Alternatives in 6DOF probing:

What it's for
Other ways to do it

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5DOF and 6DOF probing works around corners ..

- Optical systems have good range but often do not see the feature point of interest
- Portable CMM arms can work around corners but have limited range
- Many 5DOF, 6DOF solutions in commercial operation, for example
  - GSI's VSTARS/M – dual camera, targeted hand-held probe
  - METRONOR's SOLO, DUO – single/dual cameras, targeted hand-held probe
  - AICON's ProCam – camera as hand-held probe
  - Metris' K-Scan – hand-held scanner and triangulation tracker
  - Leica's T-Cam, T-Scan – hand-held probing for laser trackers
  - API's Intelliprobe, SmartTrak – hand-held probe, machine control for tracker
  - Arc Second's Vector Bar – 5DOF hand-held probe for indoor GPS
  - FARO's Combo – sequential link between tracker and arm
  - Romer/Hexagon's Orbital Tracker – sequential link between tracker and arm

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.. and gives freedom of movement

From the websites

- Metris: K-scan is "a powerful, walk-around scanning solution"
- Leica: T-Probe is "a walk-around CMM solution for arm- and wireless probing"
- Metronor: "wireless hand-held measurement probe has complete freedom of movement"
- Arc Second: "Indoor GPS gives you 360º of Freedom"

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Why discuss alternatives?

- Solutions which operate with older and legacy laser tracker systems
- Solutions which operate with any laser tracker system
- Solutions which don't require laser trackers
- Solutions which offer a better reach
- Solutions which are cheaper (for less demanding tasks?)
- Concepts here show how range, angle, image and tilt measurement could provide 6DOF probing ..
- .. and encourage the users to press manufacturers for more options or try out new variants for themselves

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Total Stations as 6DOF trackers?

- Leica's TDA5005 is an established "low-cost tracker" based on a surveying Total Station but does not have real-time distance measurement
- API's new Omnitrac is effectively a fully tracking Total Station
- Topcon's GPT 7000i provides surveyors with an image of the telescope view – could orient target probe as in T-Cam
- So is the next laser tracker an industrial Total Station with real-time 3D, target imaging and 6D probing?

