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SENSOR SYSTEM SCALING ISSUES

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SENSOR SYSTEM SCALING ISSUES

Gregory H. Canavan

A model for IR sensor performance is used to compare estimates of sensor cost effectiveness. Although, data from aircraft sensors indicate a weaker scaling, their agreement is adequate to support the assessment of the benefits of operating up to the maximum altitude of most current UAVs.

This note presents a model for infrared (IR) sensor performance, discusses its scaling, and uses it to compare estimates of sensor cost effectiveness. The model characterizes the sensors with parameters determined by detailed MRT calculations and measurements. Its analytic solutions predict ranges of 2 to 6 km for good visibility and 1 to 2 in poor. It can also predict the weights of sensors required to recognize targets, which increase rapidly with range. Data from aircraft sensors indicate a weaker scaling of mass on range. Thus, the model and aircraft data give quite different predictions of the ratio of swath width to sensor mass. However, their agreement at an altitude of about 8 km is adequate to support the assessment of operating up to the maximum altitude of most current UAVs.

Range prediction. The model for range prediction is defined by the equation

$$T e^{-kr} = A e^{mNr/h}, \quad (1)$$

where T is the target's temperature difference from its surroundings, k is the atmospheric attenuation, r is the range to target, A is related to the sensor's sensitivity ($1/D^*$), $N \approx 4$ is the number of line pairs across the target required for recognition, h is the dimension of the target in meters, and m (cycles/mrad) is related to the MTF of the sensor optics. Table I gives the values of A and m inferred from MRTs provided by NVL for five capable FLIRs that would fit on UAVs. The sensor range is then

$$r = \ln(T/A)/(mN/h+k), \quad (2)$$

from which the dependence of r on T and A is weak, but its dependence on m is strong, except when k is large, i.e., when visibility is very poor. The five NVL sensor's ranges vary from about 2 to 4 km for excellent visibility, where the Versatron gets up to about 6 km, but they all drop to 1 to 2.5 km for the conditions characteristic of northern Europe.

Weight prediction as a function of range is performed by solving Eq. (1) for

$$m = [\ln(T/A)/r - k]h/N, \quad (3)$$

relating the MTF parameter m to the optics diameter D through $m = C\lambda/D$, where $C = 2$ to 4 for current systems, and converting D to mass M through $M \approx KD^3$, where $K \approx 2,000 \text{ kg/m}^3$ for current systems. Figure 2 shows D and M for a sensor with the Versatron's A and whatever m is needed to meet the range required for good visibility conditions. The size naturally matches that

of the actual Versatron at a range of about 7 km; the mass is scaled to match it there. For shorter ranges the masses are so small that they would be dominated by fixed masses. For longer ranges they grow rapidly for $k > 0$, reaching about 400 kg by 20 km.

Aircraft sensor data are also available in this size range. They are presented in Fig. 3 along with the NVL sensor masses and ranges. The aircraft sensors are not identified, but they are at the smallest and largest masses and at the longest ranges. The data turn up sharply for ranges greater than 10 km, but it is not possible to tell from the few points there whether they turn up as fast as that from the above model in Fig. 2.

Figure of merit. A rough figure of merit for sensors is the swath they can cover. For a sensor that covers 45 degrees each side of nadir, its height is $r/\sqrt{2}$ and its swath is twice that or $r\sqrt{2}$. Its cost is typically proportional to its mass, so its ratio of benefit to cost is proportional to $r\sqrt{2}/M$, which is shown in Fig. 3 for the sensor with Versatron scaling of Fig. 2. The ratio falls rapidly with altitude, roughly as $1/z^2$ for z small, although the small sensor masses there would in practice be masked by fixed integration masses. The second curve shows the scaling inferred by NRC from five airplane sensors, which is $M_N = 1.7r^{1.35}$, which gives $r\sqrt{2}/M_N \approx 0.8/r^{0.35}$, which varies much more slowly than the first. The curves cross at about 8 km, but they disagree by a factor of 5 by 11 km. The actual Versatron only reaches an altitude of about 5 km, where the discrepancy is again about a factor of five.

