Research Statement

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My research interests are broadly in the areas of hardware/software co-design, cyber-physical systems, and inverse problems. My past research was particularly focused to the fields of diffractive optics, metamaterials, plasmonics, nanotechnology, and nanophotonics. My vision is to design and develop advanced systems by employing novel computational approaches that are neither time-consuming nor memory-intensive yet readily scalable. During the initial few years as a tenure track faculty, I plan to build a dedicated research group specializing in optimization-based modeling/simulation of such intelligent systems for real-world applications. For this purpose, I also intend to establish broader collaborations with other research groups within and across various departments of the university as well as with other universities.

1. Previous Research

My Ph.D. dissertation focuses on showcasing how computational methods can solve optical inverse design problems to achieve "extreme" or almost "thought to be impossible" results in two different sub-areas of optics: (a) diffractive optics (free-space) and (b) nanophotonics (on-chip) with the intent of reducing the weight and size of the proposed structures without any compromise in performance. Hence by developing new algorithms, new design approaches, and advanced fabrication processes, I showed a series of transformative results in both these sub-fields. In fact, I demonstrated lenses and cameras capable of imaging objects placed as close as millimeters apart from the camera and as far as meters in focus simultaneously. I showcased lenses operating with a bandwidth across several decades of the electromagnetic spectrum, which could enable in the future compact multispectral imaging systems operating from the mm-wave to the UV. In the last part, I also showed how machine learning can help in engineering amongst the smallest integrated photonic devices, which could fuel a future Moore's law for photonics.

2. Future Research Plan

Utilizing my background and line of Ph.D. research, I propose to leverage my expertise to develop real-world applications that are currently at a nascent stage. For example, my work on computationally designed Multilevel Diffractive Lenses (MDLs) has generated a lot of interest in the optics as well as the computer science community, as evidenced by these two papers (**published in ICCV'19 [1] and published in Optica, Vol 6 (12) [2, 3]**) herein. I wish to continue on this research path of employing novel computational approaches to demonstrate applications even beyond traditional imaging or simple nanophotonics devices. My objective is to move from the device level to the system level. In fact, it can be seen from Fig. 1 that my proposed approach can be quickly adopted for any application where a diffractive element or even a integrated device can be used ranging from Wireless Power Transfer to Label Free Bio-sensing to Optical Computing. Some proposed research directions are provided below:

2.1. Diffractive Elements

Computational Imaging / Computational Photography: Based upon the foundational work done with MDLs whereby tuning its surface topography, different extreme functionalities like super achromaticity, extreme depth of focus, wide field of view (FOV) and focal length tunability were achieved. This work till date has only been confined to single aperture systems. I propose to extend this work to multi-aperture systems, which can enable a lot more functionality and controllability while keeping the overall device footprint small without degradation in performance. As noted in [1], the use of multi-lens configurations can significantly improve the image quality of the captured scene by controlling the magnification and the FOV (> 180 degrees) very easily than a single lens system. Nonetheless, the use of several lenses of the same spectral range can also significantly increase the resolution of the system leading to better quality images. In addition to this, I also propose to venture out into computational photography to build a better image post-processing pipeline in addition to designing better lenses. My grand vision in the end is to uphold "computation" in every aspect of imaging right from capturing an image of a 3D scene with a computationally designed lens, right up-to post-processing that same image on the computer screen.

Wireless Power Transfer: Another area of active research these days is Wireless Power Transfer (WPT). With several WPT schemes being implemented in the near-field (coupling) and far-field (radiation) regimes [4], one of them is the use of beamed wireless power transfer system, which provides an exciting alternative to near-field magnetic coupling schemes. In particular, the advantage of such a system over magnetic-coupling schemes is the possibility of selectively beaming power to small devices located anywhere within a specified area. One such scenario is depicted in the second diagram under "Diffractive Elements" column of Fig. 1 where an aperture is used to beam power wirelessly to electronic devices- such as cell phones, laptops, computer peripherals, gaming controllers or consoles, watches, radios, and other small appliances within the confines of a room. From a fundamental standpoint, the receivers can be placed anywhere within the line of sight of the source to receive power, without the requirement of any cables or charging stations. The overarching theme of the proposed research effort will focus on creating such power-transfer efficient devices with better area coverage based on these computationally designed multilevel diffractive phase structures.

