SPATIAL FILTERS FOR TRANSVERSAL VELOCITY MEASUREMENT

Karel ČERMÁK, Doctoral Degree Programme (2)
Dept. of Radio Electronics, FEEC, BUT
E-mail: cermakk@feec.vutbr.cz

Supervised by: Prof. Friedemann Mohr

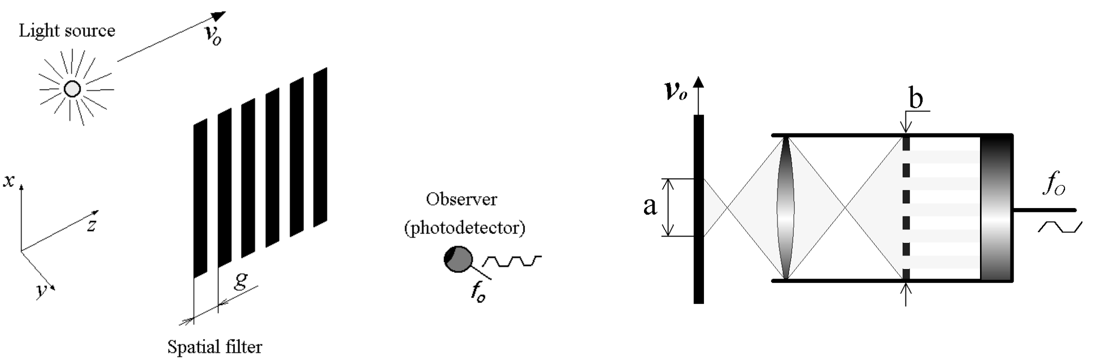
ABSTRACT

This article tries to familiarize the reader with the method GVM (Grid Based Velocity Measurement) and with the known kinds of spatial filter realisation. The article gives a brief review of the historical development of the GVM method.

1 GRID BASED VELOCITY MEASUREMENT (GVM) – THE PRINCIPLE

The use of spatial filters for velocity measurement of moving objects was first mentioned during the 40s of the 20^{th} century [1]. This method utilizes the brightness modulation B of a moving object seen through a spatial filter, which is then projected onto a photo detector. The spatial filter is formed, in most cases, by a row of slots (grid).

Let's take a closer look at the situation shown at Fig. 1*a*. There we have a source of light, which moves with uniform velocity v_o in the direction of the arrow i.e. in z direction. If we observe the integral intensity of light passing through the grating, the periodic occurrence of the light source in the transparent regions manifests itself as blinking.



(a) (b)

Fig. 1: *(a) Principle of spatial filtering method,* *(b) With lens for imaging object on grid.*

The faster the light source moves in the sensing plane, the faster gets the blinking frequency of the signal passing through the grating and vice versa. In other words, the maximum of the power spectrum, which is received by the photo detector, is settled at the frequency f_o when the velocity of the moving object is v_o. The frequency f_o, which is then obtained from the photo detector is

$$f_o = \frac{v_o \cdot M}{g}, \tag{1}$$

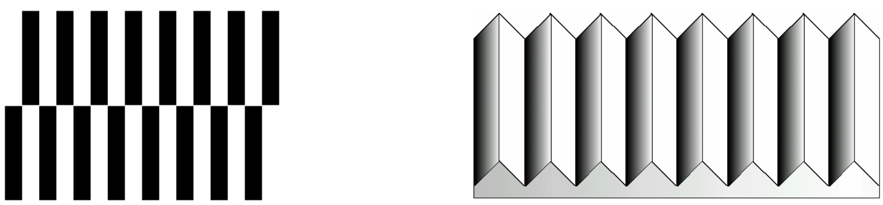
where g is the grid constant of the spatial filter and $M=b/a$ is magnification factor (Fig. 1*b*).

2 DIFFERENTIAL SPATIAL FILTERING FOR SUPPRESION OF THE DC TERM

However, using simple grid (Fig.1*a-b*) as spatial filter has shown unsuitable, because of a very high DC component occurring at the detector together with the modulation term at frequency f_o. The DC component is caused by light spots, which after imaging on the grid in Fig. 1*b* are larger than $g/2$.

