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3-D Reconstruction Scenario Computing For Low Power Consumption Using A Projector And An Imaging Camera

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Abstract: One of the major power consuming components in a computer is its display unit. On average the screen consumes ten times more power than the DSP processor itself. Thus, reducing the power consumption should be one of the most important tasks in the development of low power consumption computing systems. In this paper we present one possible solution involving micro projection device based upon lasers and a digital light processing (DLP) matrix which is a matrix of electrically controllable mirrors capable of translating electrical signal to a time varying projected image. It can serve to substitute a screen and consume ten times less power than a conventional screen. The described device is a multifunctional highly efficient customized DLP light engine being capable of serving as an image projector and simultaneously to support range and topography estimation measurements.

Keywords: portable micro projector; low power computing; electro-optics

Introduction

The low power consuming micro projector could be a very useful device for a wide set of applications such as a virtual screen of cellular phones or portable computers. The most common technique for projection uses illumination lamps, spatial light modulators and imaging lenses. Those devices consume more than 300 W as they are highly inefficient. Other techniques such as digital paper or direct retinal projection have either technological drawbacks or disadvantages in price and operation time in comparison to the technique described in this paper. According to the article published at GRASP Symposium at Wichita State University, 2010 the display consumes 25% of the energy in today's typical lap-tops. Their test showed an average of 19 W. Since display also consumes significant space and size, a substitute which could cut down size weight and power consumption while yet maintaining the capability in producing a large display, is definitely an appealing technological direction having a growing interest of large consumer electronics manufacturers worldwide.In this paper we aim to demonstrate a combination of several new and emerging techniques in virtual displays, while some of which have been demonstrated separately but so far they were never integrated together into a single projecting module resulting in a more efficient engine (compared e.g., even to an LCD based display).

Note that the directional projection approaches such as head mounted or direct retinal displays do not allow sharing the displayed information with other participants [1–5]. While in our case the suggested low energy consuming projector is based on a spatially coherent polarized diode laser and a set of spatial optical data processing elements (such as an improved spatial light modulator (SLM) that is based upon a digital light processor (DLP)) that are designed to increase the energetic efficiency.

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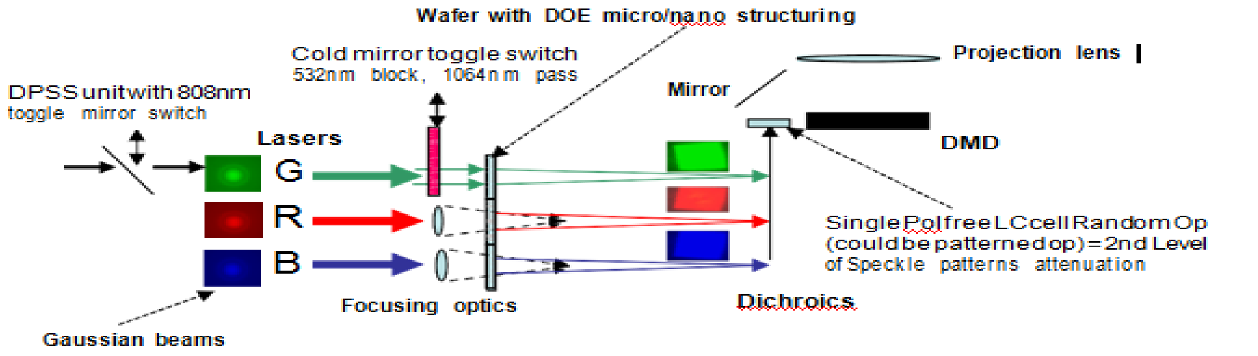
The combination of all those aspects allows the realization of this portable projector, despite of failures obtained in similar attempts in the past [6–10]. The suggested portable projector is good for both private as well as for screen sharing applications. Whereas the authors previously attempted to construct a laser based micro projection that lacked sufficient high performance [11–13], the modifications in the current demonstrator suggest a very appealing outcome with regard to overall performance. In this paper we briefly present the design, construction and preliminary characterization of a micro projector providing output colored images. This micro projector consumes an average power of less than 3 W while delivering 10 lumens of brightness to a substitute of a 12" screen. Section 2 presents the technical description of the technology. In Section 3 we present preliminary experimental results. The paper is concluded in Section 4.

