Image-guided Radiotherapy using Active Pixel Technology

John Osmond[1,3]

with

Emma Harris[1], Andrew Clark[2], Bob Ott[1], Andrew Holland[3] & Phil Evans[1]

[1]The Institute of Cancer Research & The Royal Marsden NHS Trust,
[2]STFC Rutherford Appleton Laboratory, [3]Brunel University

MI^3 Project

- Multidimensional Integrated Intelligent Imaging
- £4.4m RCUK Basic Technology Research Grant
- 11 Research Institutes
- Objectives:
  - To extend APS spectral response (e.g. γ-ray, IR, ionising)
  - To develop on-chip intelligence to improve performance
  - To customise devices and demonstrate in novel scientific applications (e.g. Medical, Biological, Security, Space Imaging)

Motivation

- Radiotherapy: Deliver x-ray dose to cancerous tissue whilst minimising the dose to surrounding healthy tissue.

- Image data taken at planning, pre-treatment, during treatment:
  - Position patient,
  - Verify treatment,
  - Compensate for motion.

- Current systems (e.g. Video, a-Si) are prone to limitations:
  - Substantial additional dose sometimes required,
  - Data not always acquired from beam's eye view,
  - Readout, transfer and downstream processing slow.

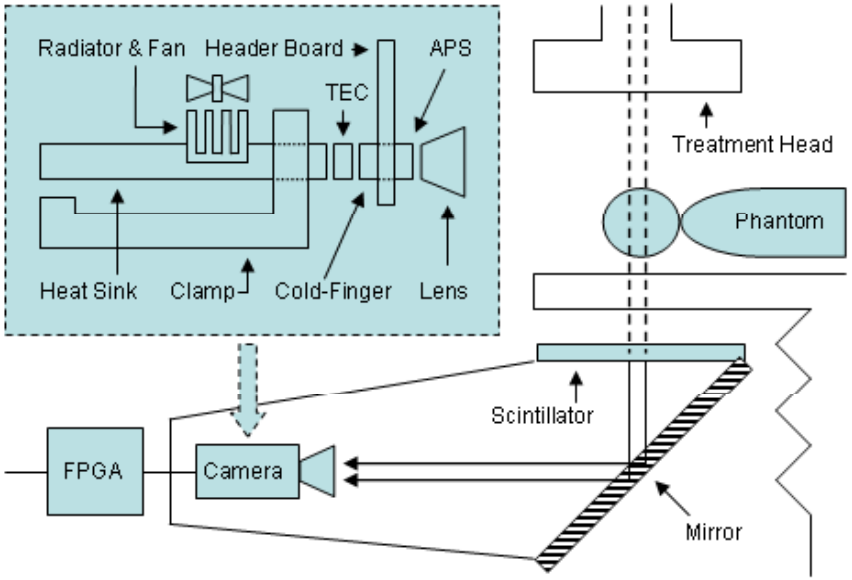
CMOS Active Pixel Sensor (APS)

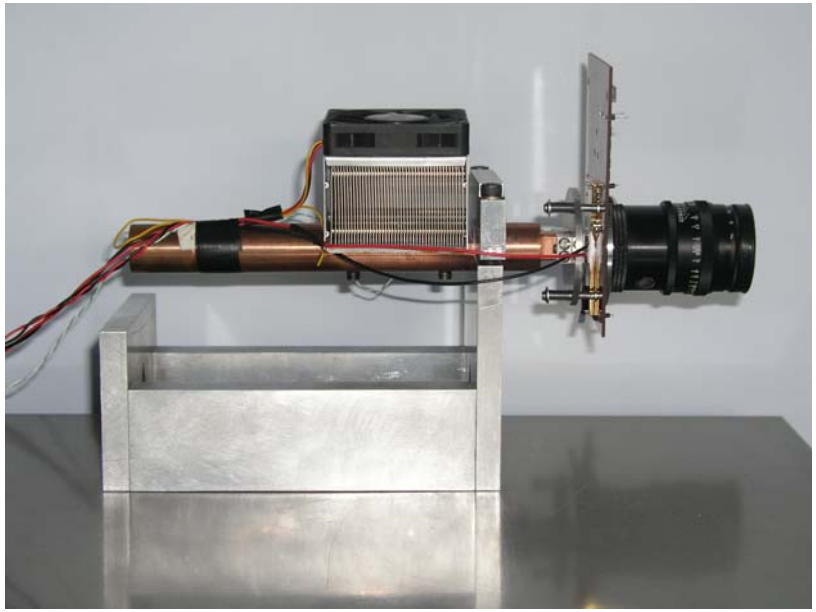
- CMOS APS may address many of these limitations:
  - Single pixel & Region-of-Interest (ROI) readout,
  - Intelligence in pixel & Field Programmable Gate Array (FPGA),
  - Radiation hardness,

