MECH5720 Sensors and Signals

UNIVERSITY OF SYDNEY · ENGINEERING · POSTGRADUATE

Full guide + ask Sia about MECH5720

SIDE 1/2 MODEL → METHOD → ASSUMPTION → DIAGNOSTIC OPEN-BOOK EXAM SHEET S2 2026 · formulas, rules & decision tables

1 · Exam map

COURSE + BRIEF

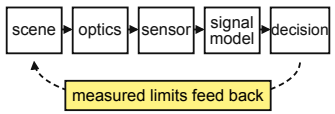
Labs 40% | Report | Tal | Final 40%

COMPONENT	WEIGHT	FORMAT
Laboratory submissions	40%	Four group submissions; 10% each
Major Project report	15%	Calibrated experiments, analysis, evidence
Major Project talk	5%	Presentation; pitch is a project hurdle
Final supervised written exam	40%	Two-hour open-book exam; separate hurdle

"Final Exam (individual) 40% supervised 2 h, open book, in the formal exam period" *(MECH5720 Lecture 1A Introduction slides, Semester 2 2026)*

2 · Universal solve chain

CH 1, 9



Co-design loop: the decision is only as defensible as the calibrated measurement chain.

1. **Represent:** choose `y = h*x+n`, `y = Mx+n` or `y = Ax+n`; define coordinates, dimensions and units.
2. **Challenge:** name the assumption—linearity, shift/depth invariance, stable scene, adequate sampling, Lambertian view, calibrated geometry.
3. **Compute:** keep signs, normalisation and physical units visible; do not stop at a scalar.
4. **Diagnose:** predict another symptom and a control that separates the closest alternative.
5. **Bound:** state the tested field, depth, exposure, frequency and noise range.

RESIDUAL TEST

```
r = y - ŷ = y - A x̂
Structured r → likely model/calibration fault.
Small r alone → may still be noise fitting.
```

EXAM MOVE *Full rank answers uniqueness; conditioning answers survival under noise. A plausible image is not proof of measured detail.*

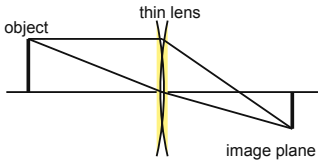
2A · Operator audit

CH 1

AUDIT QUESTION	EVIDENCE	IF IT FAILS
Does each unknown change y?	Distinct columns / measurement directions	Unidentifiable scene states
Are directions independent?	Rank test	No unique noiseless recovery

3 · Lens geometry

CH 2



Three-ray construction checks image position, inversion and scale before algebra.

THIN LENS — FIRST-ORDER SENSOR PLACEMENT

```
1/f = 1/dₒ + 1/dᵢ   ⇒   dᵢ = 1/(1/f - 1/dₒ)
m = -dᵢ/dₒ = image size/object size
Use: ideal conjugate distance and signed magnification.
```

CHECK	MEANING / ACTION
One unit	Convert f and d_o before reciprocals.
m < 0	Image inverted; |m| gives reduction/enlargement.
Real camera	Focus sweep checks principal planes, thickness, aberration, tolerances and sensor placement.
Defocus	Sensor displaced from ideal d_i; test known target across position.

4 · Sensor chain & limits

CH 2

★ *Pixel* integrates light over area, wavelength response and exposure; quantum efficiency maps photons to electrons; finite well capacity, offset, gain and quantisation form the recorded value.

LIMIT	SIGNATURE	DISCRIMINATING CONTROL
Shot noise	Photon-count fluctuation; variance grows with expected count	Repeat at changed exposure/light
Read noise	Electronic uncertainty at readout	Dark frames; compare exposures
Dark/fixed pattern	Structured offset/response	Dark + uniform-field captures
Quantisation	Analogue values become discrete codes	Inspect code steps; bit depth ≠ usable range
Saturation	Many bright inputs share ceiling	Shorter exposure/smaller aperture

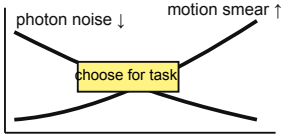
F-NUMBER

```
N = f/D   (focal length / effective aperture diameter)
Compare apertures only with focal length visible.
```

Gain rescales the recorded signal; it does not create photons. Report the usable span between noise floor and saturation, not nominal bit depth alone.