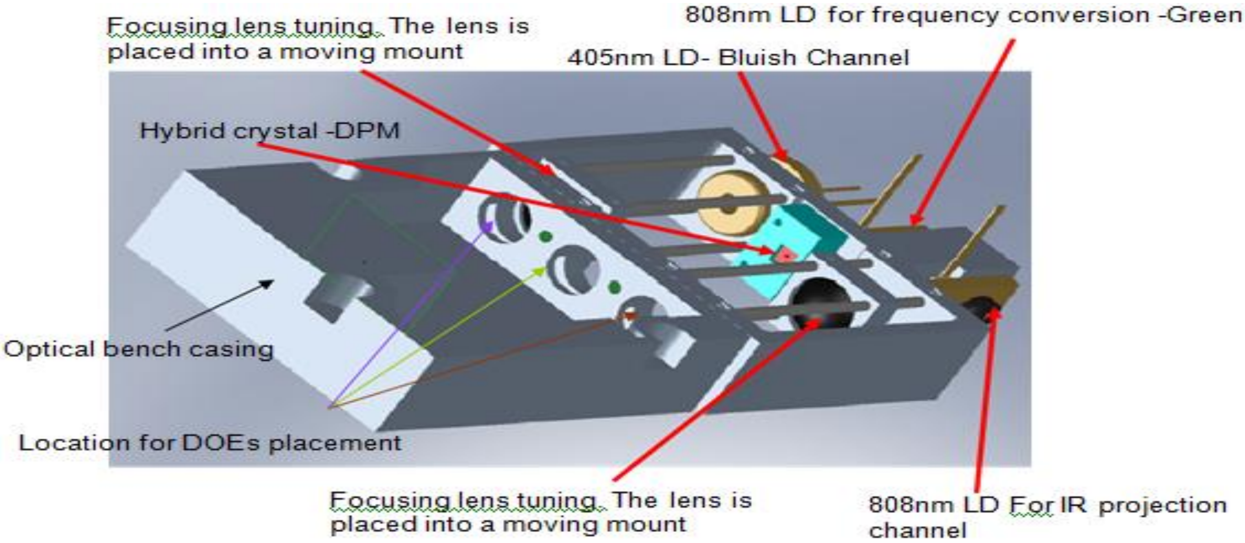
1. Technological Description

The main goal demonstrated in this paper relates to the preliminary realization of an integrated and multi-functional DLP based pico projector. We believe that these multi-functional capabilities are going to be integrated in many future developed projection devices. Thus, let us first start by describing the main difference between the DLP based multi-functional projector that is being presented in this paper, and other existing micro/pico projection techniques. In recent years, there have been significant changes in the integration of projection engines for new applications. A trend of implementing these light engines is evolving in commercial and industrial applications. The popular growing application is micro/pico projection which is a miniature video projector that can project large image displays out of small devices such as portable light weight electronic devices. Efficiency in an essential feature in mobile electronics especially due to the need to reduce the dimensions and the obtainable heat dissipation while, in parallel, maximizing the operating time of small sized batteries. The Digital Micro-mirror Device (DMD) is a miniature component that can modulate light while maintaining high optical and electrical efficiency. This makes this technology an attractive solution in mobile devices. For example, a DMD from DLP1700 mini series (0.17", 0.3") is a miniaturized version designed by TI (Texas Instruments) for the pico projection market. The reflectivity of the mirrors is approximately 90% and they consist of a fill factor of 92%. The electrical energy consumption of the DMD is surprising and is equals to ~84 mW. General schematic illustration of the suggested projection device may be seen in Figure 1(a). There, the projector is comprised from 3 lasers (red, NIR and blue) that are utilized to support red, green and blue (RGB) projected wavelengths where the green is obtained by frequency conversion done within the diode pumped solid state (DPSS) laser unit (pumped by the NIR laser diode). Nevertheless this projector may still maintain a toggling capability between stand alone NIR projection or a combination of a semi color projection with NIR.

Figure 1. Description of the various components of the micro projector. (**a**) The schematic sketch of the projector; (**b**) 3-D drawing of the constructed prototype; (**c**) The beam shaping phase diffractive optical element (DOE); (**d**,**e**) Experimental results for the beam shaping DOE; (**f**) The digital light processing (DLP) chip.