- Aims:
  - Build APS (520x520 25 μm pixels, ROI readout, >100 fps),
  - Incorporate APS into MeV imaging system,
  - Assess imaging performance & compare to standard imager,
  - Demonstrate simple logic to verify treatment (offline).

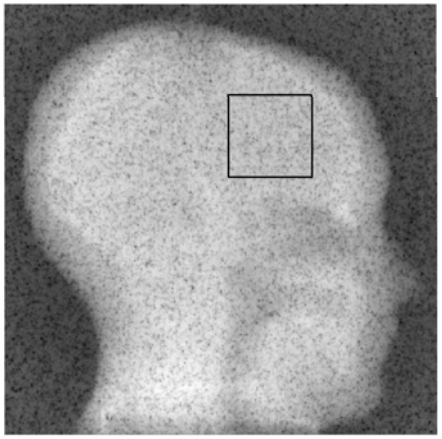
Experimental Set-Up

- Mirror configuration used in camera EPIDs.
- Sensor and electronics remain outside treatment beam.





Head Phantom

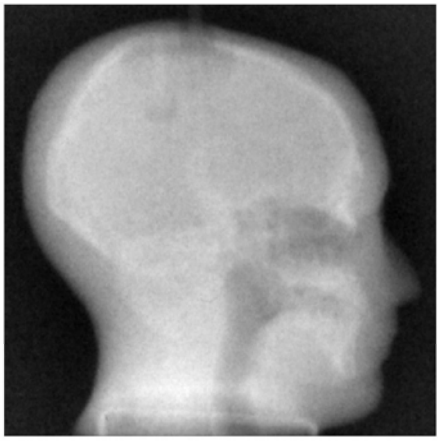