Quantum Chip Scale Devices: Based on recent work done at NIST [5] where the design of two basic devices i.e. atomic diffractive grating spectroscopy and atomic Fresnel lens were shown to be beneficial for quantum communication applications, I propose to leverage my skills in broadband multilevel diffractive optics to develop even more efficient quantum on-chip diffractive optical elements. How is that possible? Multilevel systems as already proven have a better performance metric (theoretically up to 100% diffraction efficiency for continuous phase profiles) in contrast to their binary counterparts since they enable vast degrees of freedom in device design [6]. This area of research is pretty new and unexplored. Coupled with the recent renewed interest in Quantum Computing, I believe developing efficient diffractive optics for such applications (or even for quantum communication systems in general) are quite challenging as well as exciting from a theoretical point of view.

2.2. Integrated Devices and Systems

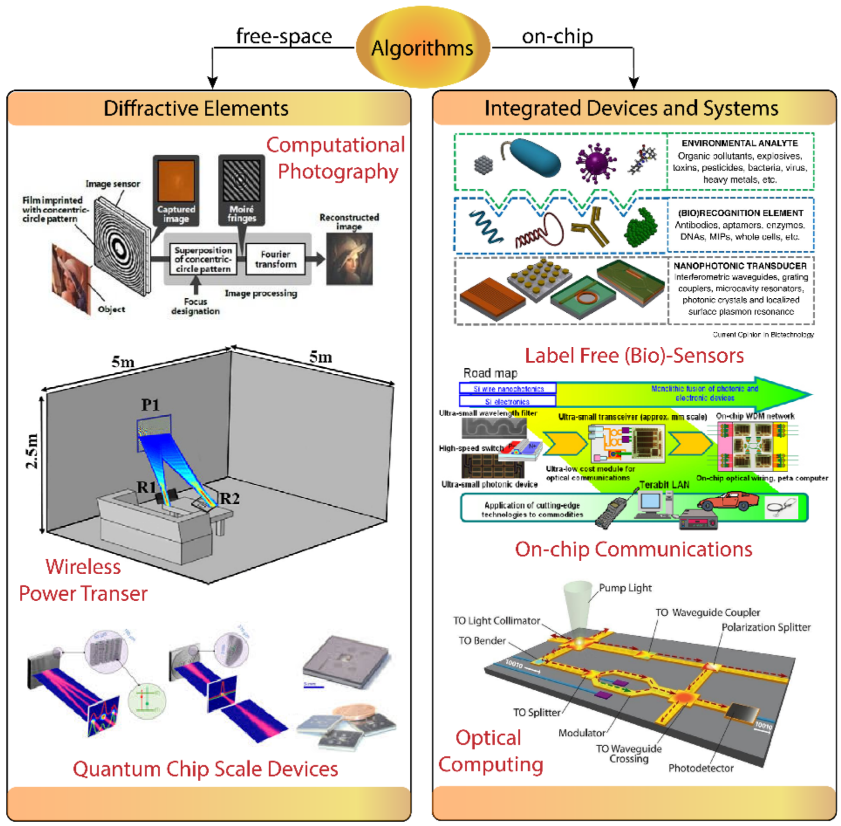

Figure 1 *Future Research Plan*

Label Free (Bio)-Sensors: In the last few years, the field of environmental monitoring has witnessed substantial progress [7, 8]. However, on-site control of contaminants remains an elusive problem till today. Now-a-days, (bio)-sensing devices have emerged as promising candidates, yet their miniaturization and their operation outside the laboratory have prevented their use on-site. From this perspective, the use of nanophotonic (bio)-sensors based on the fundamental principle of an evanescent (plasmonic) sensing is poised to be an outstanding choice for portable point-of-care diagnosis thanks to their miniaturization as well as multiplexing capability, label-free detection, and integration in lab-on-a-chip platforms. In fact, adopting an optimization-based strategy can simultaneously miniaturize the device without much compromise of the detection quality [9]. In this regard, I propose to leverage my expertise in the domain of both computational optimization and plasmonics to demonstrate robust and high-yield label free (bio)-sensors, with potential for possible commercialization.

