Demonstration of Free-Space Optical Communications

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***Abstract*—We introduce a new communications technology for consumers in Smart Cities, which we refer to as Augmented-Reality Optical Narrowcasting (ARON). This technology has the potential to significantly enhance mobile consumer communications by enabling information exchange between multiple transmitters and multiple receivers using free-space optical data transmission in the near infrared. A practical communication range of 400 meters in broad daylight is achievable with miniaturized optics transmitting HD video, for example, to smartphones and 1,000 meters to vehicles. An augmented-reality-style user interface, wherein visual representations of available information sources are overlaid on a live display of local video imagery allows users to conveniently manage transmissions from multiple parties. The new technology is envisioned to be installed in smartphones and other mobile devices and in vehicles, opening new vistas for commerce and social interaction. We have demonstrated key features of the technology using custom optical communications hardware and software developed especially for this purpose.**

Keywords- optical communication; augmented reality; smartphones; automobiles; nonimaging optics.

I. INTRODUCTION

To demonstrate the feasibility and functionality of the Augmented-Reality Optical Narrowcasting (ARON) concept [1], we have developed and fabricated a Technology Demonstration Unit (TDU) that provides a communication channel in the 810-890 nm Near-Infrared (NIR) wavelength band, with a data rate greater than 1 megabit per second and an operational range tested to work in excess of 200 meters in broad daylight. The unit consists of an Optical Transmitter (OT) in Fig. 1 and an Optical Receiver (OR) in Fig. 2. This unit can transmit and receive HD video and other digital files.

II. THE TECHNOLOGY DEMONSTRATOR UNIT

An ARON Optical Beacon Receiver (OBR) measures the horizontal and vertical angular positions of ARON transmitters detected within its Field Of View (FOV) and then creates visual representations of the locations of the transmitters, including the identities of entities operating the transmitters. These representations comprise icons and text overlaid at the positions of these transmitters within live imagery produced by a video camera collocated with each ARON receiver. For example, the availability of information transmitted from a pizza restaurant may appear in the form of an iconic representation of a pizza accompanied by the name of the restaurant, where the icon and text are overlaid at the location of the actual restaurant within the live video imagery. Controls are provided for allowing users to opt to receive high-bandwidth information of interest to them from the pizza restaurant's ARON transmitter or from additional ARON transmitters that may also be viewable in the FOV.

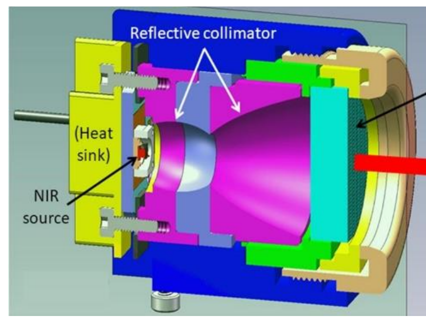

Figure 1. Cross-sectional perspective view of optical transmitter assembly for technology demonstration unit employing a nonimaging wineglass collimator.

The TDU's OT design comprises OT electronics, an incoherent solid-state NIR emitter, and a nonimaging beamforming optic. Our transmitter requires a mere 4 W of electrical power and has an exit-pupil diameter of 18 mm. The ARON system requires each OT to simultaneously transmit two types of modulated optical beams. The first type, referred to as a beacon, provides the means for an OR to: (1) detect the presence of OTs, (2) identify entities operating OTs, and (3) determine the positions of OTs within the FOV of the OR's visible-light camera. The second type of modulated beam, referred to as the signal, provides the actual information the operator of the OT wishes to send. Typically, the average data rate transmitted by an OT in the form of signals will be much higher than that transmitted in the form of beacons. Temporary obstructions of the beam path that may occur due to moving obstacles are handled effectively using forward error correction algorithms. To simultaneously transmit beacons and signals, the TDU uses a double-modulation scheme, in which a beacon having a data rate of 10 bits per second modulates a signal having a data rate greater than 1 megabit per second (ARON systems having far higher bit rates are feasible). The double-modulation scheme has the advantage of allowing it to utilize a single NIR source and beamforming optic to simultaneously transmit both beacons and signals.

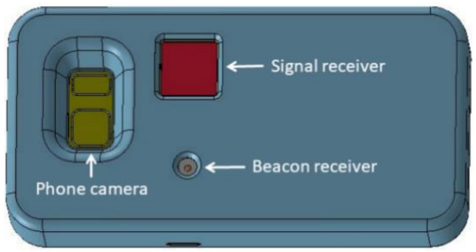

Figure 2. Optical receiver assembly of technology demonstration unit, mounted in a smartphone case.

Fig. 1 depicts a cross sectional view of the NIR source and beamforming optic for the TDU's OT. The efficient, highly compact nonimaging optical design of the beamforming optic utilizes an advanced reflective collimator followed by a Köhler homogenizer to transform the output of the source into a NIR beam that is highly uniform within an 8°-square angular region. The uniform square output beam allows copies of this optic, each with its own emitter, to be combined as modules to produce a customized tiled beam swath consisting of multiples of the 8°-square, arranged horizontally and/or vertically. A wide beam swath enables widely separated receivers to be able to simultaneously tune in to the transmission. The beamforming optical design used in the TDU is representative of a design that could be used for an OT mounted at a fixed installation (e.g., outside or inside a building) or on a vehicle. The wineglass collimator optic achieves a volume reduction factor of 2.5 compared to a conventional parabolic reflector. This is because the wineglass collimator is an aplanat and therefore experiences much less étendue dilution when collecting light from an extended source than the parabolic reflector.