0.25s


0.5s


1s

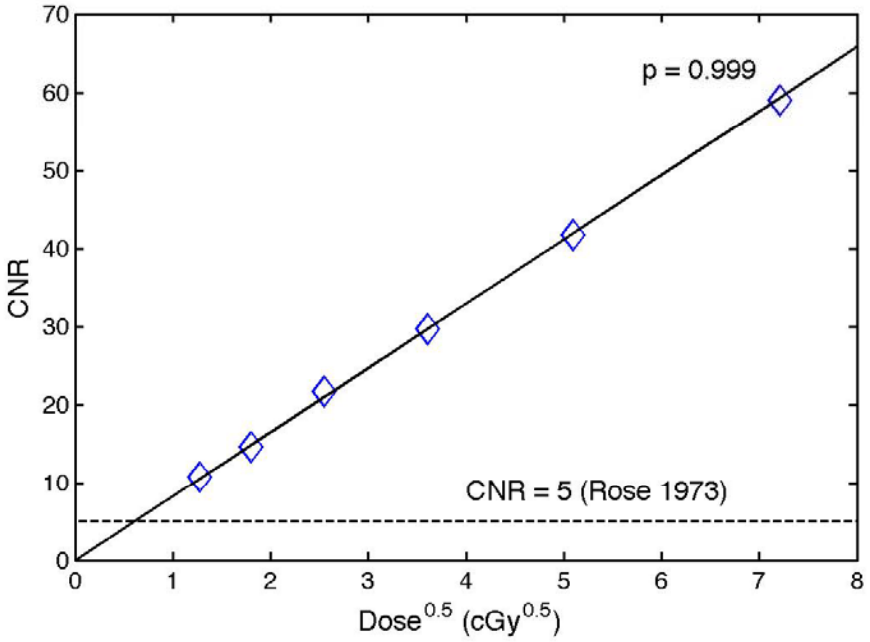

2s


4s


8s

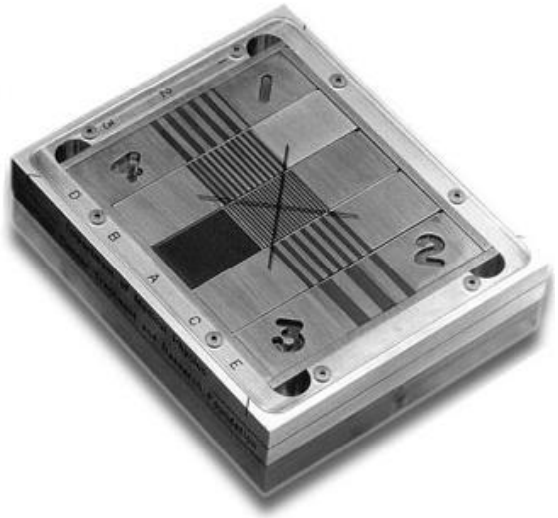
Contrast to Noise Ratio vs Dose

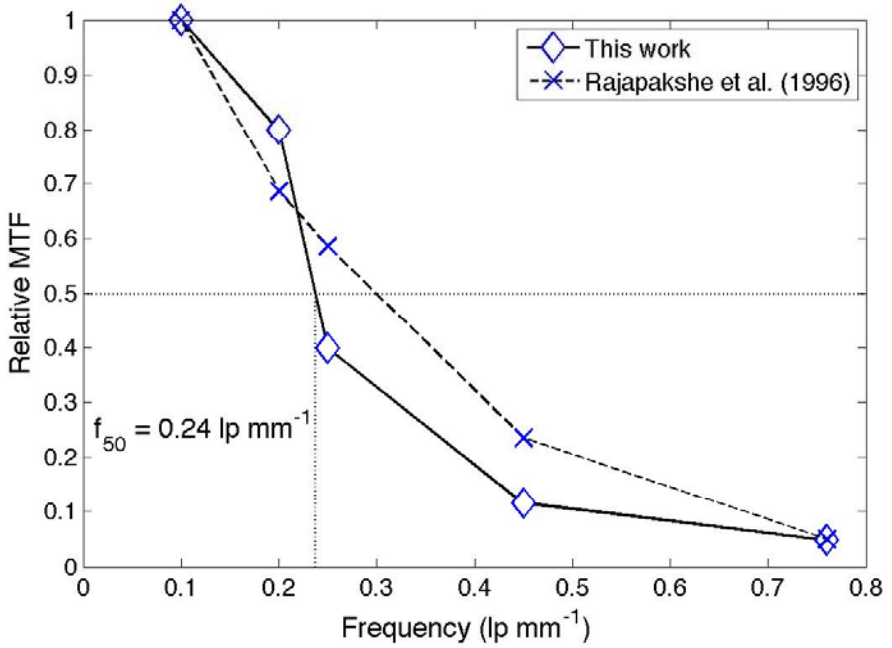
- CNR calculated in square region of skull.
- CNR = 8.1 x Dose$^{0.5}$.
- CNR = 5, Dose = 0.38 cGy.
- Time = 1/18 s.



Relative MTF

- Calculated using the QC3 phantom:

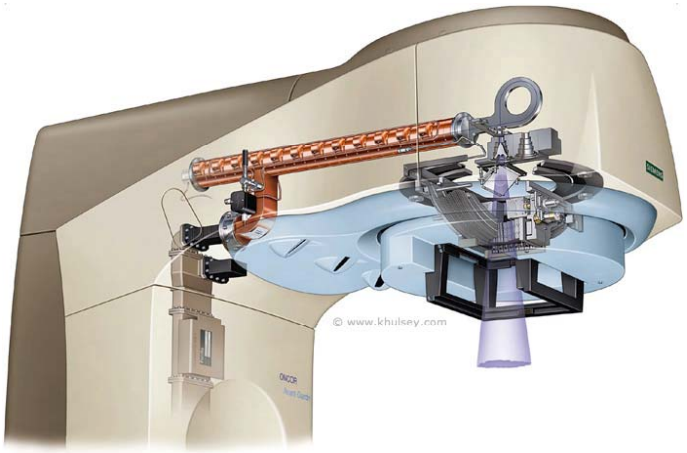




- Reasonable agreement with comparison data (lower f_{50})

