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Dot projector based on phase diffuser

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ABSTRACT

This disclosure describes low-weight, low-cost, high-efficiency techniques to project coherent infrared dots onto a subject to sense the depth contour of the subject while capturing a photograph. The techniques generate dot patterns of high number and density. A phase diffuser placed in the path of an infrared laser beam causes the wavefront of the laser beam to develop random undulations. The speckle pattern formed at the plane of the subject due to the randomized wavefront serves as a matrix of infrared dots.

KEYWORDS

- Depth camera
- Depth determination
- Depth sensing
- Dot projector
- Phase diffuser
- Infrared laser
- Speckle pattern

BACKGROUND

Some cameras project infrared dots onto a subject for the purposes of depth sensing while capturing an image. The dots can be aligned to a grid or be arranged in a random pattern. Various depth-sensing techniques use the dot patterns that are projected onto and reflected from the subject to derive a depth contour of the subject. For example, stereo algorithms match unique features in two camera images to determine depth via parallax shift.

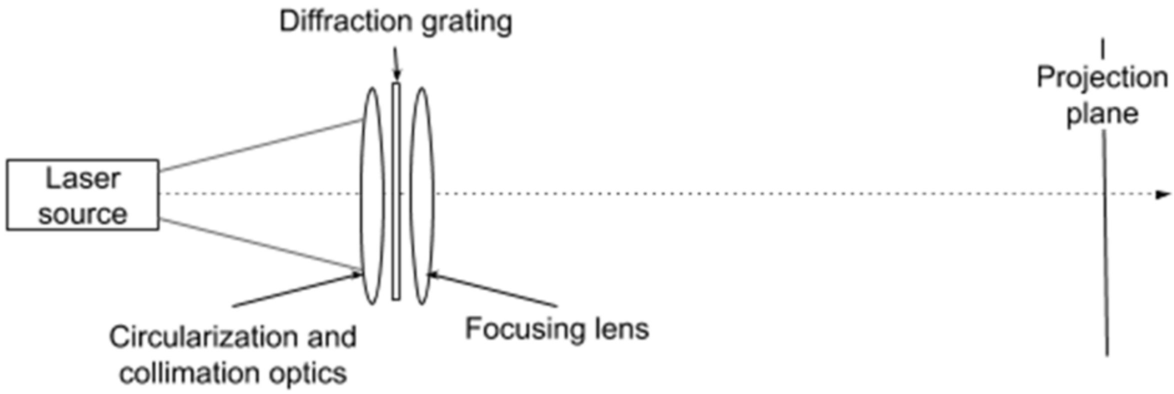


Fig. 1: Example dot projector

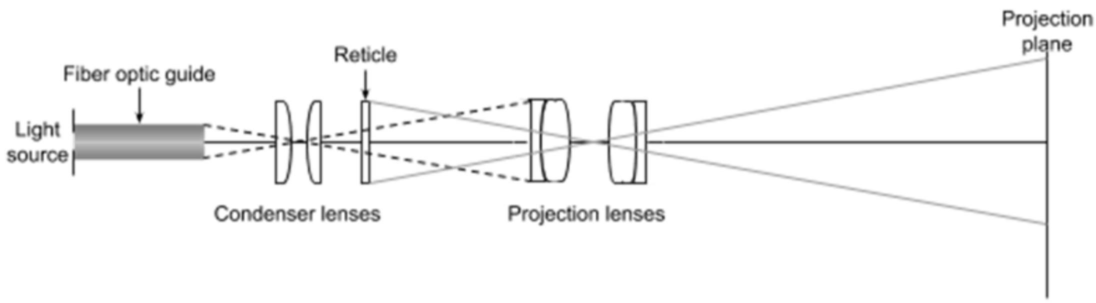


Fig. 2: Example dot projector

Current dot projectors, examples are which are shown in Fig. 1 and Fig. 2, are relatively complex. For example, in the scheme of Fig. 1, a laser source and precision optical components such as collimators, diffraction gratings, focusing lenses, circularization optics, etc. are needed. In the scheme of Fig. 2, in addition to a light source, fiber optic light guides, condenser lenses, reticles, projection lenses, etc. are needed. The relatively complex optics with tight specifications on image quality, point spread function, diffraction efficiency, etc. make size, weight, power, and cost targets difficult to achieve, especially on small form factors such as mobile devices.