5 · Trade-offs & sampling

CH 3



Longer exposure collects more light but integrates more motion.

CONTROL ↑	BENEFIT	COST / CONFOUND
Exposure time	More photons; shot/read-noise influence often improves	Motion smear; saturation
Aperture D	More light; shorter exposure possible	Narrower depth of field; aberrations
F-number N	Stopping down can enlarge depth of field/reduce some aberration	Less light; eventually diffraction
Gain	Uses output code range	No new photons; noise/clipping can worsen
Magnification	Spreads target over more pixels	Changes field of view/working distance
Sampling density	Raises representable spatial frequency	Smaller pixels collect fewer photons at equal irradiance/time

SAMPLING DECISION

```
v = cycles / pixels   ;   v_N = 0.50 cycles/pixel
v > 0.50 → aliases fold to misleading lower frequencies.
Repair before sampling: magnify, sample more densely or optically prefilter.
```

TRAP *Interpolation after capture can smooth an image but cannot identify which high frequency already folded.*

6 · Bottleneck diagnosis

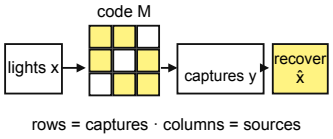
CH 2–3

SYMPTOM	CHANGE ONE FACTOR	CLOSEST ALTERNATIVE
Moving edge streak	Shorten exposure	Static target checks defocus
Fine pattern changes after subpixel shift	Increase sampling/magnification	Optical blur should be less phase-sensitive
Depth range sharpens when stopped down	Sweep aperture with compensated exposure	Very small aperture adds diffraction
Sharpness score rises with speckle/ringing	Known target + repeated capture	Metric may reward noise, not detail

Record geometry, exposure, aperture, gain and measurement region. A control must isolate the claimed cause; changing several settings destroys causal attribution.

7 · Multiplex & relight

CH 4



Code order is physical: swapping files or source labels creates structured cross-talk.

LINEAR CODING

```
y = Mx + n
Square/full rank: x̂ = M⁻¹y
Relight with weights w: I_new = Σᵢ wᵢ Iᵢ
```

QUESTION	TEST	CONSEQUENCE
Enough information?	Rank / dependent columns	Rank loss → distinct sources give same data
Stable?	Singular values; condition number	Weak direction amplifies noise/mismatch
Correct order?	One source at a time	Recovered energy should enter expected channel
Linear?	Several intensity levels	Saturation or response curvature breaks superposition
Scene stable?	Repeat code sequence	Motion violates one fixed x across captures
Offsets removed?	Dark/ambient capture	Otherwise inverse mixes bias into all sources

Multiplex advantage is conditional. Read-noise-dominated capture may benefit; photon noise, saturation, timing drift and motion can remove the gain. State the operating regime.

8 · Verification loop

CH 4

1. Black/ambient-correct coded frames.
2. Write every code row before inversion.
3. Recover source images; preserve physical scale.
4. Forward-check $M\hat{x} \approx y$.
5. Directly capture one lighting combination and compare it with the synthetic relight.

EXAM MOVE *An inverse returning numbers proves only that the algebra ran. Use forward reconstruction and single-source trials to test whether the numbers describe the measured transport.*

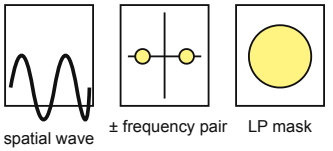
8A · Relighting bounds

CH 4

CHOICE	VALID WHEN	WARNING
Weighted sum $\Sigma w_i I_i$	Camera/illumination response linear and scene unchanged	Extreme or negative weights amplify recovery error and may lie outside captured lighting

9 · Fourier method

CH 5



For a real cosine, conjugate peaks lie along the direction of intensity change.