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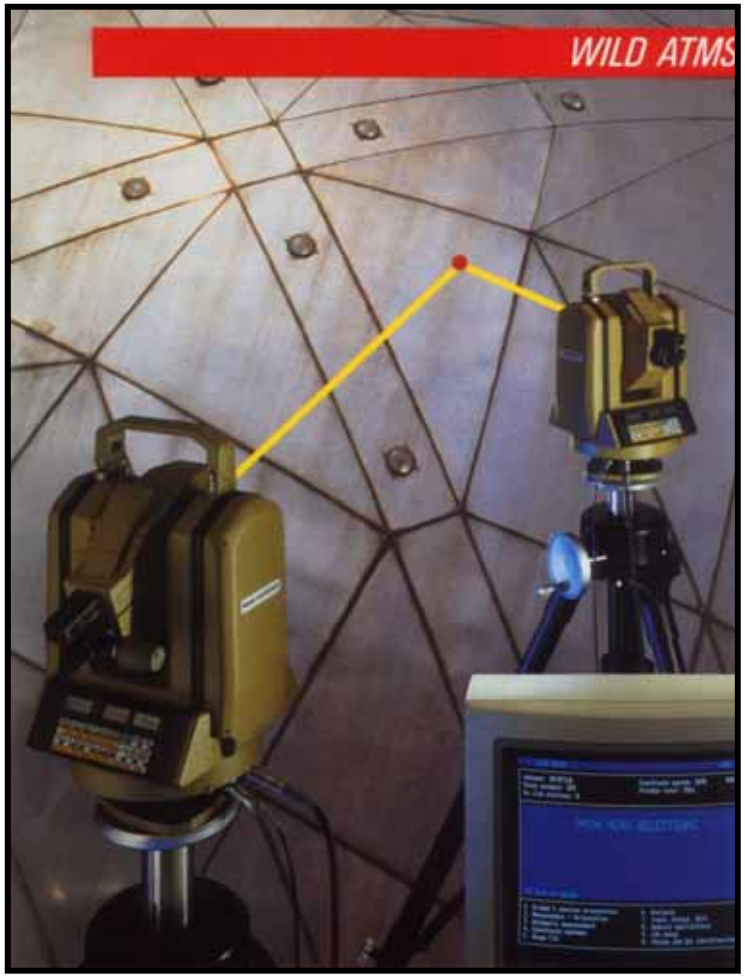
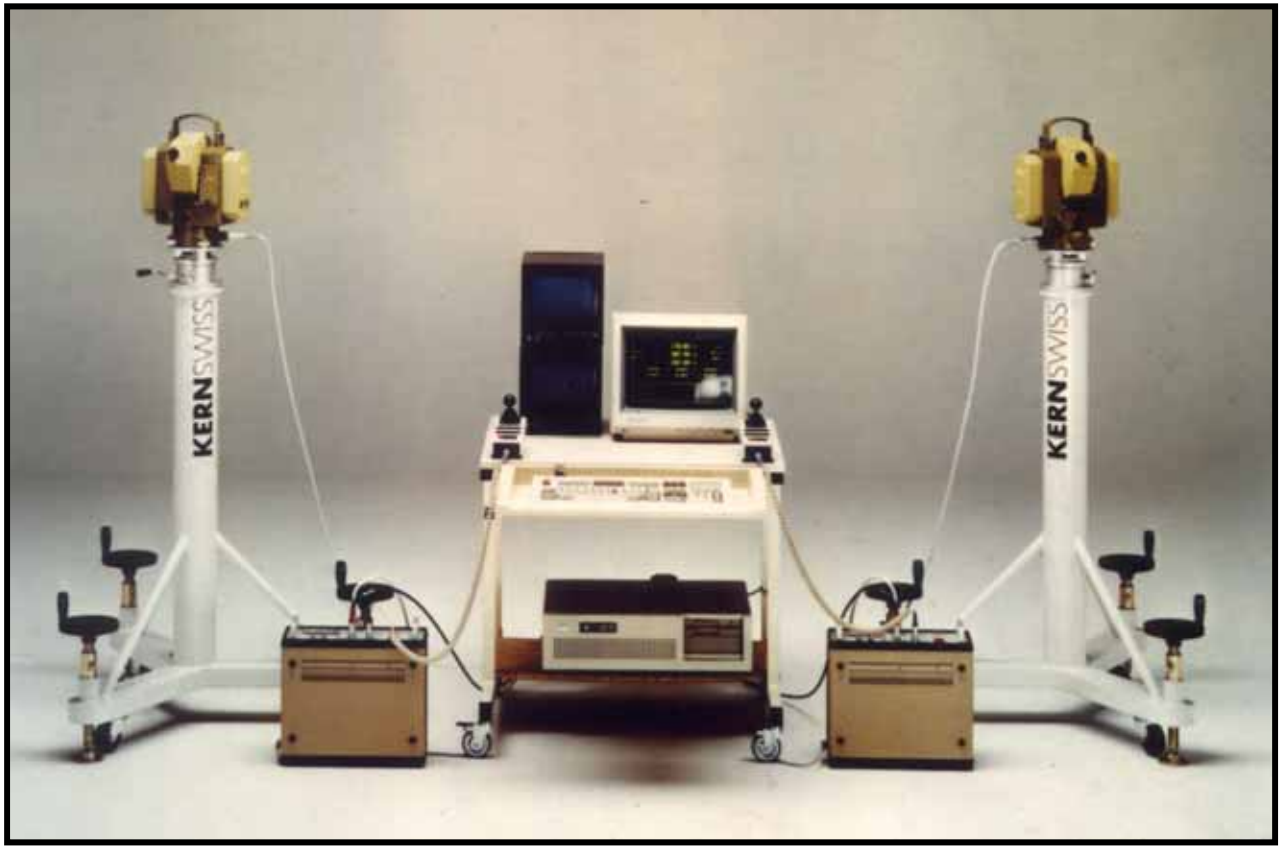
Video theodolites as 6DOF trackers?