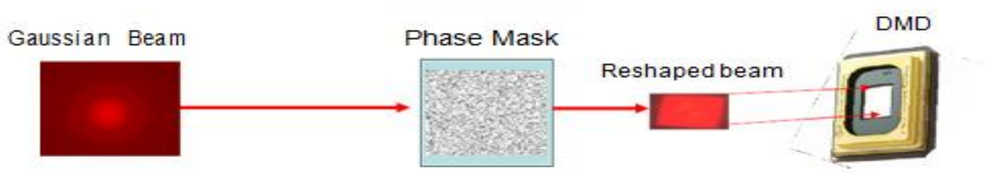


(a)

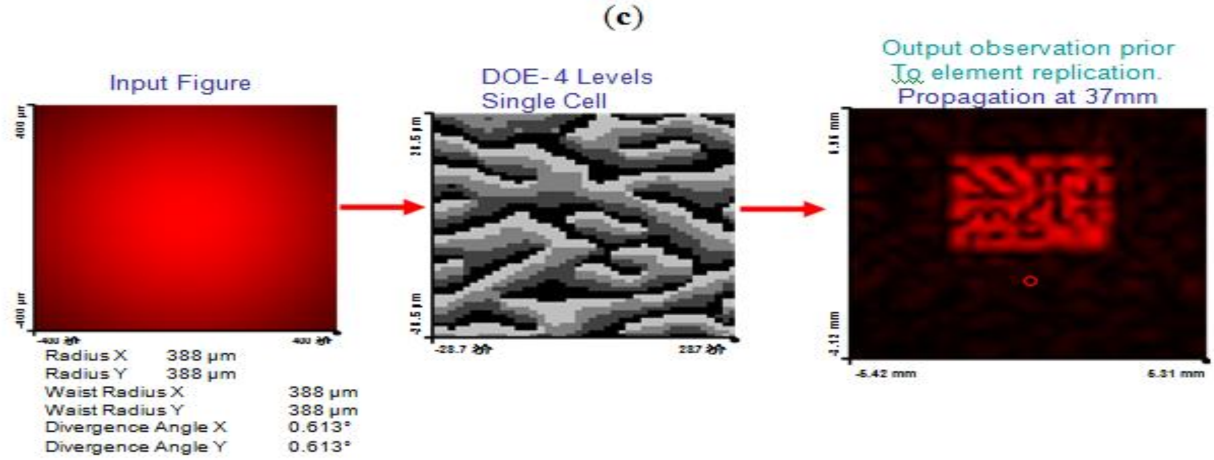


(b)

Figure 1. *Cont.*



(c)