TRANSFORM PAIR

```
y = h*x + n   ⇔   Y = HX + N
Convolution in space ↔ multiplication in frequency.
```

READ	MEANING / EXAM CONSEQUENCE
Magnitude |X|	Amount of each spatial frequency
Phase ∠X	Alignment that builds edges/recognisable structure
Peak direction	Direction of change; perpendicular to visible stripes
Shifted display	Moves zero frequency to centre; transform itself unchanged
Low-pass	Attenuates rapid variation; broadens transitions
High-pass	Emphasises changes and often noise
Abrupt mask	Narrow frequency support spreads in space → ringing

Axis units matter. Use image size and sample spacing to convert bins to cycles/pixel or cycles/mm. A log-magnitude display changes appearance, not coefficients.

10 · Sampling & boundaries

CH 5

- Sampling repeats the continuous spectrum; overlap folds high frequencies into baseband.
- Anti-alias filtering must occur before discrete sampling.
- The DFT assumes periodic extension: opposite edges meet under circular convolution.
- Zero padding, reflection and windowing create different boundary evidence; report the choice.
- For a real image, preserve conjugate symmetry; one-sided editing generally makes a complex result.

TRAP *The DFT is the transform; an FFT is an efficient algorithm for computing it. Switching between them does not remove optical blur.*

10A · Spectrum prediction

CH 5

1. **Write the wave:** identify which coordinate changes and its frequency in declared units.
2. **Place peaks:** a real cosine gives a signed conjugate pair; distance from zero gives frequency magnitude.

11 · PSF → OTF → MTF

CH 6

TRANSFER DEFINITIONS

```
H = ℱ{h}   ;   MTF = |H|   ;   phase transfer = ∠H
DC term → total throughput. Near-zero |H| → weakly recorded pattern.
```

Measure assembled-system h. Open area/DC tests throughput; normalised 2-D |H| tests support; centre/corner and multi-depth PSFs test kernel validity.

12 · Wiener recovery

CH 6

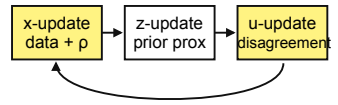
REGULARISED INVERSE

```
X̂ = H*Y / (|H|² + K),   K > 0
Plain inverse: X̂ = Y/H
Use: suppress amplification where measured support is weak.
```

Choose K by sweeping a known target; compare residual, target error and ringing. Before tuning, test whether the PSF matches field position, depth and boundary policy.

13 · Lensless + ADMM

CH 7



stop from residuals + validation, not looks

ADMM separates measurement agreement from the prior, then reconciles the copies.

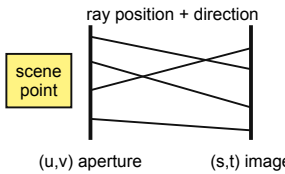
OBJECTIVE + CYCLE

```
min_x  ½‖Ax-y‖² + λR(x), with x=z
x ← argmin ½‖Ax-y‖² + (ρ/2)‖x-z+u‖²
z ← prox_(λ/ρ)R(x+u)   ;   u ← u+x-z
```

Diagnose: data residual tests sensor agreement; primal tests x−z; dual tests movement. λ sets prior strength; ρ changes numerical negotiation. A^* backprojects; it is not A^{-1}.

13A · Light fields & depth

CH 8



Two-plane coordinates retain direction; EPI line slope and view disparity encode depth.

SHIFT-AND-SUM REFOCUS

```
I_α(s,t) = (1/N) Σ L(u,v,s+k(α)u,t+k(α)v)
Chosen-depth features align; other depths blur.
```


Semester 2 formal examination period, from 16 November 2026 (the Exams Office publishes the exact date). Check your unit's exam rules for any limit on what may be brought in.

MECH5720 Sensors and Signals · Worked Drills

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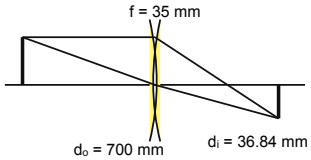
SIDE 2/2 WORKED NUMBERS · TRAPS · METHOD CHOOSER · FAST RECALL

OPEN-BOOK EXAM SHEET

Show model, substitution, answer, interpretation, control

14 · Worked: thin lens

CH 2 · EXAMPLE



The negative magnification records inversion; the magnitude records reduction.

Given: f = 35 mm, d_o = 700 mm. Find ideal d_i and m.