The solution to this problem is using differential spatial filters, i.e. two spatial filters, which are phase-shifted by 180° (Fig. 2*a*). Using two such filters we are able to get differential signals, which, after subtraction, provide a DC component free output. However, this simple variant of a differential spatial filter has shown unpractical because of problems with possible different structure passing below each half of the spatial filter. Different structure below each half could cause different intensity on the fotodetector and after subtraction we would still obtain a residual DC term in addition to the AC component at f_o.

In 1971, the company CORRSYS [2] patented a differential spatial prism filter 1D (two in one) [3] shown at Fig. 2*b* and soon after this a differential spatial pyramid filter 2D (two in one) shown at Fig. 3*a*. Other types of differential spatial filters are based on the use of cylindrical lenses in a grid arrangement, and a fiber based differential spatial filter as depicted at Fig. 3*b* and 3*c*. The next possible alternative to create an adjustable spatial filter is based on the use of a liquid crystal arrangement.



(a) *(b)*

Fig. 2: *(a) 1D simply differential spatial filter, (b) 1D differential spatial prism filter (two in one).*

The signals that we obtain on the output of photo-detectors D_1 and D_2, which are placed behind the differential spatial filter, and the differential signal after passing a simple differential amplifier, are shown in Fig. 3*d-f*. Figure 4*a* shoes the principle scheme of the optical part of a GVM device using 1D differential spatial filter (two in one).

The discussion so far used as velocity source a single light point (Fig.1*a*). More of practical concerns, however, are systems measuring the lateral velocity of extended objects, e.g. a sheet of paper, steel bar, etc. (Fig. 4*b*).

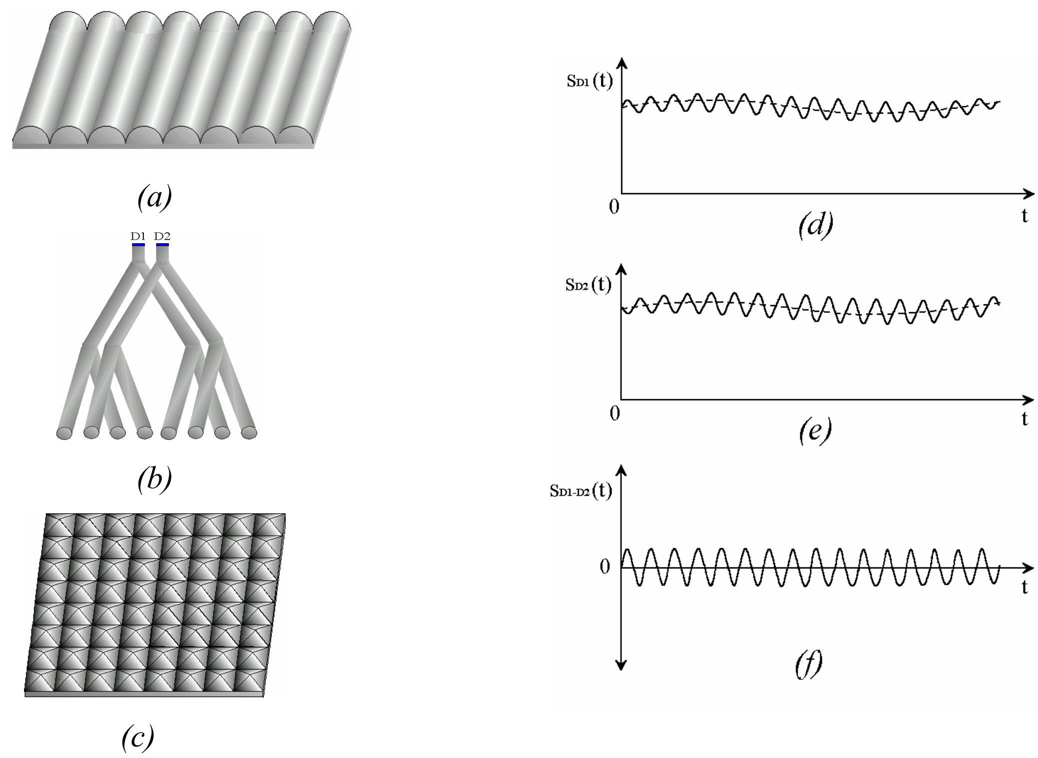


Fig. 3: *(a) 1D differential lenses spatial filter(two in one), (b) 1D fiber based differential spatial filter, (c) 2D differential spatial pyramid filter (two in one); Signals at the photo-detectors D_1 (d), D_2 (e), the differential signal (f).*