Systems not new but out of production – e.g. ATMS and SPACE from early 90s
Offered auto measurement of single points - no 6DOF tracking

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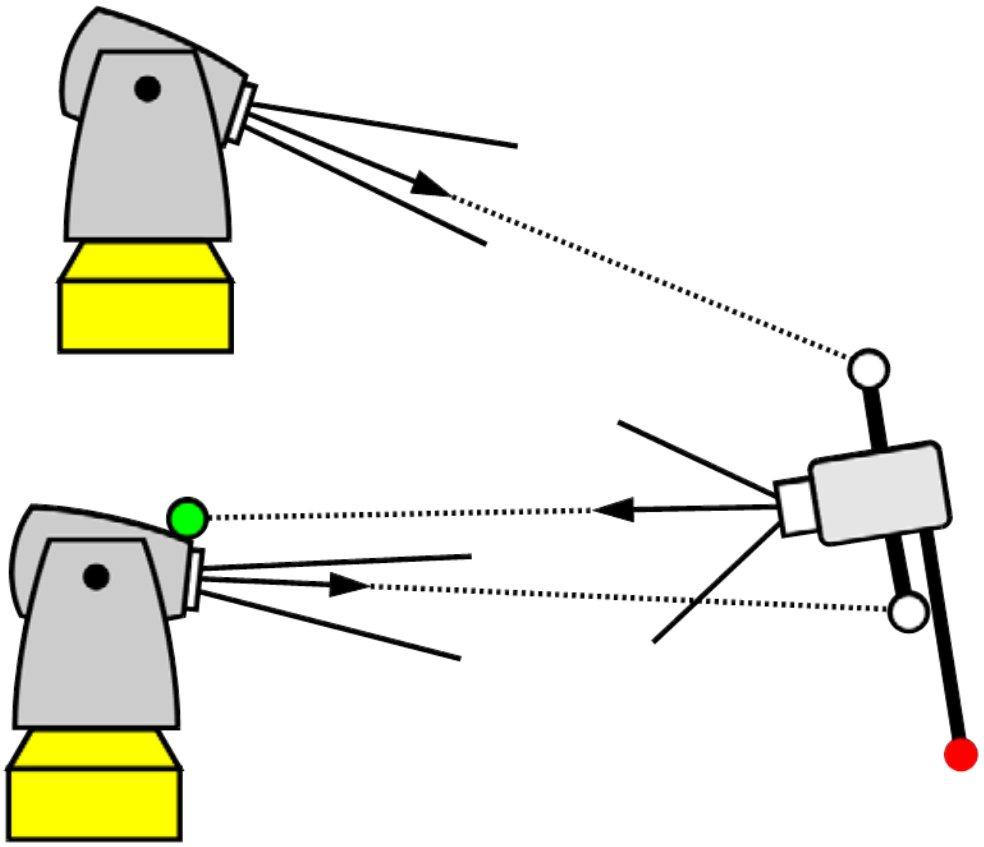
Video theodolite - 6DOF from single points



New video theodolites possible? E.g.

- Give the T-Cam its own horizontal drive (+ a few other modifications)
- Take the EDM out of the Topcon instrument (shame to waste it)
- DIY – see Michael Brenner's work at the conference

Concept diagram shows 6DOF probing with a camera probe and 3 single target pointings – one for each instrument