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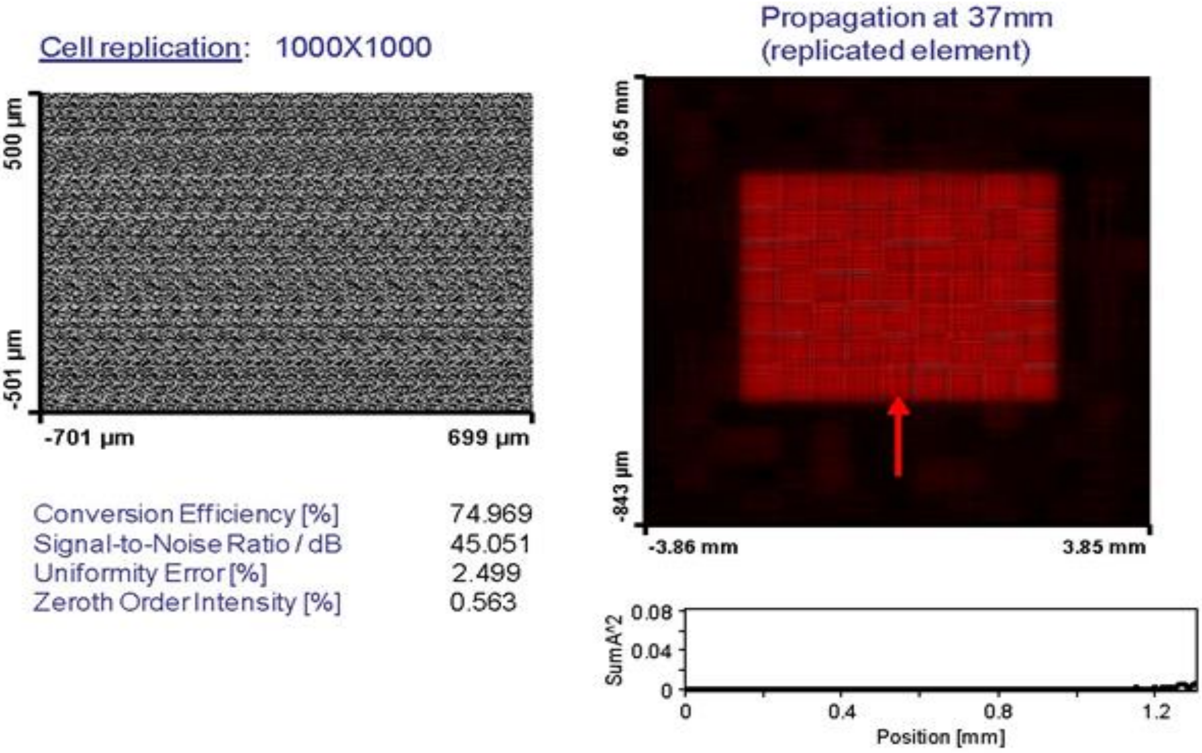
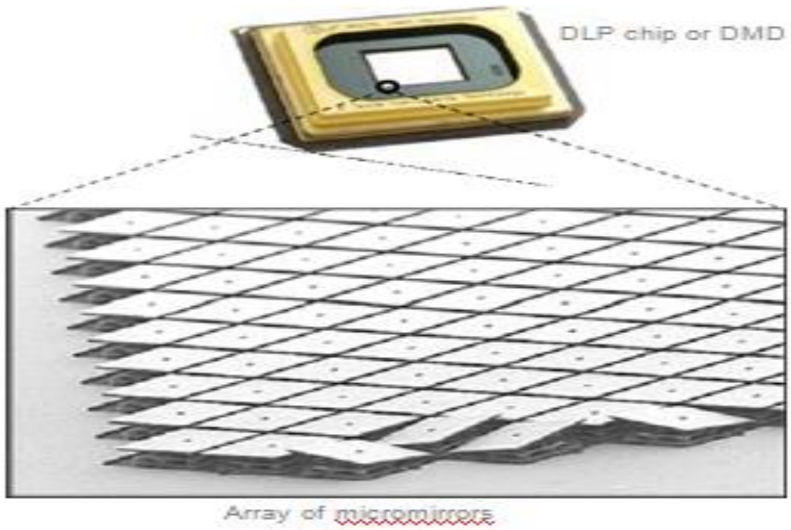


(e)

Figure 1. *Cont.*



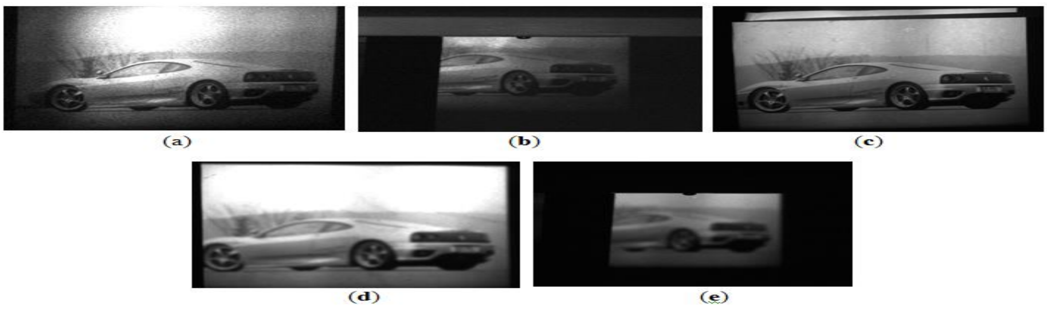
(f)

The DPSS laser emits two wavelengths of 532 nm and 1064 nm when no hot mirror is utilized to block the 1064 nm. Providing the option for a mechanical switch consisting of cold mirror, the user can block the 532 nm wavelength and allow free pass of the 1064 nm wavelength. This opens an opportunity for marking a target in NIR that is not easily detected by sensors of common cameras. y mechanically switching the NIR to bypass the DPSS channel, the user can allow IR patterns projection.

projection of any required data that can be utilized for 3-D measurements while simultaneously presenting information to the user in the VIS. Altogether, these capabilities could be considered as drastic improvements of efficiency in comparison to existing systems having separated display and projection units in order to realize the same tasks. The measurements in Figure 1(c,d) were performed for a targeted distance of ~37 mm between the beam shaping DOE and the DMD. The wavelength was NIR wavelength of 808 nm and the formation of reshaped figure of 4 × 3 mm was designed to cover the active area of the DMD. The DLP itself contributed to the high overall energetic efficiency by providing mirrors with fill factor of about 90% and with reflectivity level of close to 100%. The image of the DLP can be seen in Figure 1(f).