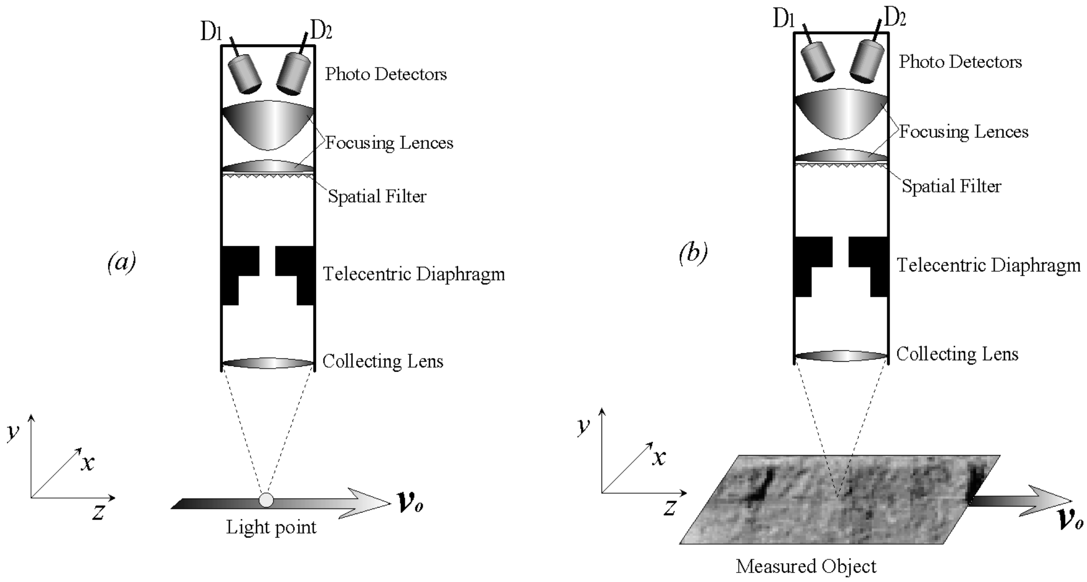


Fig. 4: *Principle scheme of optical part of GVM device using 1D differential spatial filter: (a)With single light point, (b) Real application with extended moving object.*

3 SPATIAL FILTERING USING CCD DETECTORS

With the advent of CCD chips, there appeared the idea of using the CCD matrix not only as a photo detector but also as a spatial filter. Based on this idea, measuring devices using CCD chips have been built (for example by the manufacturer ASTECH [4]). The differential signal is collected in the way shown in Fig. 5.

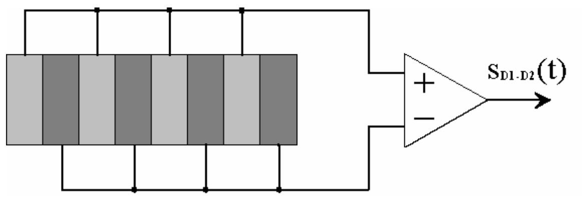


Fig. 5: *Reading the differential signal from CCD chip.*

4 DIRECTION DISCRIMINATION

With all above described systems the problem still remains unsolved to determine the direction of movement because the direction cannot be recognized simply from two signals in counterphase, i.e. from two signals, which are shifted by 180°.

The following possible solutions have been proposed:

a) Systems with mechanical grid can modulate the spatial filter through mechanical vibration [5] or by use of a rotating spatial filter [6]. These ways are a little dull because of the demands for realization and long-term stability of the measuring system.
b) Connecting the reading elements [7] on the CCD chip as shown in Fig.6 or in Fig.7 generates quadrature signals which can be used to determine the direction of movement.
c) Using liquid crystals with controlled individual elements makes it possible to generate a moving grid, thus making the direction of the frequency shift discernable and eliminating ambiguity of direction.

