Drone Swarms for Sensing-of-Sensing

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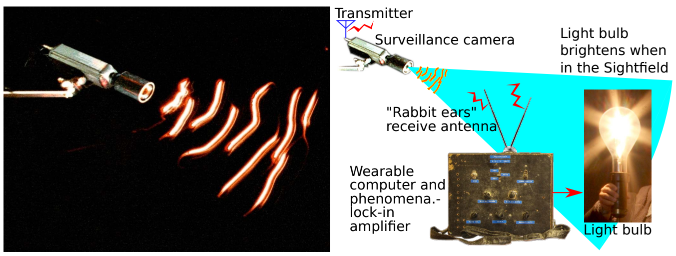

Fig. 1. Mann's metaveillance apparatus from the mid 1970s [15], [16], [17] used one or more light bulbs fed from a wearable computer and lock-in amplifier designed to lock in on television signals from surveillance cameras. The light bulb transitions from a dim red glow to a brilliant white whenever it enters the camera's field-of-view, and then the bulb brightness drops off again when it exits the camera's field of view. Waving it back and forth in a dark room reveals to the human eye, as well as to photographic film (picture at left) the camera's capacity to "see".

***Abstract*—The use of drone swarms is proposed for the sensing-of-sensing (metaveillography and metaveillogrammetry) with applications in surveillance audits, security audits, autonomous-vehicle sensory verification, and testing automotive sensors and automotive sensing.**

I. Background and Related Work

The sensing-of-sensing (also known as *metasensing*) is an area of increasing importance because people are now surrounded by a proliferation of sensors [1] [2] that they often know little about in regards to their efficacy, or agency e.g. whether the sensors are for surveillance [3], [4], [5], [6], [7], [8] , sousveillance [9], [10], [11], [12], [13], [14], or networked machine intelligence, which we call IoT^3 (Internet of Things-That-Think).

The Greek word "meta" means "beyond". For example, metadata is data about data. Likewise, metaveillance is the veillance of veillance (sensing sensors and sensing their capacity to sense). See Fig. 1 to see the original invention that led to the study of metaveillance.

Metaveillance was created as both visual art [18], [16], [17] and scientific exploration [15], [19].

II. The Case for Drones

Metaveillography is proposed as a scientific measurement to visualize the capacity of sensors to sense. Consequently, high spatial resolution and repeatability are mandatory criteria. There are various methods by which metaveillographs can be created, including wearable SWIMs, 2D plotter SWIMs (Fig. 2), robotic arms, and 3D plotter SWIMs [20]. These methods are effective in many circumstances, but there are situations when they fall short, such as when the sensors are

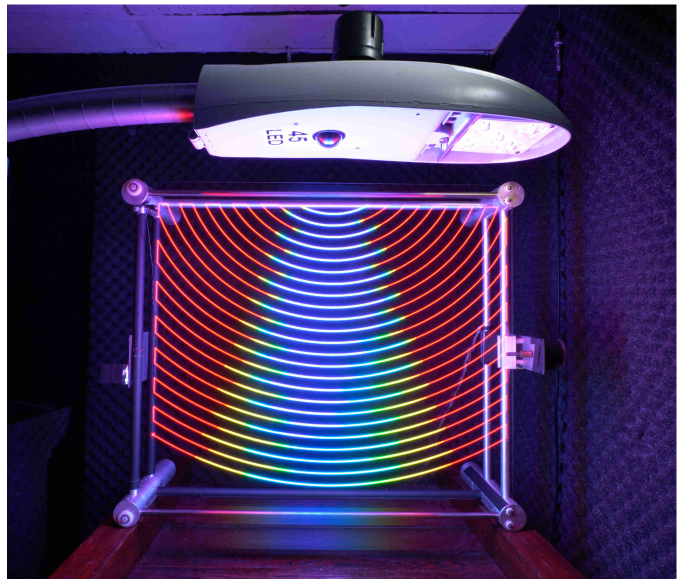

Fig. 2. Photograph of a smart street light with a metaveillographic mechanism showing the streetlight's built in camera and its capacity to sense. The physical phenomenon underlying the picture can be seen clearly in the form of the hysteresis of even and odd arcs. Compare this with Fig. 1

in difficult to access locations. This situation can arise when a sensor is placed high on a ceiling, in an area that pedestrians cannot access, or in high traffic areas where there is only a very limited amount of time to create a metaveillograph.

