPLIED SCIENCES MITTELHESSEN (THM)
Wiesenstraße 14, 35 390 Gießen, Deutschland

Optical gesture detection using efficient reduction of ambient light interference

Prof. Dr Klaus WÜST

Born 1955, study of physics at the Justus-Liebig-Universität in Gießen, Germany. From 1986 to 1994 developer of software for measurement technology in industrial companies, since 1994 with the Technische Hochschule Mittelhessen (university of applied sciences). The fields of work are microprocessors, robotics and programming.

e-mail: Klaus.wuest@mni.thm.de

M.Sc. Michael KREUTZER

Born 1977, study of computer science at the Technische Hochschule Mittelhessen (university of applied sciences). Since 2007 scientific staff at the Institute of Technique and Computer science at the same university and since 2011 working on his doctoral thesis on the subject "Computerised calibration of technical systems". The fields of work are computer vision and robotics.

e-mail: michael.kreutzer@mni.thm.de

Abstract

For the detection of gestures there can be used low cost circuits that simply receive reflected infrared LED-light from objects moving within the sensitive area. But the interference of ambient light must be reduced significantly for practical applications. We present a design with a compensation LED in a control loop giving the possibility of eliminating the ambient light. This functional principle is realized in a single chip and we present some good results gained with this chip.

Keywords: gesture detection, ambient light elimination, HALIOS.

Optyczna detekcja gestów z redukcją zakłócającego wpływu otaczającego światła

Streszczenie

Rozpoznawanie ludzkich gestów w celu wykorzystania ich do sterowania urządzeniami elektronicznymi jest tematem aktualnym o szerokim obszarze zastosowań obejmującym między innymi urządzenia elektroniki użytkowej, technikę motoryzacyjną i robotykę. W wielu zastosowaniach do rozpoznawania gestów mogą być stosowane stosunkowo proste i tanie systemy optoelektroniczne wykorzystujące odbite od obiektów promieniowanie podczerwone emitowane przez diody LED. Jednym z istotnych czynników zakłócających poprawną pracę takich systemów jest promieniowanie świetlne pochodzące od otoczenia. W pracy przedstawiono projekt układu z zastosowanie kompensacyjnej diody LED eliminujący skutecznie wpływ zakłócającego działania otaczającego światła. Przedstawioną koncepcję eliminacji wpływu otaczającego światła zilustrowano praktycznym przykładem bazującym na wykorzystaniu komercyjnego specjalizowanego układu scalonego. Przedstawiono analizę działania zaproponowanego rozwiązania oraz wstępne wyniki badań modelu fizycznego.

Słowa kluczowe: rozpoznawanie gestów, eliminacja otaczającego światła, HALIOS.

1. Introduction

Gesture and motion recognition is currently a topic of interest with the aim of controlling electronic devices with human gestures or motions. The fields of application are devices of the consumer electronics, cars, lights, robot arms, computers and recently even industrial controls. For instance a good detection of the movement of pedestrians can be used for an intelligent controlling of e.g. doors, lamps and escalators thus saving energy. A lot of work has been done in this field recently. If the gestures are done with the whole human body, a larger equipment is needed. If the gesture is done only by one hand, low cost devices can be used and introduced into mass production.

For the detection of gestures and motions we need systems that can gain 3D-data from the received signals. We find a lot of different systems with very different functional principles. These systems are mainly divided into active and passive systems. In active systems the gesturing people have to wear some active devices like special suits, gloves or finger rings equipped with a LED, an acceleration sensor, a magnetic field or a even a camera (e.g. "Eye on finger"). The signals from these parts are processed by external units and 3D-coordinates of the emitter are calculated. This works well but the equipment is large and not very convenient in practical use.

In passive systems we do not need wearable devices because they work with the detection of reflected light or reflected ultrasound from the peoples body. We find systems based on stereo cameras which need a powerful and fast image processing. Other systems use laserlight scanning of objects and calculating the 3D-surface by means of triangulation.

The laserline can be replaced by a random pattern of IR-Light which leads also to good results, for instance in the primesense sensor build in the microsoft kinect sensor.