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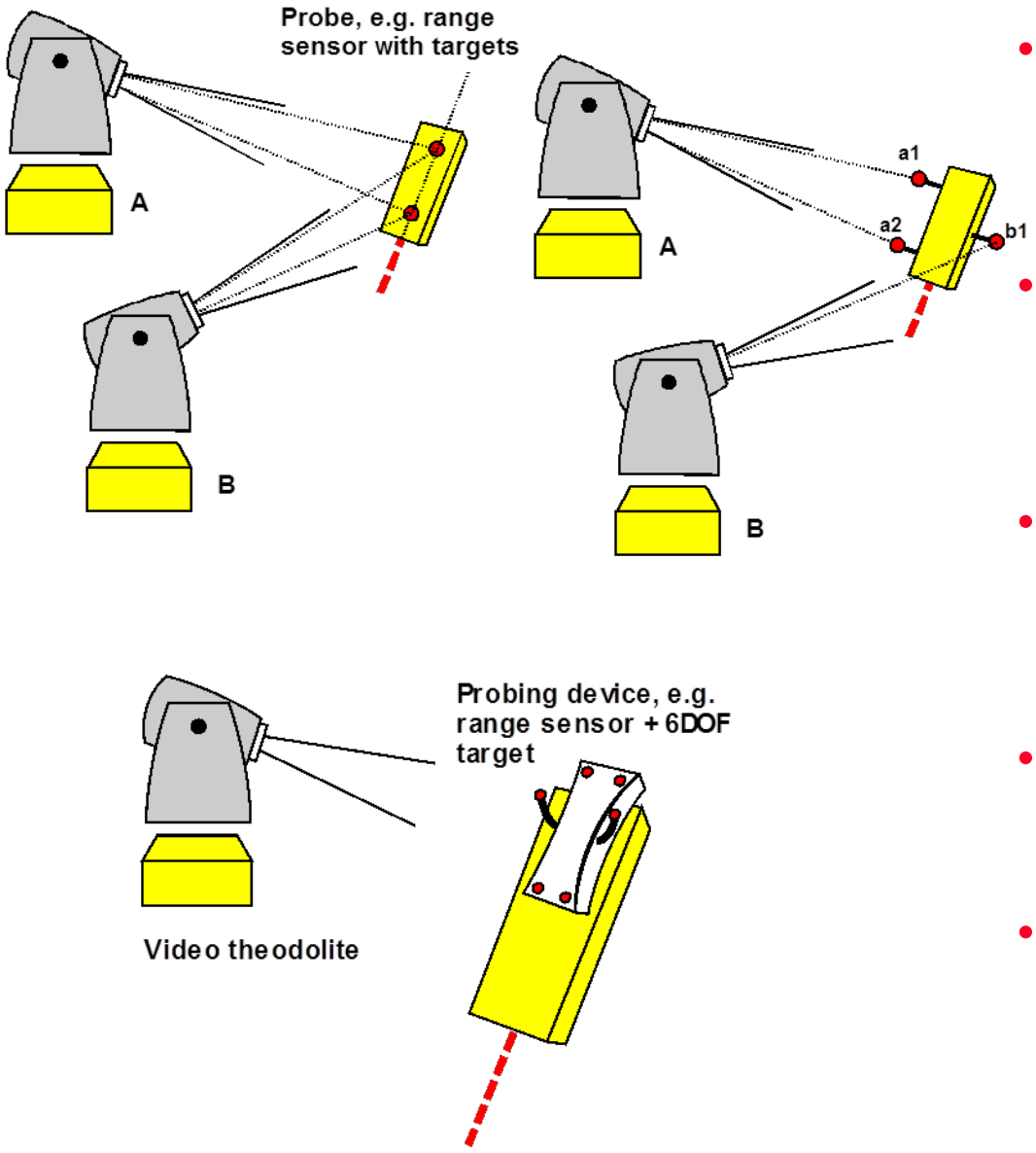
Video theodolite - 6DOF from multi-points



- Dual target intersection gives a 5DOF probe, triple target intersection gives a 6DOF probe
- 3-target 6DOF also works with single rays to multiple targets (2 rays from one instrument, 1 ray from a second)
- Can reduce to a single instrument, 3-target space resection. Cheaper, but range to probe potentially inaccurate
- Multiple targets resolve problem with line-of-sight interruptions
- *Compared with reflector tracking and camera probes, intersection/resection offers wide probe orientation angles*