Drones provide a significant advantage over other methods because of their ability to fly to high places and to transgress bounds (terrain, hostility, traffic, and fencing) that humans or ground-based robots cannot normally cross [21] [22]. The ability to fly high is important, as most surveillance cameras are mounted in areas in which it would be difficult or impossible to setup a plotter or reach the sensor with a portable SWIM.

Additionally, drones are versatile [23], as meta-sensing can be performed whilst flying over small areas (e.g. in a bathroom stall for sensing of sensors used in electronic toilet flushing) or very large areas (a foyer or cathedral where surveillance is being analyzed). Drones are also much cheaper than an industrial robotic manipulator. Both the versatility and much lower cost of the drones means that metaveillographs can now be created quickly, cheaply, and effectively. This extends the possibilities for hobbyists and professionals alike to explore metaveillance almost anywhere.

Finally, in the past, most metaveillographs were created in 2D-space. Utilizing the drones allows research to continue into 3D-space. This is significant because imaging in 3D-space

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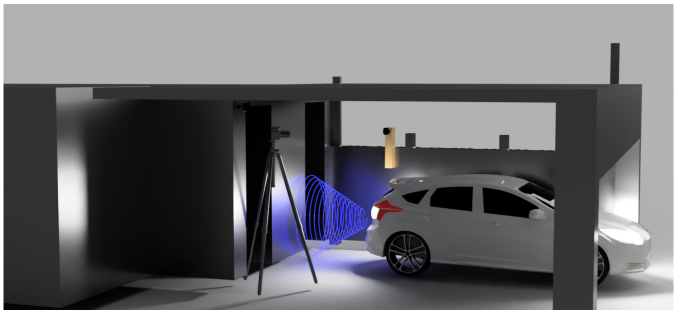

Fig. 3. Experimental setup utilizing drones, HTC Vive VR™ system, LEDs, and camera.

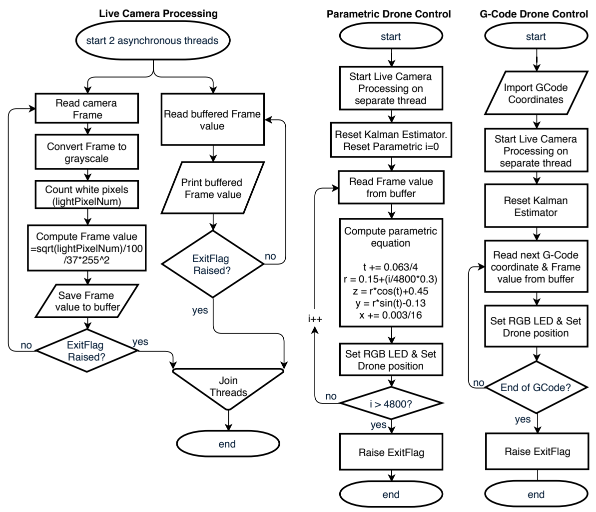

Fig. 4. Flowcharts for the Live Camera Processing, Parametric Drone Control, and G-Code Drone Control routines

represents a measure of the true veillance field of a sensor [24]. For those researching metaveillance, it also creates images that provide an intuitive understanding of the veillance field.

III. Drone-based metaveillance

The goal of drone-based sensing-of-sensing is to investigate metasensing in applications where 3D space is needed to fully understand the sensor, such as the sensory systems of electric, autonomous vehicles [25], [26]. We also wish to investigate sensors that are installed in locations that are difficult to access

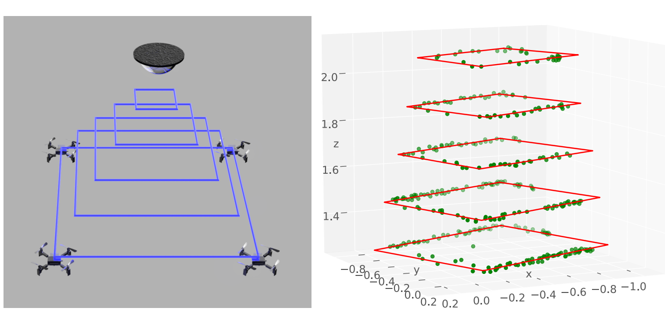

Fig. 5. Left: CAD Model depicting the setup for metaveillography of a surveillance camera. Right: Computerized 3D model of veillance flux.