1 · MODEL

$1/d_i = 1/35 - 1/700$

2 · COMPUTE

$1/d_i = 19/700\ mm^{-1}$

$d_i = 700/19 = \mathbf{36.84\ mm}$

3 · SCALE + SIGN

$m = -36.84/700 = \mathbf{-0.0526}$

Interpret: ideal sensor plane 36.84 mm from the lens principal plane; negative m means inverted, |m| means reduced. **Physical check:** focus sweep because thickness, principal-plane offsets, aberrations and tolerances are omitted.

15 · Check: aliasing

CH 3 · EXAMPLE

Given: 22 cycles across 40 pixels.

FREQUENCY

$v = 22/40 = \mathbf{0.55\ cycles/pixel}$

$0.55 > v_N = 0.50 \rightarrow$ **aliases**

Acquisition repair: increase optical magnification or sampling density, or prefilter before sampling. Interpolation is too late.

MARK-BEARING LINE	WHAT IT PREVENTS
Write cycles/pixel	Unit-free comparison errors
Compare with 0.50	Calling every fine pattern "high frequency" without a limit
Name pre-sampling repair	Claiming display enlargement recovers lost identity

16 · Aperture mini-drill

CH 2–3 BODY

For f = 50 mm: D = 10 mm gives N = 50/10 = **5**; D = 25 mm gives N = 50/25 = **2**. The 25 mm pupil admits more light and tends to reduce depth of field. Separate the radiometric test (same exposure/gain) from the geometric test (compensate brightness).

MEASURED APERTURE COMPARISON

$D_1 = 6$ mm, $D_2 = 3$ mm → ideal area ratio $= (6/3)^2 = 4$

Measured black-subtracted means: $720/165 = \mathbf{4.36}$

The ratios are close, not identical: transmission, vignetting and sensor response can shift the result. Hold exposure, gain, scene and lens fixed.

17 · Worked: demultiplex

CH 4 BODY



Pairwise codes are solved per pixel, then checked against every recorded capture.

Given: $M_1 = I_1+I_2 = 90$, $M_2 = I_1+I_3 = 70$, $M_3 = I_2+I_3 = 60$ raw units after offset removal.

RECOVER I_1

$2I_1 = M_1+M_2-M_3 = 90+70-60 = 100$

$I_1 = \mathbf{50}$

BACK-SUBSTITUTE

$I_2 = 90-50 = \mathbf{40}$

$I_3 = 70-50 = \mathbf{20}$

FORWARD VERIFICATION

$50+40=90;\ 50+20=70;\ 40+20=60$ ✓

Rows are capture recipes; columns are source responses. Writing the matrix first prevents accidentally inverting the transpose or applying a correct inverse to misordered files.

18 · Stability check

CH 1 · EXAMPLE

$y_1 = x_1 + x_2$, $y_2 = x_1 + 1.01x_2$; matrix rows [1,1] and [1,1.01].

UNIQUENESS ≠ STABILITY

$\det(M) = 1(1.01)-1(1) = \mathbf{0.01 \neq 0}$

Unique noiseless solution, but rows are nearly parallel → errors cause large changes.

FAILURE	OBSERVED PATTERN	TEST
Poor conditioning	Noise spread across recovered sources	Singular values + perturbation simulation
Code-order error	Structured channel swap/cross-talk	One source at a time
Black offset	Bias mixed into every source	Dark/ambient subtraction
Motion	Ghosting inconsistent across code sequence	Repeat faster/static capture

Design improvement: use more distinct response vectors or a complementary measurement; compare singular values and recovery error under realistic noise.

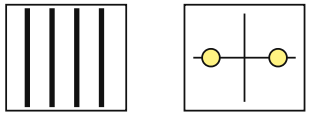
18A · Two-source speed check

CH 4 · EXAMPLE

$y_1 = x_1 + x_2 = 10$, $y_2 = x_1 - x_2 = 4$. Add equations: $2x_1 = 14 \rightarrow \mathbf{x_1 = 7}$. Subtract the second from the first: $2x_2 = 6 \rightarrow \mathbf{x_2 = 3}$. Verify: 7+3=10 and 7−3=4.