The utilization of lasers in 4 wavelength channels is an important feature in improving the energetic efficiency of the proposed projector in comparison to conventional spatially incoherent illumination source. First, due to the spatial coherence of the laser, the above mentioned beam shaping can be done efficiently. Beam shaping for spatially incoherent illumination is much more complicated and much less energetically efficient. Again, due to spatial coherence, the laser may be efficiently directed towards suitable beam expanding device and imaging lens, without having any energetic loss. Incoherent beams are much less confined in their angular distribution and thus they are less efficient in this sense. In addition, the projected image produced by the coherent source has much larger depth of focus (this extended depth of focus is obtained due to the preservation of the phase information in coherent illumination) and may be used for 3-D image display using the ability to direct the beam only to one eye of the observer at a time. To further explain this point, we wish to emphasize that although the depth of focus is strongly related to the numerical aperture (NA) of the imaging lens, it is also affected by the spatial coherence of the illumination. The reason is that when imaging with spatially coherent illumination, one deals with the CTF (coherent transfer function) of the imaging lens and the defocusing is expressed there as a parabolic phase function that does not block any spatial frequencies from passing through. In the spatially incoherent case, nevertheless, one talks about the OTF (optical transfer function), which, in the case of defocusing, has zero transmission values to some of the spatialfrequencies.

Figure 2. Out of focus comparison between spatial coherent and spatial incoherent cases. Laser projection obtained at a distance of 70 cm; (**b**) Laser projection obtained at a distance of 180 cm; (**c**) LED projection obtained at a distance of 70 cm; (**d**) LED projection obtained at a distance of 90 cm; (**e**) LED projection obtained at a distance of 180 cm.



(a) (b) (c)

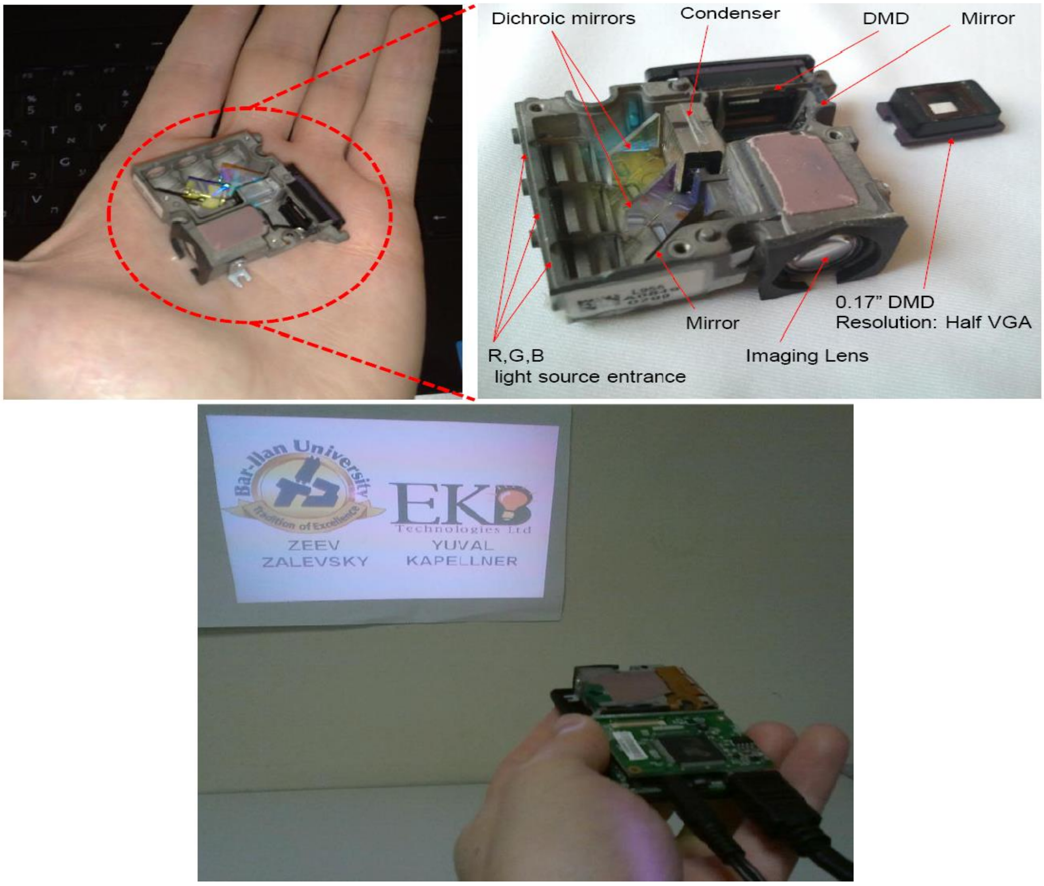
(d) (e)