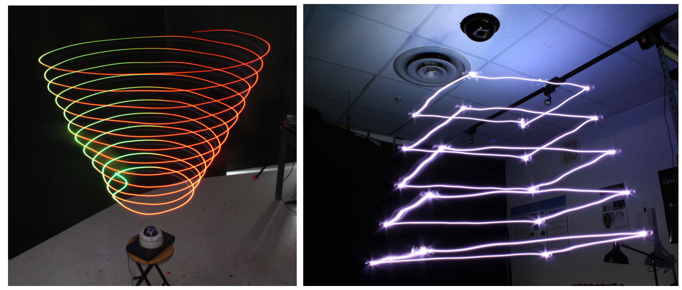

Fig. 6. Left: Helical flight path metaveillograph of a dome surveillance camera, placed on a stool for testing purposes. Right: Skeletonized metaveillograph of a surveillance camera, depicting the boundaries of the sensor's veillance field in 3D space.

[27], [28], [29], thus veillance of ceiling mounted security cameras is investigated.

To create a metaveillograph of a vehicle, a dark parking lot was setup with all of the technology needed to create a metaveillograph. Fig 3 depicts this setup.

The Bitcraze Crazyflie™ 2.1 drones were chosen due to their ability to fly in the dark, as most drones use optical flow techniques that do not work in complete darkness. HTC Vive™ Base Stations [30] are used to pinpoint the location (localization) of the drones in 3D-space. The Crazyflie's™ software and hardware are both open source as well, allowing us to make both hard and soft modifications to the system.

These drones were used to create metaveillographs in 3D space as they followed a flight path around the sensor under test. On the drones was mounted a ring of RGB LEDs on the bottom, two forward-facing white headlight LEDs, and a single top-mounted RGB LED. These LEDs were used in various configurations as test lights and as metaveillographic lights. The test light provides a stimulus to be sensed by the sensor-under-test (e.g. camera), while the metaveillographic light serves to show the metaveillance of the sensor-under-test. The metaveillographic light is RGB, and its colour is a function of the sensing of the camera. When the test light is not sensed by the sensor-under-test, the metaveillographic light is red. When the test light is strongly sensed, the metaveillographic light is blue. The frame captured from the testing camera is processed by first converting to gray-scale colour space, then converting to black-and-white by a threshold, and counting the number of white pixels. The number of white pixels is then passed into an activation function to determine if the metaveillographic light should be blue or red (or an RGB gradient between these colours). A long exposure photo is then taken by an external camera. This captures many values of the metaveillographic light in 3D-space, constructing an image that reveals the veillance flux of the sensor that is being sensed.

The drones' flight is controlled from the command station server using radio communication (Bitcraze Crazyradio™ PA radio dongle device). Every 0.02 seconds, a new point in 3D-space is sent to a drone over the radio link. The drone travels to this location and then waits for the next command.

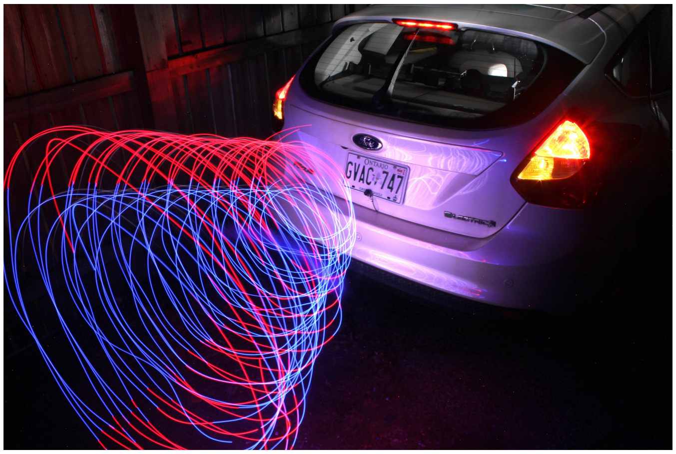

Fig. 7. Metaveillograph of an electric, semi-autonomous vehicle.