IMRT

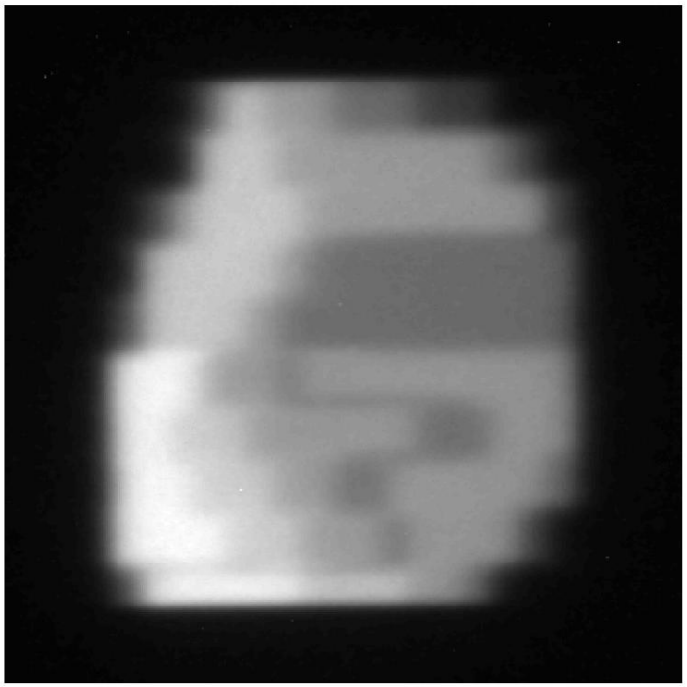
- Intensity Modulated Radiation Therapy (IMRT):
  - Linear accelerator (Linac) produces MeV x-ray radiation;
  - Multi-Leaf Collimator (MLC), an array of movable tungsten leaves, shapes the radiation field;
  - Sequence of shaped fields are delivered to form spatially varying dose.



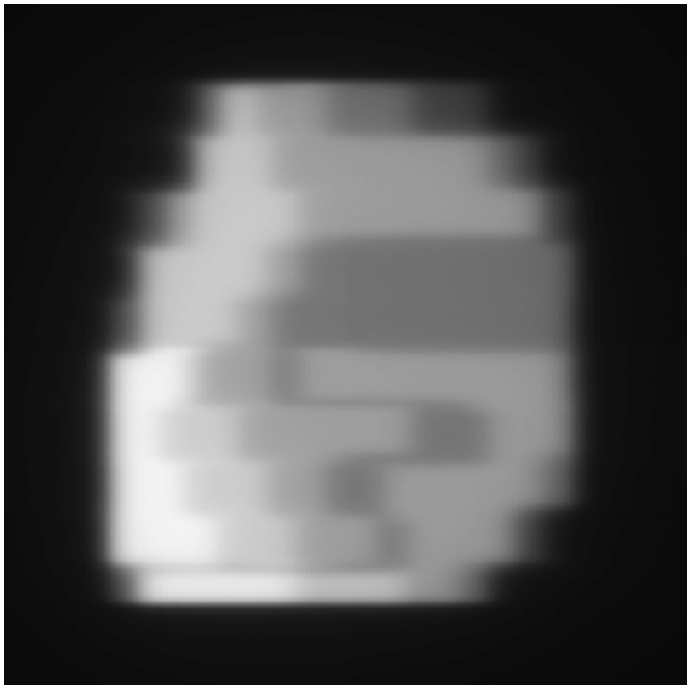
Total IMRT Dose

- Lung treatment delivered in 6 segments over 35 s.
- Good agreement between APS and a-Si flat-panel EPID.