For low cost systems finally we can simply use assemblies of infrared emitting LEDs and receiving photo diodes in an appropriate geometrical configuration. If the LEDs are operated, we get some reflected light from the object we want to detect, for instance a human hand. This method is simple and cheap. One of the main problems of these systems is the influence of the ambient light which can be very intense. One possible solution of this problem is the use of receiver devices with a very small bandwidth of spectral sensitivity [1, 2]. Operating the emitter LEDs inside this spectral band reduces the disturbing influence of ambient light, but for many application this reduction is not sufficient. Other systems provide a simple measurement of ambient light using a second receiver diode which is sensitive mainly to infrared light [3].

In this paper we describe a way of a very efficient reduction of the influence of ambient light by means of a compensation LED operated in a control loop. The receiver diode receives the light from the reflecting object, from the compensation LED and all the time ambient light. If we switch between operating the transmitter LED and the compensation LED and subtract both signals we eliminate the influence of the ambient light and this is the main point of this method.

2. The elimination of ambient light with a compensation LED

We see the schematic of an assembly containing one Transmitter LED emitting the infrared light, one compensation LED and the receiver photo diode in Fig.1.

The optical power of the light from the transmitter LED at the receiver photo diode is

$$L_T = I_T \eta_T O_T \qquad (1)$$

where I_T is the current of the transmitter LED, η_T is the efficiency of the LED and O_T is a factor representing the part of the emitted transmitter light reaching the receiver diode. That means O_T contains all the properties of the optical path between transmitter LED and receiver diode, particularly the reflectance and distance of the detected reflecting object.

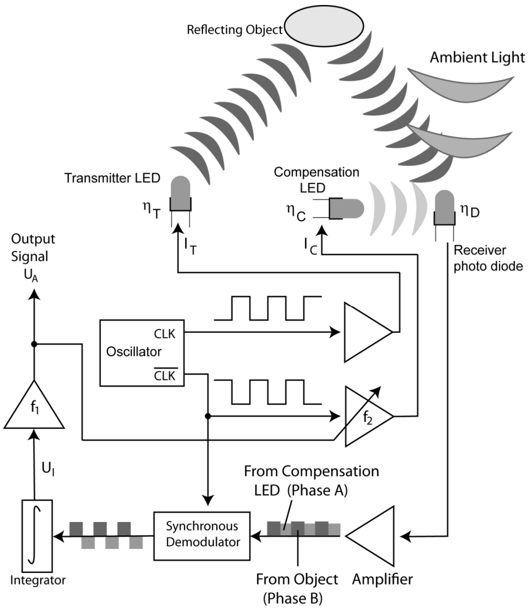

Fig. 1. Schematic diagram and the principle of operation of the control loop with a compensation LED
Rys. 1. Schemat i zasada działania układu z diodą kompensującą LED

In similar way we write the light power of the compensation light at the receiver diode as

$$L_C = I_C \eta_C O_C \tag{2}$$

The factor O_C represents the properties of the optical path from the compensation LED to the receiver diode which is a constant after assembling the measuring system. Additionally the diode receives incident ambient light L_A. The power of this ambient light can be higher than the power of the two LEDs. So in Phase A, when the compensation LED is working, the receiver diode produces a signal

$$U_D = \eta_D \left(L_C + L_A \right) \tag{3}$$

where η_D is the efficiency of the receiver diode. In the same way during Phase B, when the transmitter LED is working, the receiver diode produces a signal which is

$$U_D = \eta_D \left(L_T + L_A \right) \tag{4}$$

These signals pass the synchronous demodulator which has an amplification of +1 during phase A and -1 during Phase B. The control circuit drives the integrator to integrate this signal over an integration time for instance T_I = 0.2 ms comprising several cycles, each cycle consisting of Phase A + Phase B. So if we assume the light intensities to be constant during integration, the output of the integrator gives a signal

$$\begin{aligned} U_I &= \int_0^{T_I} \eta_D \left[\left(L_C + A \right) - \left(L_T + L_A \right) \right] dt = \\ &= \int_0^{T_I} \eta_D \left(L_C - L_T \right) dt = \eta_D \left(L_C - L_T \right) T_I \end{aligned} \tag{5}$$