The TDU OT electronics shown in Fig. 3 consist of a smartphone interfaced via USB On-The-Go (OTG) to a Universal Asynchronous Transmitter/Receiver (UART) which converts the byte-wise transmit data into a proprietary return-to-zero serial data format with a high level of embedded forward error correction. A current driver is used to modulate the solid-state NIR LED emitter with this data.

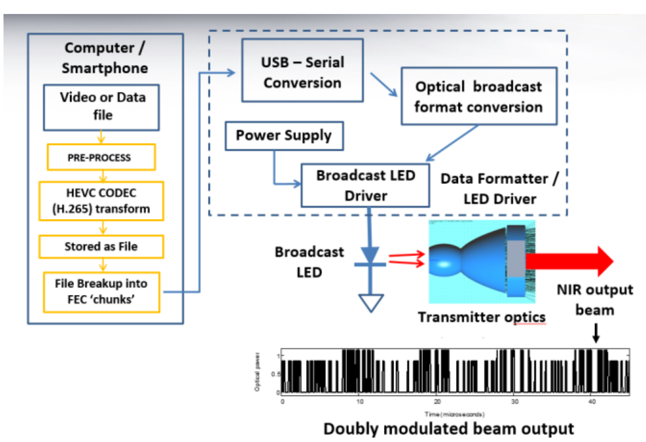

Figure 3. Technology Demonstrator Unit transmitter block diagram.

The OR design for the TDU (Fig. 4) comprises OR electronics, a beacon receiver, and a signal receiver, all mounted within a smartphone case and interfaced with a smartphone by means of a USB connection. An ARON app installed in the receiver smartphone provides the capability of combining beacon information received from OTs with live imagery produced by the phone's camera to create and display AR presentations.

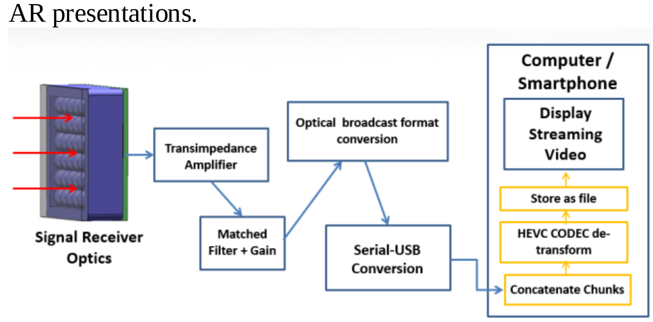

Figure 4. Technology Demonstrator Unit signal receiver block diagram

The TDU's beacon receiver is a monochrome NIR video camera, which serves the purpose of detecting beacon data transmitted by the OT and using this data to determine the angular position of the OT within the FOV of the visible-light camera. The beacon receiver also receives and decodes identifying information encoded in transmitted beacons, allowing the OR to identify the entity operating the OT. Once a beacon has been detected, the processor determines its horizontal and vertical position within the visible-light camera's FOV and generates and overlays an augmented reality icon with identifying text at the correct location on the live video imagery, where the icon and text represent the identity of the detected OT obtained from its beacon. Multiple beacons can be handled. These functions could easily be integrated with a cell phone's existing camera if the OR is also integrated into the phone, as opposed to being in a cell phone case for the TDU.

The TDU's signal receiver uses a 6x6 array of square-aperture lenslets to concentrate flux onto a 6x6 array of silicon photodetectors. The outputs of all 36 detectors are summed, amplified, filtered and digitized to produce the signal output. The signal receiver has a 3.6°-square FOV within which it can receive signals. Since this FOV is much smaller than the FOV of the beacon receiver and the phone's visible-light camera, in order to receive a signal from a detected OT, the TDU user needs to manually tilt the phone until the OT is within the signal receiver's FOV.

Fig. 5 depicts the display screen of the receiver smartphone after the ARON app has been activated, showing the live video feed, overlaid with a central box representing the FOV of the signal receiver and an icon and text representing a detected OT. To receive a signal from the detected OT, the phone is tilted manually until the icon is located inside the box, at which time signal data will begin to be received. Receipt of signal data will continue as long as the icon is kept

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within the box. Once received, the app allows the user to view the signal data in various ways.

Figure 5. Display produced by augmented-reality optical narrowcasting app in technology demonstration unit's receiver smartphone.

III. CONCLUSION

In this work, we have described the elements of a technology demonstrator unit that provides an optical communication channel in the 810-890 nm near-infrared (NIR) wavelength band, with a data rate greater than 1 megabit per second and an operational range tested to work in excess of 200 meters in broad daylight. In its planned production configuration, as an integrated internal component within a smartphone, an ARON receiver and optical assembly will ultimately occupy a footprint no larger than a conventional video camera. In this consumer configuration, the phone will not require tilting to receive signals.

REFERENCES

[1] N. Shatz and M. Squire, "Augmented-Reality Optical Narrowcasting," SMART 2023, The Twelfth International Conference on Smart Cities, Systems, Devices and Technologies, Nice, France, 2023.