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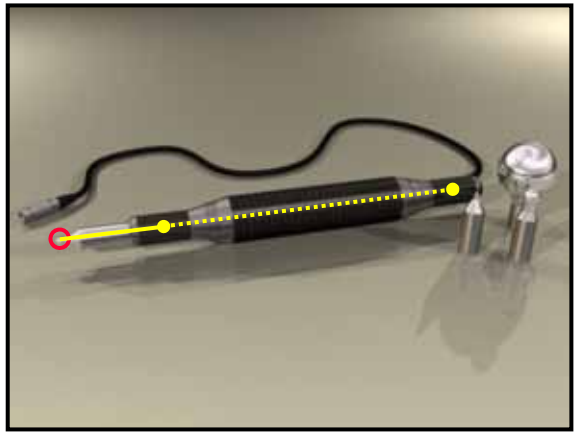
New hardware, old geometry – 5DOF examples



- Different ways of implementing the concept of a 5DOF probe using video (motorized) theodolites, as follows:
- Leica's hidden point rod for manual theodolite intersection – not real time
- Arc Second's vector bar – real-time 5DOF by triangulation
- Verisurf's V-Probe – dual theodolites replaced by dual laser trackers – real time 5DOF by dual polar location
  note device independent of tracker

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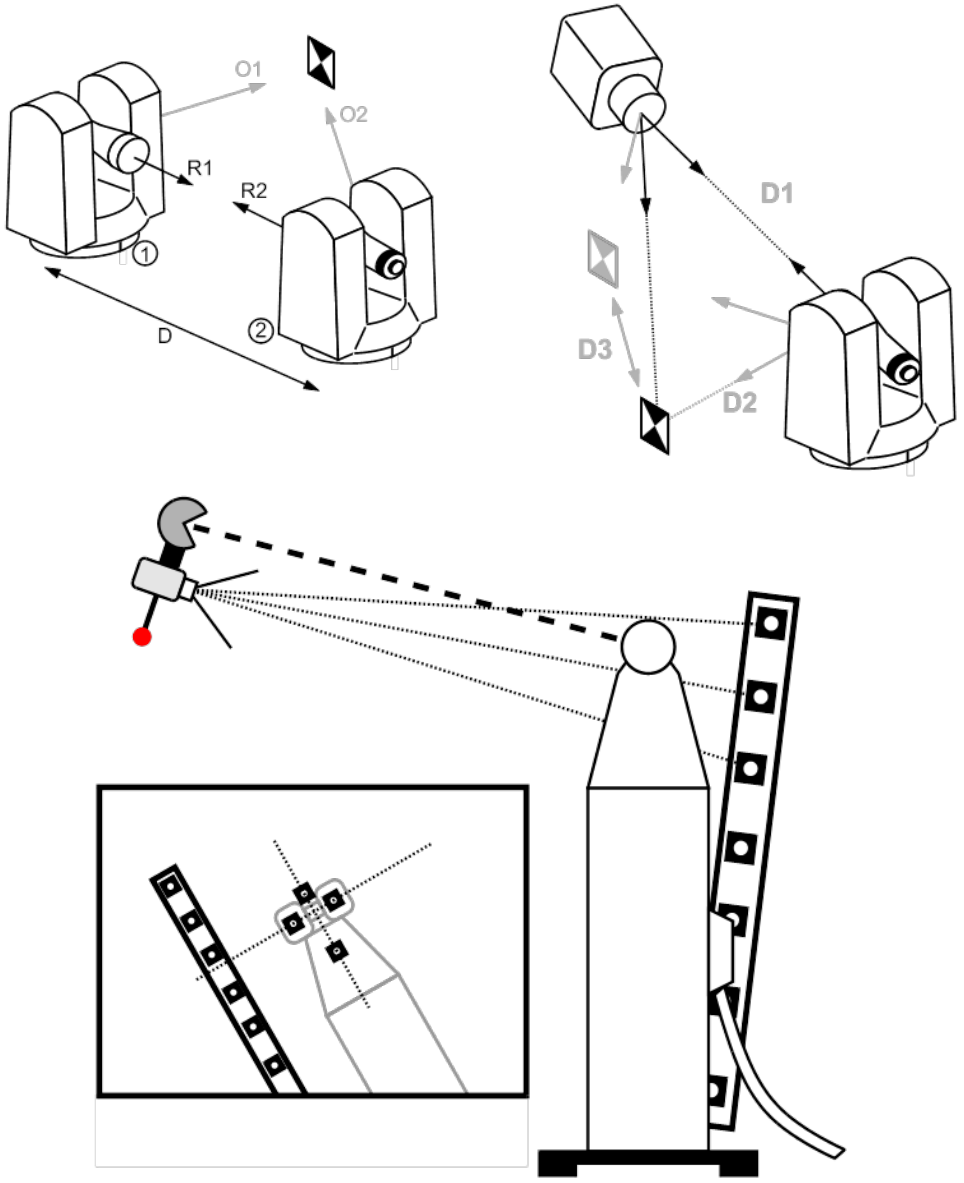
Camera as probe – a low-cost option?