So we see that the influence of the ambient light is completely eliminated and this is the main goal of the construction of the circuit. If we combine equations (1) and (2) with the last equation we get

$$U_I = \eta_D T_I \left(I_C \eta_C O_C - I_T \eta_T O_T \right) \tag{6}$$

In Fig. 1 we see that the electronic driver controls the current of the compensation LED as

$$I_C = f_1 f_2 U_I \tag{7}$$

where f_1 is a constant amplification factor and the amplification factor f_2 is variable. The amplification f_2 is part of the control loop. It is controlled by the hardware in such a way that L_C is approximately equal to L_T and thus U_I is small. Substituting (7) into (6) leads to

$$U_I = C_C I_T O_T \tag{8}$$

with the circuit constant C_C

$$C_C = \frac{\eta_T \eta_D T_I}{\eta_D \eta_C f_1 f_2 O_C T - 1} \tag{9}$$

During measurement C_C is constant. The current of the transmitter diode I_T is held constant as well by the circuit during measurement. Thus we find U_I being linearly dependent on O_T which represents mainly the reflectance and proximity of the reflecting object. So the signal $U_A = f_1 U_I$ can be used as the output signal of the whole circuit.

It is important to note in Eq. (9), that U_I depends linearly on I_T O_T so if we get much reflected light due to high O_T we have to lower I_T in avoidance of saturation at the output signal U_I. The circuit constant can drift slightly due to the aging of components but this can easily be handled by appropriate software. If the circuit operates more than one LED, they can emit fast alternating.

3. Example signals transmitted by HALIOS

In some recent works algorithms were developed for gesture control of lights and shutters at windows [4] and for a non-contact mouse device for computers [5]. Fortunately integrated circuits realizing the functional principle of the elimination of the ambient light influence with a compensation LED are available, namely the HALIOS (High Ambient Light Independent Optical Sensor) [6, 7]. These chips drive several LEDs including the compensation LED, evaluate the signals and transmit the results over a serial bus. Moreover HALIOS chips contain a state of the art 16 Bit RISC microcontroller unit with a lot of peripherals and their operation can be controlled completely by software. So all adjustments of intensities can easily be done by means of programming the HALIOS registers. All LEDs can be driven quickly alternating so that the chip delivers continuous signals of all circuits. The integrated RISC microcontroller instruction set is compatible with the MSP430 family of Texas Instruments, this means that many software development tools are available. The LEDs and the photo diode are connected directly with the HALIOS so the assembly of the hardware is easy and the available time can be used for the development of algorithms for detection of several gestures and movements. The moving object in this case is mainly a hand or a finger. The recognized movements include temporary approaching ("dip" or "click"), passing ("wipe") and moving in circles ("rotate"). These gestures can be used to switch electronic devices and change their parameters.

As a simple example we can imagine controlling a radio receiver with this gestures. A „dip" could switch on or off the receiver, a „wipe" could control the sound volume and a „rotate" could change the frequency - all functions at the same optical sensor unit non-contact, without wearout and safely protected behind glass.

In the first example (Fig.2) we assume that an object (e.g. a fingertip) dips down to the one of the LEDs ("dip"). The dip can be recognized by the steep sides of the signal maximum.

In Fig. 3 we give an example for the typical signals from an assembly of 4 LEDs while an object is passing in constant height e.g. the wipe of a finger. The direction and path of the movement can roughly be determined from the order and height of the peaks.

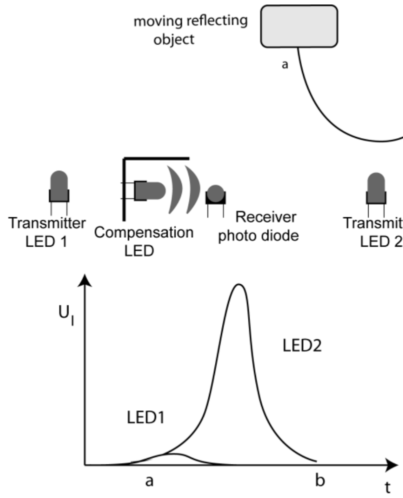

Fig. 2. Upper Part: Assembly with 2 Transmitter LEDs and a reflecting object moving from a to b. Lower Part: Schematic signals during movement. The light of the LEDs is reflected by the object; according to the distance and angle the signal is much higher if LED2 is emitting. The steep peak is typical for a short approach