19 · Check: Fourier orientation

CH 5 · EXAMPLE



Frequency direction is perpendicular to stripe orientation.

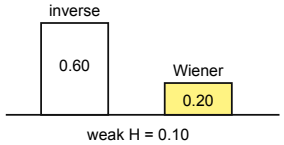
Given: intensity varies as $\cos(2\pi \cdot 0.2x)$.

1. Dependence on x → frequency vector lies on horizontal f_x axis.
2. Real cosine → conjugate impulses at $\mathbf{f_x = \pm 0.2}$ **cycles/pixel**.
3. Constant-phase lines are vertical → visible stripes are vertical.
4. Magnitude gives component strength; phase preserves alignment.

FAST CHECK *Horizontal intensity change ↔ peaks on the horizontal frequency axis ↔ vertical stripes.*

20 · Worked: Wiener coefficient

CH 6 · EXAMPLE



Regularisation suppresses an unstable weakly supported coefficient.

Given: real H = 0.10, Y = 0.06, K = 0.02.

REGULARISED ESTIMATE

$H^2 = 0.01;\ \text{denominator} = 0.01+0.02 = 0.03$

$HY = 0.006$

$\hat{X} = 0.006/0.03 = \mathbf{0.20}$

COMPARE PLAIN INVERSION

$Y/H = 0.06/0.10 = \mathbf{0.60}$

Interpret: Wiener recovery trades detail for reduced amplification where measured transfer support is weak. Sweep K on a controlled target; track residual, target error and visible ringing together.

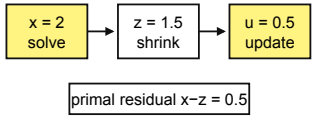
21 · Transfer traps

CH 6

WRONG SHORTCUT	CORRECT MOVE
Use binary mask as h	Measure the assembled-system PSF
Equal open area ⇒ equal recovery	Separate throughput from frequency support
Tune one K for every field/depth	First test the operator at corners and ranges
Radial MTF only	Inspect 2-D support for directional weakness

22 · Worked: one ADMM cycle

CH 7 · EXAMPLE



After one cycle the split variables still disagree, so convergence has not occurred.

Given: A = 1, y = 3, ρ = 1, z = 1, u = 0. Minimise $\frac{1}{2}(x-3)^2 + \frac{1}{2}(x-1)^2$; soft-threshold x+u by 0.5.

X-UPDATE

$d/dx:\ (x-3)+(x-1)=0$

$2x-4=0 \rightarrow \mathbf{x=2}$

Z-UPDATE

$\text{soft}(2,\ 0.5) = \text{sign}(2)\cdot\max(|2|-0.5,0) = \mathbf{1.5}$

DUAL UPDATE

$u \leftarrow 0+2-1.5 = \mathbf{0.5}$

$\text{primal residual } x-z = \mathbf{0.5}$

Interpret: the copies have not converged. ρ controls the numerical negotiation; λ controls prior strength in the original objective.

23 · Lensless diagnostic ladder

CH 7

OBSERVATION	LIKELY SEAM	DISCRIMINATING CHECK
Structured data residual	Shift/crop, depth kernel, background or calibration	Apply A to known target; inspect residual pattern
Speckle falls but narrow lines vanish as λ rises	Prior too strong for real sparse/fine structure	Target with both smooth regions and narrow lines
Primal high, data low	Split not reconciled	Track primal/dual histories; revisit ρ/stopping
Sharp image, validation worsens	Noise fitting/metric mismatch	Held-out calibrated target; save intermediate states
Result changes under small λ/ρ shift	Claim is parameter-sensitive	Sweep under fixed normalisation; mark feature uncertain

Before optimisation: confirm A predicts a known measurement and A^* passes its inner-product test. Record operator version, normalisation, λ, ρ, initialisation, iterations and stopping rule.

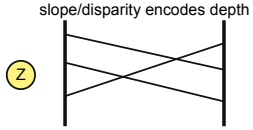
24 · Priors choose structure

CH 7

PRIOR/CONSTRAINT	FAVOURS	CAN ERASE
Sparsity	Few transform coefficients	Distributed texture
Total variation	Piecewise-smooth image	Fine oscillation/narrow lines

25 · Worked: disparity depth

CH 8 · EXAMPLE



Metric depth needs calibrated baseline, focal scale, axes and sign convention.