- 6DOF from a standard orientation technique for non-levelled instruments
- Theodolite orientation shows principle which also works with a camera
- Real-time probing potentially possible by triangulation with video theodolite:- *low-cost probing*?
- Equivalent concept with tracker also shown (Metronor patent application)
- This option *works with any tracker*
- Good pitch and yaw but limited target spread could reduce roll accuracy and restrict range or length of tip offset

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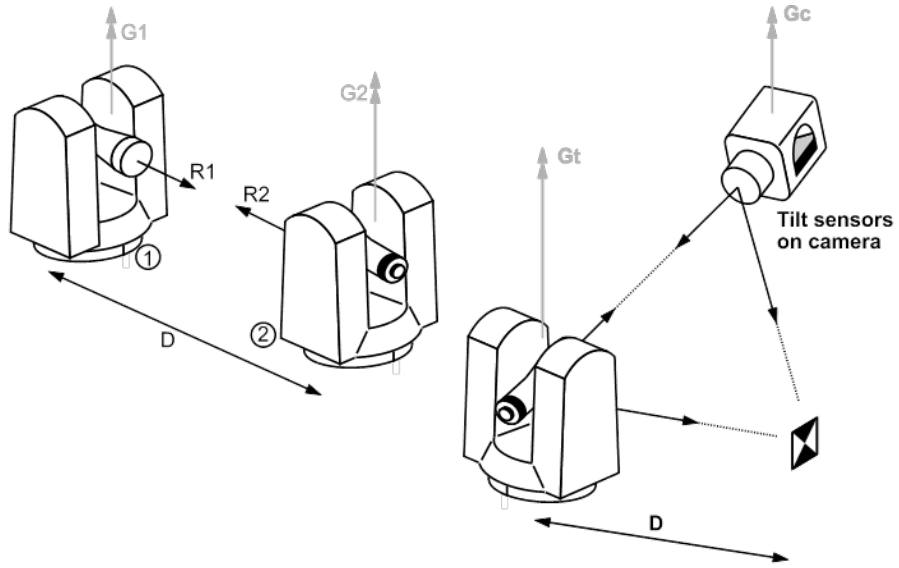
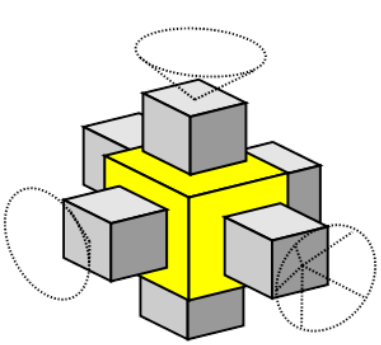
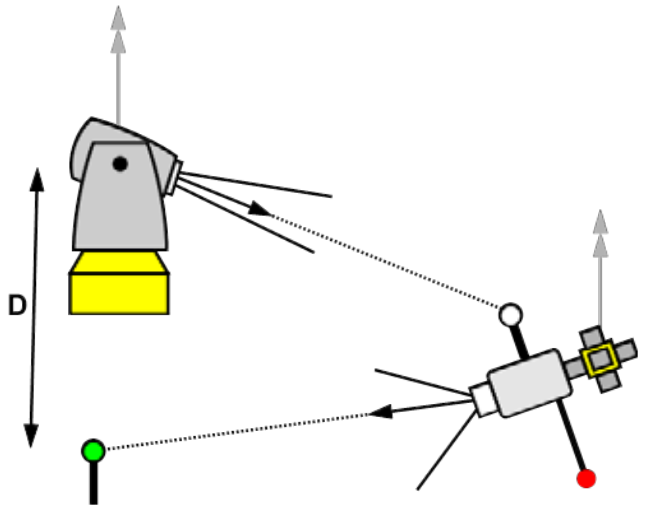
Use tilt sensing to calculate roll and reduce targeting