Rys. 2. Część górna: układ z 2 diodami nadawczymi LED i jedną odbiorczą. Obiekt przemieszcza się od punktu a do b. Część dolna: schematyczny przebieg sygnałów podczas ruchu. Światło emitowane przez diodę LED odbija się od obiektu; w zależności od odległości i kąta, sygnał jest znacznie większy, jeśli emituje dioda LED2

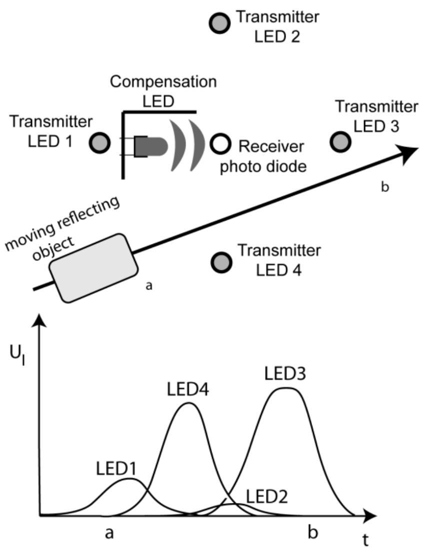

Fig. 3. Upper Part: Assembly of 4 Transmitter LEDs in a plane and a reflecting object moving from a to b in constant height over this plane. Lower Part: Scheme of typical Signals during movement. The signal maxima are high if the distance of the object is small

Rys. 3. Część górna: układ z 4 diodami nadawczymi LED umieszczonymi w jednej płaszczyźnie i obiektem przemieszczającym się od punktu a do b w stałej odległości od płaszczyzny. Część dolna: przebieg typowych sygnałów podczas ruchu. Maksima sygnałów są większe jeśli odległość jest mała

In Fig. 4 we show some real signals recorded in a circle driven by a HALIOS chip while a finger rotated over the same assembly as in Fig. 3. Of course real signals contain some noise but this can be reduced by methods of signal processing without problems. All this signals can be interpreted by appropriate software and were used for a reliable detection of gestures and thus the controlling of electrical equipment.

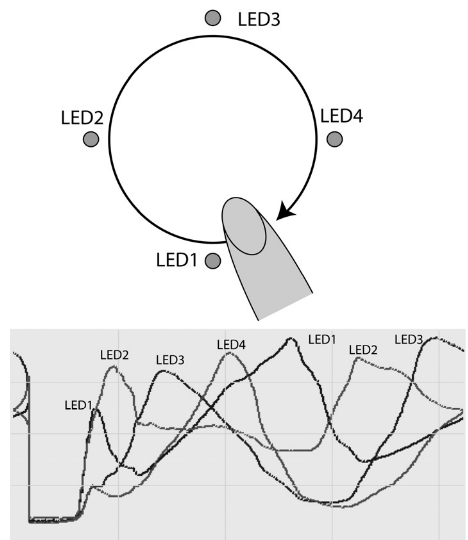

Fig. 4. Upper Part: Assembly of 4 LEDs in a plane circle. Lower Part: Recorded Signals transmitted by HALIOS during a finger describes circles over this assembly. Despite of noisy signals the peaks are found easily and so the rotating sense and the rough rotation angle can be determined by from the order and number of the peaks [4]

Rys. 4. Część górna: układ z 4 diodami umieszczonymi na okręgu. Część dolna: zarejestrowane sygnały emitowane przez układ HALIOS podczas ruchu palca po okręgu. Mimo występowania szumów maksima sygnałów można łatwo określić i tym samym wyznaczyć kierunek i kąt obrotu w oparciu o kolejność i liczbę maksimów [4]

4. Conclusion

The function principle of reducing the ambient light influence by a compensation diode is very efficient and opens a wide field of applications for gesture and motion detection. The accuracy of the method is low, but the method enables a very robust detection and classification of movements e.g. of a finger. Available low cost integrated circuits allow reliable recognition of several gestures of a human hand by means of software. The practical tests in [4] and [5] led to contact-free industrial products, e.g. a controlling device for lights and a computer mouse.

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