DESCRIPTION

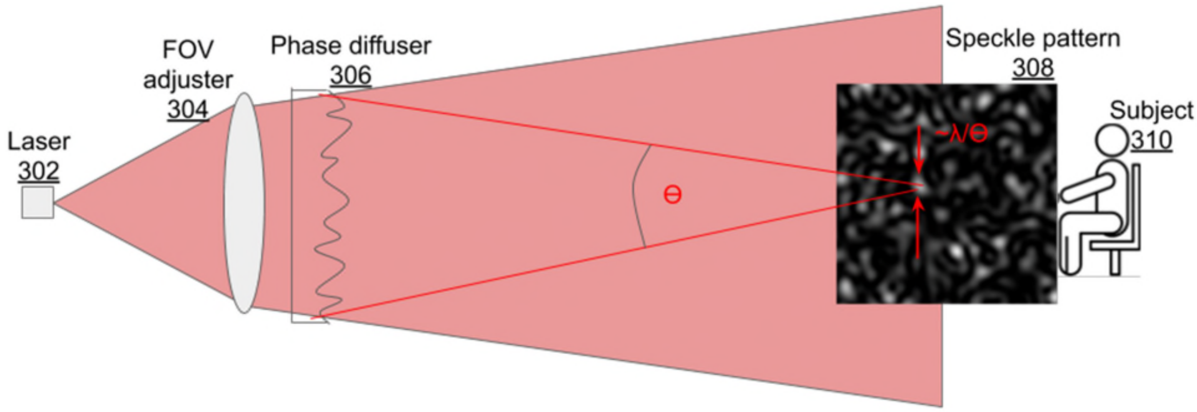


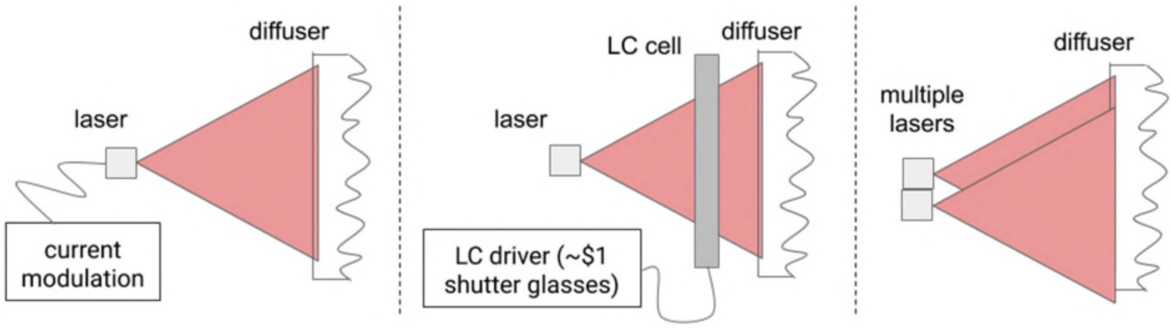
Fig. 3: Dot projector based on phase diffuser

Fig. 3 illustrates an example of generating a dot pattern using a phase diffuser, per the techniques of this disclosure. The beam of an infrared laser source (302) is adjusted by a field-of-view (FOV) adjuster (304), which can be a relatively inexpensive condenser lens. A phase diffuser (306), which can be a relatively inexpensive piece of ground or frosted glass or plastic with surface undulations and scratches, is inserted in the path of the laser beam. The phase diffuser randomizes the wavefront of the laser beam, which in turn causes a coherent interference effect, e.g., a speckle pattern (308), at the plane of the subject (310) that is being captured. The speckle pattern serves as a matrix of infrared dots that can be used for sensing depth in the photograph.

The typical spatial scale of the speckle pattern is of the order of $\lambda/\boldsymbol{\theta}$, where λ is the wavelength of the infrared beam and $\boldsymbol{\theta}$ is the angle subtended by the phase diffuser aperture at the plane of the subject. A designer can target a typical dot size by adjusting $\lambda/\boldsymbol{\theta}$. For example, a dot size of 1 mm can be attained by adjusting $\boldsymbol{\theta}$ such that $\lambda/\boldsymbol{\theta}$ is approximately unity. The value of $\boldsymbol{\theta}$, in turn, depends on typical distances between the projector (or camera) and the subject.

The exact pattern and size of the dots in the speckle pattern are of relatively low importance; rather, to infer a depth contour, it is sufficient that the statistics of the spatial distribution and size of the dots are within design limits. Since it is easier to achieve a target statistic than a target pattern, the techniques of this disclosure enable easy implementation of the dot projector. For example, a target statistic of infrared dots can translate to a target statistic of undulations on the surface of the phase diffuser. A phase diffuser with a random surface pattern is relatively easy and inexpensive to fabricate.

Rather than a lens that focuses a laser beam on the subject, the techniques use a relatively low-quality condenser lens to illuminate a region on the plane of the subject. The techniques use coherent interference effects without zeroth-order diffraction to achieve the dot matrix. These features add to the efficiency and safety of the dot projector.



(a) **(b)** **(c)**

Fig. 4: Generating a time-varying speckle pattern

Some depth-sensing algorithms use multiple dot patterns, e.g., by alternating between several unique patterns. This is known as space-time depth-sensing, and the patterns are alternated, for example, at 180 Hz. Fig. 4 illustrates examples of techniques to achieve multiple dot patterns across time.

Fig. 4(a) illustrates a technique wherein the supply current to the laser source, which can be, e.g., a VCSEL, is modulated. The wavelength of the emitted laser beam varies with the current and the speckle pattern exhibits a sensitive dependence on the wavelength. Thus, multiple dot patterns can be achieved by modulating the supply current of the laser source.

Fig. 4 (b) illustrates a technique wherein some property of the laser beam, e.g., its polarization or its speed, is changed electro-optically, e.g., by a liquid crystal cell placed in the path of the beam. The liquid crystal cell changes the properties of the laser beam based on a controlling voltage. For example, the speed of the laser beam can be modified by changing the refractive index of the liquid crystal cell. The speckle pattern exhibits a sensitive dependence on the properties of the laser beam. Thus, multiple dot patterns can be achieved by changing the controlling voltage of a liquid crystal cell placed in the path of the laser beam.

Fig. 4(c) illustrates a technique wherein multiple dot patterns are generated by turning on one or more lasers in an array of lasers. The speckle pattern exhibits a sensitive dependence on the number and relative positions of the laser sources. Thus, multiple dot patterns can be achieved by turning on various combinations of multiple laser sources.

A greater multiplicity of dot patterns can be achieved in the above techniques by using mechanical actuators to move slightly the laser sources.

CONCLUSION

This disclosure describes low-weight, low-cost, high-efficiency techniques to project coherent infrared dots onto a subject of a photograph, so as to sense the depth contour of the subject. The techniques generate dot patterns of high number and density.

REFERENCES

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