Tilt sensor cluster.
Each sensor 71g
2" over ± 60º
www.geomechanics.com

- 6DOF from a standard orientation technique for levelled instruments
- Tilt sensors on camera can make camera function like levelled theodolite
- Tilt sensor clusters offer a possible option for very wide-angle tilt sensing but at high precision
- Diagram top right shows scale length D for instrument separation
- Diagram bottom right shows possible configuration with single targets for each instrument

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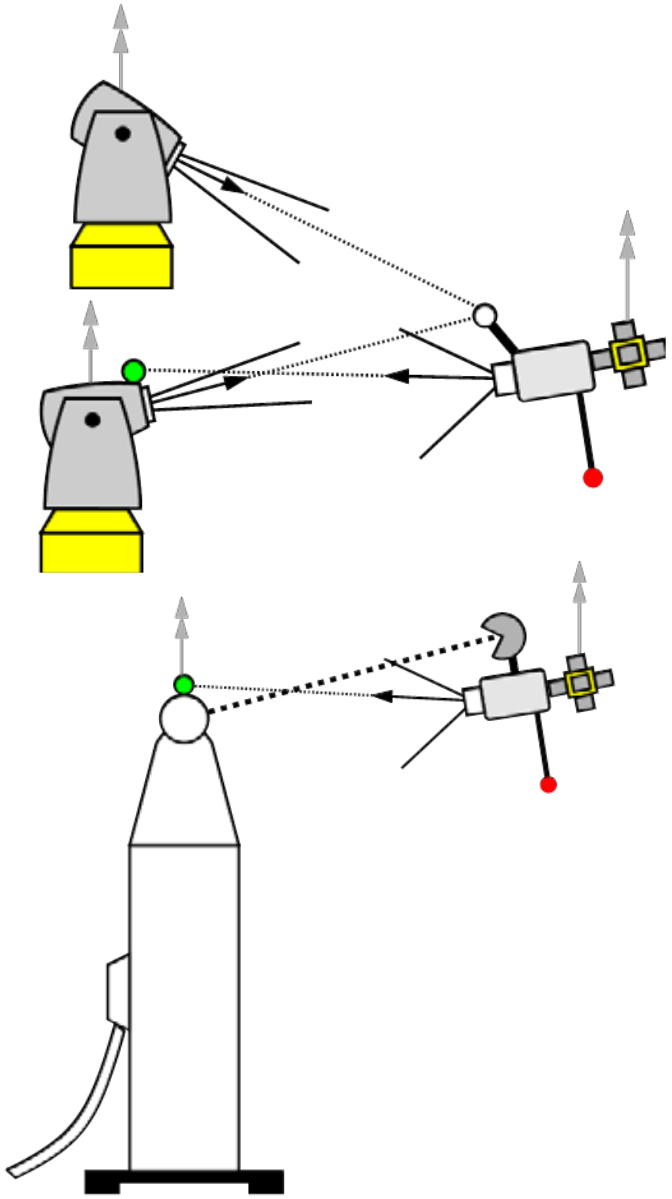
Improving the gravity-referenced camera probe