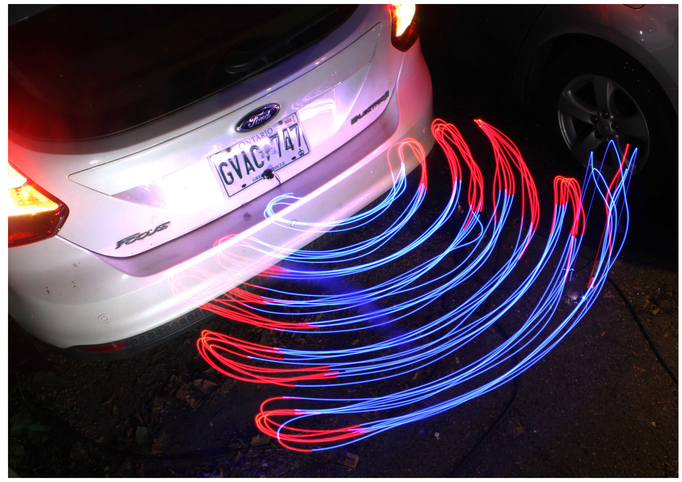

Fig. 8. Metaveillograph of a backup camera captured by the drones flying arcs in a 2D plane.

Three different methods were developed in order to generate drone flight paths. For some paths, parametric functions were used to create cones, circles, etc. Another method was first developing the flight paths in CAM (Computer Aided Manufacturing) software. The tool path designed in CAM software was then exported to G-Code, extracted the Cartesian coordinates, rotated, and translated in order to fly a path around the sensor. Flowcharts for these two processes are shown in Fig 4. The final method was to generate the paths dynamically. The drones would sweep a large planar area under the camera, and the command station would mark whenever the drone flies into or out-of the field-of-view of the camera. These markings would represent the boundary points of the camera's field-of-view (Fig 5, Right). The boundary points would then be used to compute the drones' flight path by fitting four straight lines on the data points to form a rectangle and then calculating the four intersection points at the four vertices of the rectangle. The drones would fly only at the boundaries of the camera's field-of-view (Fig 6, Right). The entire process would then be repeated at various distances from the camera to achieve a 3D model. This final method was the most versatile because a camera can be re-positioned anywhere within the area being swept, without requiring any changes to the drone's code. In contrast, moving the camera would require translating or rotating the parametric functions and G-Code accordingly.

IV. Results and Discussion

Drones have been instrumental in creating 3D and 2D metaveillographs of autonomous vehicles, as demonstrated in Figs 7 and 8. As we approach a future of ubiquitous self-driving cars, the efficacy of the sensory systems of autonomous vehicles comes into question [31]. This is why we have developed the method of imaging the sensory capabilities of autonomous vehicles, so that end-consumers can know that their cars are safe [32], [33], [34].

Also, drones have been effective in achieving the goal of metaveillance in hard-to-access areas, see Fig 6. This development may be used to identify surveillance coverage leaks, giving insight into the safety level of security and recording systems. A high-demand commercial application of this technology is quantifying the safety level of a location according to the metaveillance flux density coverage. This quantitative measure of veillance flux can then serve as a requirement for insurance premiums.

An important aspect of our results is the fact that these methods yield photos of veillance. Thus, this is a technique that preserves information as photographic evidence. Photographic evidence is necessary and holds great power in a court of law, where evidence is most always considered stronger than testimony.

Drones have proven useful as a tool of metaveillance. However, there exist some drawbacks. The drones' precision outdoors can sometimes be less than optimal, depending on factors such as wind and solar IR radiation. The Crazyflie™ 2.1 drones' motor mounts and expansion hats are fragile, but this is somewhat offset by the ease of 3D-printing new parts and finding schematics through Bitcraze's™ website. In the future, we aim to explore the creation of an Augmented or Virtual Reality visualization of any sensor's veillance flux by utilizing the techniques we have developed of using drones to create high resolution computerized 3D models of a sensor's veillance flux (See Fig 5).

V. Conclusion

A novel metaveillance technique (visualizing the veillance field of sensors) has been implemented using drones. This method provide consumers (car manufacturers, banks, malls, and anyone who relies on sensors) an intuitive understanding of their veillance efficacy, whether this be for surveillance, sousveillance, or autonomous and electronic systems.

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