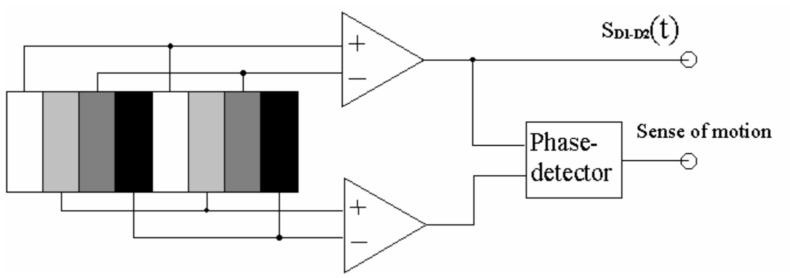


Fig. 6: *Connection of CCD chip with the possibility of determining the direction of movement through quadrature demodulation.*

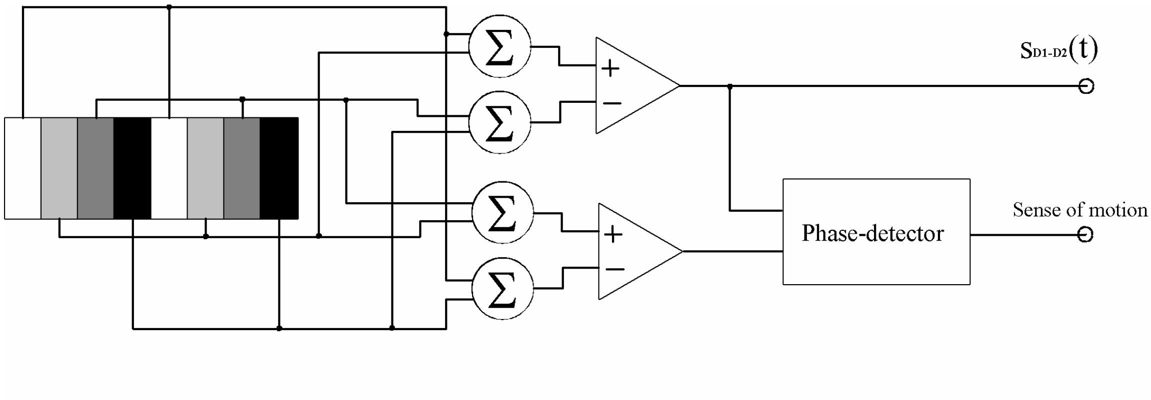


Fig. 7: *Improved alternative of connecting the CCD chip, allowing determination of the direction of movement through quadrature demodulation.*

5 CONCLUSION

The contribution gives an overview on basic operating concepts of optical non-contact velocity meters including speed and direction determination. Systems based on the above described principles achieve accuracies better than 0.1 % and are able to measure the object velocity up to 600 km/h without need for a coherent source of radiation. They are therefore permanent competitors to the recently developed coherent light based methods like LDV (Laser Doppler Velocimetry).

REFERENCES

[1] GERALD FITZ.A.S.: Photo Electric System. US Patent No.: 2,016,036, Oct.1, 1935.

[2] http://www.corrsys.de

[3] ERNST LEITZ GMBH., of 6330 Wetzlar, Germany: Apparatus for measuring properties of movement. London Patent Office, Patent Nr. 1 389 309, 1971.

[4] http://www.astech.de

[5] HEITMANN, K., SCHNEIDER, E., EISENKOPF, H.: Einrichtung zur berühungslosen Messung der relativen Geschwindigkeit, Lage, Entfernung oder Verschiebestrecke von Objekten. Schweizerische Patentschrift CH 548 605, 1974.

[6] DELINGATE, E.: Berührungslose Geschwindigkeits- und Abstandsmessung. Leitz Mitteilungen für Wissenschaft und Technik, Bd. VI, Nr. 7, 1976/4.

[7] MICHEL, K.C., FIEDLER, O.F., RICHTER, A., CHRISTOFORI, K. and BERGLER, S.: A Novel Spatial Filtering Velocimetr Based on Photodetector Array. IEEE Transactions on Instrumentation and Measurement, vol. 47, No. 1, February 1998.