In Figure 3, we tested the functionality of various sub modules of the micro projector. Figure 3(a) presents a rectangular beam shaper that is based on multi level DOE in off axis data projection that is planned to match the shaped beam to the aspect ratio of the active area of the DMD. Figure 3(b) displays the outcome of the beam shaping testing procedure performed with the DOE and the DMD.

A twin image was visible due to having the off axis data close to the border of the design field. To further improve efficiency, it is possible to increase the field size (which would require changing feature size to reach the correct dispersion angle) or to move the data closer to the center. Figure 3(c) shows the tuning of visible green/red lasers with DOE and DMD setup.

2. Projector's Testing

Figure 5. Experimental results: (**a**) Construction of the micro projector; (**b**) Experimental image projection with average power consumption of 1.43 W for the RGB light sources and 1.2 W for the electronics. The obtainable output brightness is 10 lumens for 12" screen.



Based on the results, we repeated the experiment using the miniature size *DLP PICO V2* development kit manufactured by *YoungOptics* [20–24] on which we had performed a customization procedure with the stock LEDs (light emitting diodes) based light engine by taking apart the original RGB LEDs and replacing them with new laser light sources, as well as modifying the optical route accordingly to allow efficient illumination across the DMD. This was performed in order to demonstrate a more efficient and innovative approach in delivering structured light capability for volume measurements with simultaneous visible image projection that were both done by the same