Summary and conclusions. This note presents a model for IR sensor performance, discusses its scaling, and uses it to compare estimates of sensor cost effectiveness. The model characterizes the sensors with parameters determined but detailed MRT calculations and measurements. It admits of analytic solution, predicting ranges of 2 to 6 km for good visibility and 1 to 2 in poor. It can also be used to predict the weights of sensors required to recognize targets at given ranges, which increase rapidly with range. Data from aircraft sensors indicate a weaker scaling. The model and aircraft data give quite different predictions of the ratio of swath width to sensor mass, although their agreement at about 8 km is adequate to support the assessment of the benefits of operating up to the maximum altitude of most current UAVs.

SUMMARY UAV FLIR PAYLOAD INFORMATION

MODEL	INFRAMETRICS 445G MKII	IAI TAMAM POP-100	VERSATRON	RAFAEL TOPAZ	ULTRA 3000D FSI
FPA TECHNOLOGY	InSb	PtSi	InSb	HgCdTe	PtSi
ARRAY FORMAT	256x256	320x240 Hz Dither	256X256	240 Scanning (x240)	320x244
SPECTRAL BAND, um	MWIR 3.4-5	MWIR 3.5-5	MWIR 3-5	LWIR 8-12	MWIR 3.5-5
WEIGHT (lbs)	39	33	45	52	36.7
POWER REQ. (Watts)	200	130		100	130
NFOV (deg)	2.2	4X3	1.2X0.9	1.5X1.9	5X4
WFOV (deg)	9.3	12.7X9.5	7X5.2	5.3X6.7	25X19
NIFOV (mrad)	140	182	89	85X110	
NFOV eff (deg)	2.2	3.464101615	1.039230485	1.688194302	4.472135955
WFOV eff	9.3	10.98407939	6.033241252	5.959026766	21.79449472
NIFOV eff(deg)	8.022	10.4286	5.0997	5.540646307	
WIFOV (mrad)			560		
STABILIZATION (urad)	75	42	50	25	
OPTICAL SPEED	F/3	F/1.5	F/4	F/1.8	
WFOV DETECTION, km (Veh, 0.75 c/mrad, 4 deg. dt,	3.63	4.14	5.6	6.1	4.5
NFOV RECOGNITION, km (Veh, 3 c/mrad, 4 deg, dt, 3.5m target)	3.42	3.34	8.3	5.4	3.4
NFOV DET/REC, km (Man, 0.75 c/mrad, 4 deg dt, 0.75m	3.16	3.34	3.2	1.4	
SENSITIVITY (NETD, deg)		2.92	0.025	0.1	
NOTES:			F/4 130mm Aper., 500mm/80mm lens	Doesn't indicate TDI staring MWIR options. 3 FOV	110mm Lens
EXPONENTIAL CURVE FIT PARAMETERS FOR MRTD					
A* (300K)	0.0034	0.01	0.0022	0.035	0.012
m* (300K)	1.44	1.54	0.88	0.85	2
**50% PROB. REC RNG,km - 0.8/km Atm ext., dt=4, tgt	2.49	2.05	3.19	2.04	1.75

*NOTE: MRTD = $A \exp (mf)$; where f = cycles/mrad for task*range (km)/target dimension

**50% PROBABILITY OF DETECTION/RECOGNITION = $-\ln(A/DT)/(2 \cdot \text{Atm ext.} + m \cdot \text{cycles/Tgt dim.})$;

TABLE 4.

NVL sensor range vs vis

Fig. 1 Sensor ranges.

wt & D vs range

2. Sensor range and diameter versus weight.

wt vs r: NRC

Versatron vs NRC W/m vs z

4 Comparison of Versatron and NRC swath/mass estimates.

wt & D vs range

Sensor range and diameter versus weight.

sensor range (km)

$$h = 0.01 / km$$

swath/mass vs z; Versatron

Ratio of cost to mass vs altitude.

altitude (45 deg swath) ($h = 0.41 / \text{km}$)