Given: rectified pair; f = 700 pixels, B = 0.08 m, d = 14 pixels.

DEPTH

$Z = fB/d = (700\ px \times 0.08\ m)/(14\ px)$

$Z = 56/14 = \mathbf{4.00\ m}$

ONE-PIXEL SENSITIVITY

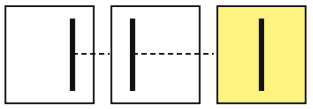
$d = 13\ px \rightarrow Z = 56/13 = \mathbf{4.31\ m}$

$\text{Change} = \mathbf{0.31\ m}$

Interpret: small-disparity depth is sensitive to pixel error; distant estimates need uncertainty/confidence, texture checks and several baselines.

26 · Refocus by shift-and-sum

CH 8 BODY



Shift each view by the candidate disparity, then average aligned samples.

REFOCUS

$I_a(s,t) = (1/N)\ \Sigma\ L(u,v,\ s+k(a)u,\ t+k(a)v)$

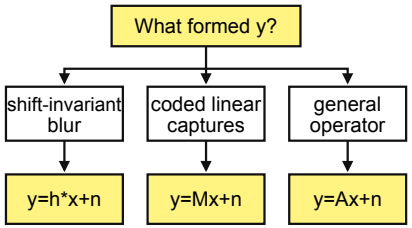
Two views at u = −1 and +1 show a point at 18 and 14: midpoint = **16**; shift symmetrically by −2 and +2 to align. A zero-disparity point is separated by those shifts and blurs in the sum.

FAILURE	RAY-SPACE EVIDENCE
Occlusion	EPI line disappears over part of aperture
Motion	Sequential views produce broken/curved structure
Specular response	Brightness/feature changes with view direction
Calibration/sign error	Known front/back planes sharpen in wrong order
Boundary/crop bias	Sharpness varies with padding rather than geometry

Lenslet trade-off: under a fixed detector budget, more angular samples leave fewer independent spatial samples.

27 · Method chooser

CH 1–9



Choose the representation before choosing the inverse or diagnostic.

IF ASKED TO…	START WITH	MUST MENTION
Place sensor / image scale	Thin-lens + m	Units, sign, real calibration limits
Explain blur/noise trade-off	Photon/exposure/aperture stage	One-factor control; saturation/motion/DoF cost
Detect aliasing	cycles/pixel vs 0.50	Repair before sampling
Separate coded lights	y=Mx+n	Rows/captures, rank, conditioning, offsets, motion
Read orientation/filter	2-D Fourier pair	Axes, ± peaks, phase, boundary choice
Recover coded aperture	measured h, H=ℱ{h}	Support vs throughput; field/depth validity
Regularise deconvolution	H*Y/(|H|²+K)	Weak support, sweep K, residual + target metric
Reconstruct lensless	y=Ax+n + objective	A/A*, λ vs ρ, data/primal/dual diagnostics
Refocus / infer depth	shift-sum; Z=fB/d	Calibration, units, sign, occlusion, uncertainty

28 · Evidence funnel

CH 9

Four-move diagnosis: (1) write the forward model; (2) name the challenged assumption; (3) compute or predict the consequence; (4) propose a discriminating test.

METRIC CAN FAIL BECAUSE…	PAIR IT WITH…
Sharpness rewards noise/ringing	Known spacing + residual + repeat captures
Low residual reflects overfitting	Held-out target + parameter stability
One resolution target is narrow	Multiple frequencies/orientations + natural scene
Best example is selective	Predefined region/aggregation + all repeated runs

29 · Final error sweep

ALL CHAPTERS

AUDIT	QUESTION BEFORE SUBMISSION
Units	Are distances/focal scales compatible? cycles/pixel stated?
Signs/axes	Did I interpret inversion, stripe direction, disparity convention?
Dimensions	Do matrix rows equal captures and columns equal unknown sources?
Information	Is recovery identifiable and well conditioned?

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