APS

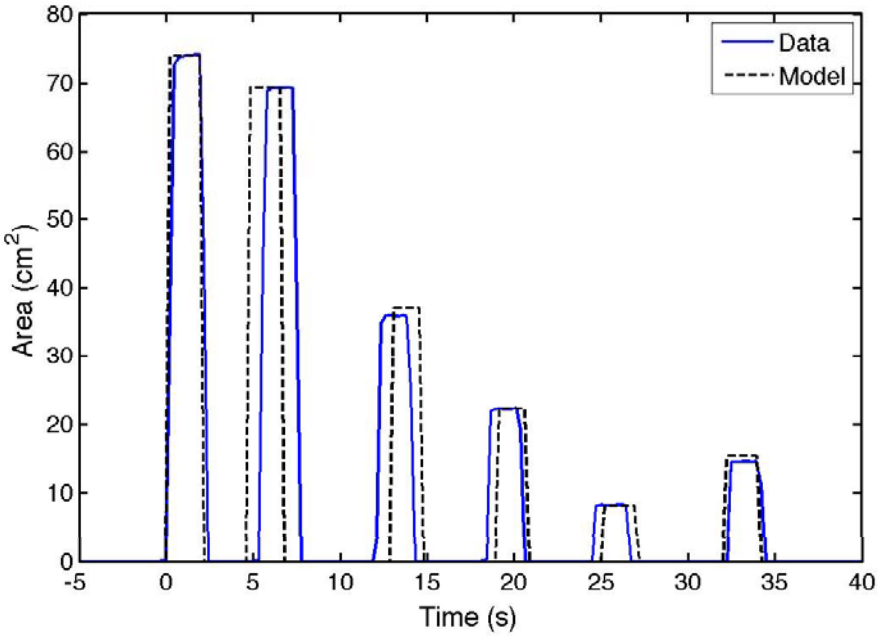


EPID



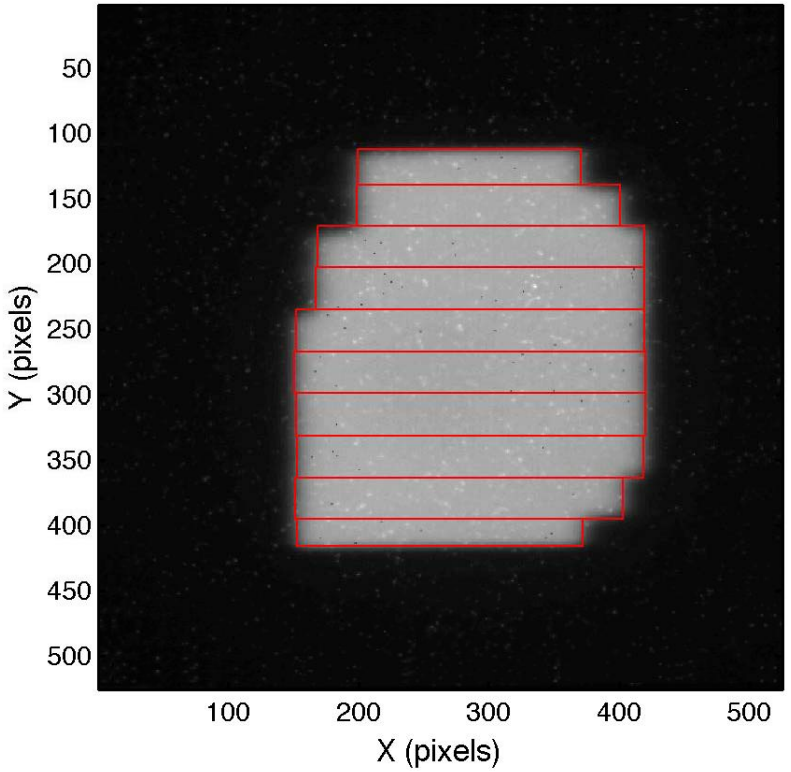
Area-Time Analysis

- Area above threshold (50% of max) vs. time.
- Model based on:
  - Prescribed leaf positions,
  - Prescribed dose and measured dose-rate,
  - Leaf speed, acceleration and time delay.
- Simple algorithm calculated offline in software, then eventually online in FPGA.



Edge-Detection

- Threshold at 50% of max
- Mean scalar discrepancy in leaf edges of 0.03 cm.
- Mean discrepancy in area of < 1%
- ROI readout will greatly improve speed (x26)



Summary and Future Work

- Current system can:
  - Resolve bone structure (~2 cGy) and MLC leaf edges,
  - Verify IMRT to 0.12 s (time), 1 cm^2 (area), 0.3 mm (leaves).
- Limitations:
  - Frame rate required for CNR > 5 is 18 fps (Linac ~ 400 Hz).
- Future work:
  - Develop system using Large Area Sensor (x20 area),
  - Evaluate in contact configuration (greater light collection and resolution, less FOV),
  - Improve FPGA to utilise ROI, increased frame-rate, on-sensor intelligence.

Questions?