On-Chip Communications: Quite recently, nanophotonic interconnects have emerged as a viable stand-in technology solution for the design of network-on-chip (NOC) systems because of communication bandwidth, reduced power consumption, and wiring simplification [9]. In fact, the most common feature amongst all of these proposed NOC approaches is the integration of the entire optical network onto a single silicon waveguide layer. However, keeping the entire system on a single layer has severe implications with respect to power losses and design complexity. Nonetheless, inverse designed nanophotonics recently met with some success in this field with the demonstration of efficient on-chip couplers, multiplexers, and demultiplexers with an area footprint orders of magnitude less than their operational bandwidth. Apart from miniaturization, device performance metrics like insertion loss of 2-4 dB and crosstalk less than 11 dB also proved to be promising to develop the next generation of on-chip communication systems. However still, the lack of demonstration of active or reconfigurable counterparts has prevented its widespread adoption within the scientific community. The final objective of the proposed research effort will be to develop nanophotonic devices via digital metamaterials (DMMs) with an optical gain media for reconfigurability and incorporate these into networked systems to demonstrate full-scale functionality.

Optical Computing: In the 1980s and 90s, dedicated research in optical computing took place across the entire world. However, the results were not promising enough to surpass the performance of today's CMOS processors, and research in the following field waned [10]. Optical/Photonic computers are just regular computers with light taking the place of an electronic circuit to do the same thing. In principle, optical computing is equivalent to a nondeterministic Turing Machine. That is, it can solve any of the problems a quantum computer can and probably more. It is even better in the fact that it is less prone to error than a quantum computer. That is, while a quantum computer is probabilistic in accuracy, an optical one is deterministic. Nonetheless, with the current progress made in nanophotonics, I believe that it is an excellent time to reconsider optical computing. I propose to realize DMMs to do system-level design for the development of practical optical processors.

3. Collaboration and Research Funding

I have learned the value of collaborative research while working towards my Ph.D. under my advisor Prof. Sensale-Rodriguez and my co-mentor Prof. Rajesh Menon here at the University of Utah. I think that multidisciplinary research and collaboration are crucial for solving most of our current engineering problems. An area of particular interest in which I plan to collaborate with other disciplines strongly is on label free (bio)-sensing (biomedical applications), both for sensing as well as diagnostics and also for therapeutics (including circuits intended for implantable system applications such as in pacemakers, development of system-on-a-chip solutions, etc.). In this context, I plan to establish a direct collaboration between academia and the biomedical industry while working in R&D projects to understand their needs, and thus, try to develop new research lines that can lead to innovative solutions for some of their current problems. My intention is also to look for opportunities for collaborative multidisciplinary research in partnership with other faculty from XXX.

I will write proposals and seek funding from agencies such as NSF, AFOSR, DARPA, NIH, and SRC, both alone and in collaboration with other groups. My stay at Utah has provided me with extensive experience in expressing my ideas in front of audiences (i.e., by delivering talks at international conferences and project reviews) and learn how the proposal writing/funding mechanism works. In fact, I have been successful in securing a couple of small research grants ($10,000 & $15,000) from Amazon Cloud Credits for Research Program and National Science Foundation (NSF) for my proposal entitled **"Free Space Optical Devices Based on Computational Design of Diffractive Optic Elements" (Grant No.: 051241749381)** and **"Advancing compatibility of novel flat lenses with commercial lens design processes"** respectively.

My research program will be accompanied by the pursuit of a strong patent/publication record, and a constant thrive on inventing new technologies that can be transitioned into real-world applications. My goal is to leave my imprint in the field and to create new areas of application. I will also expand my professional service to the IEEE, OSA, and SPIE and enhance my participation in related societies.

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