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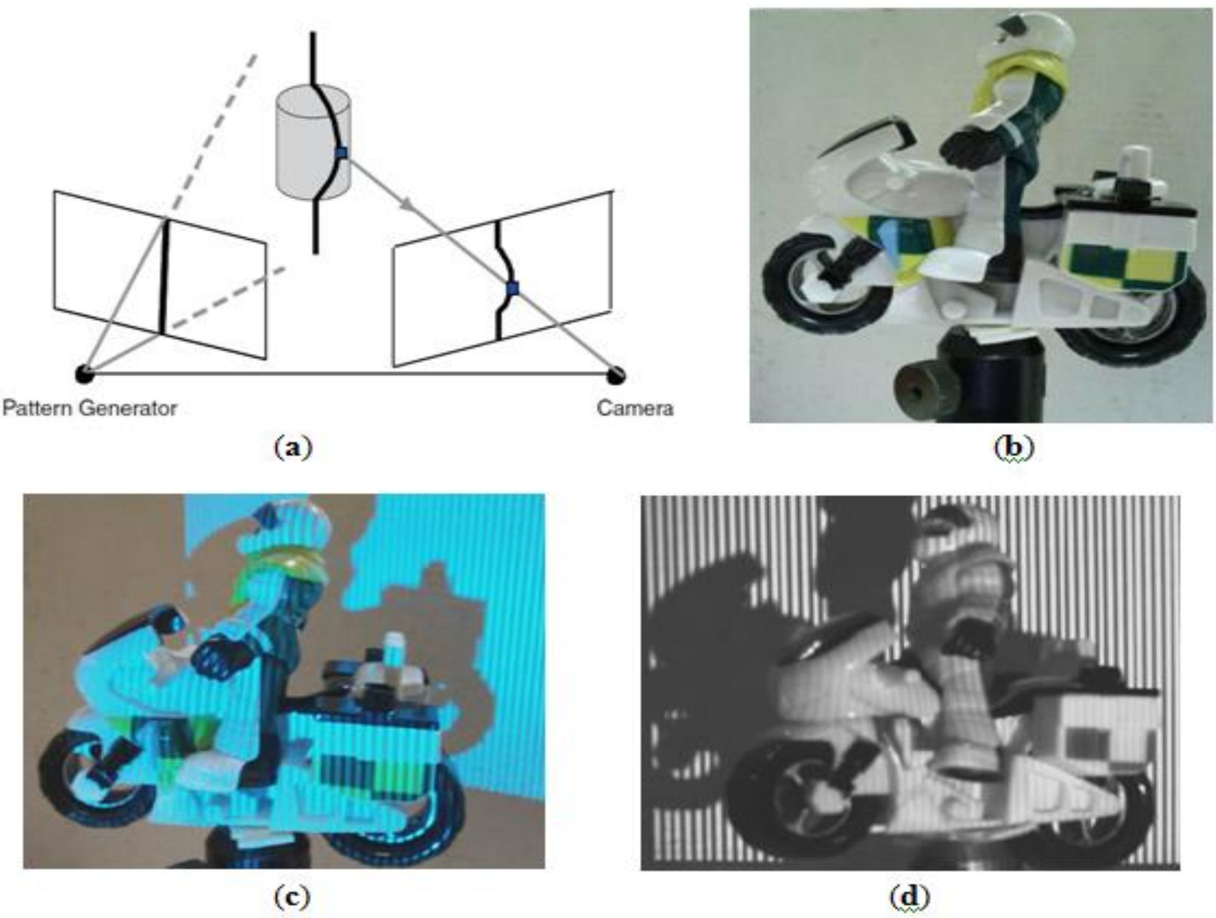
single projection engine. The demonstration resulted in a high depth of focus while opening new 3-D user interactivity possibilities and is an additional reason for making the proposed DMD based solution as an efficient and flexible replacement of different sizes of conventional miniature displays (such as LCD, LEP, OLED, *etc.*). Specifically, the demonstrator contained three lasers (in red, green and near IR) and one LED (in blue). All the above described components were packaged in a device having a volume of less than 10 cm^3. The DMD that was integrated was 0.17” in size producing half VGA projection resolution. The overall electronic average power consumption of the prototype included 1.43 W for the RGB light sources (operated at color sequential mode) and additional 1.2 W for the electronics. This produced overall brightness of 10 lumens on a 12" screen (for the above mentioned color sequential operation mode). This power consumption is more than ten times lower than the power consumption of a conventional screen having identical dimensions and brightness. Please note that the distribution of the lumens between the different colors is not uniform (since this division is wavelength dependent, e.g., the eye is much more sensitive to the green than to the blue) so the overall of 10 lumens does not mean that each color had 3.3 lumens. The experiment yielded the projection image that is displayed in Figure 5(b).

Figure 6. (**a**) Schematic sketch of 3-D reconstruction scenario using a projector and an imaging camera; (**b**) The modelled object; (**c**) Pattern projection in the visible; (**d**) Pattern projection in the IR; (**e**) Point cloud 3-D reconstruction; (**f**) 3-D reconstruction where color change signifies changes in topography.



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Note that in the discussed experimental results of Figure 6, the 3-D reconstruction is based upon triangulation while the projector, the object and the camera define a triangle. The projector can be combined together with the imaging camera to allow estimation of ranges by projecting Z varied patterns [28,29]. In this case, since the projected patterns vary with Z, the specific pattern reflected from the object will designate the range to the object.

3. Conclusions

This paper presents the technological description, as well as several experimental testing, of a portable micro projector prototype serving as a critical component in the construction of low power consuming computing systems. The proposed projector provides about 3 lumens per Watt and its overall power consumption is more than 10 times less than the power consumption of similar conventional computer displays. In the experimental results presented in this paper, we have been able to demonstrate projection brightness of 10 lumens. In addition, due to usage of a laser (spatially coherent source) as the illumination source, the device could also be used to provide extended projected depth of focus. It can also be used for 3D illustrations when different images are projected directly to each of the two eyes of the observer (the coherent illumination is directional as opposed to an incoherent one, and thus the illumination can be formed in such a way that different images will directionally be projected in each of the two eyes of the observer. This will create a 3D perception.). Further, the device could be used for volume measuring, such as ranging and object's topography estimation.

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