- Dual theodolite intersection gives better range
- Only one target per instrument for full 6DOF
- Probe handling similar to T-Probe, Intelliprobe?
- Replace dual theodolites by laser tracker to get alternative solution with potential advantages
  - Single line of sight
  - *Works with any tracker, old or new*
  - Single target for camera + tilt sensor enables *probe operation over wide tracker range*
  - *Potentially low cost*
- Potential to reduce dynamic tilt errors? E.g
  - Redundant tilt measurement in camera
  - Tracking and compensating for acceleration

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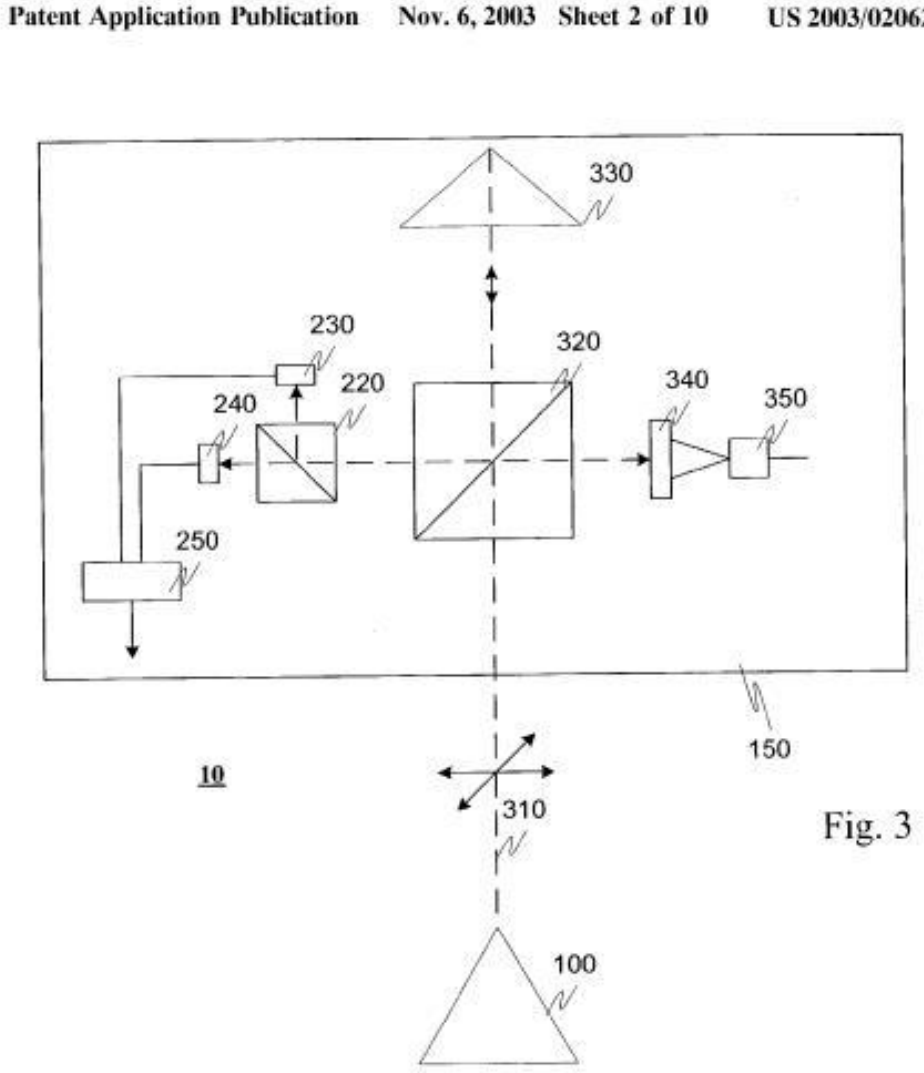
Different solutions: API's 6D laser tracking system



Patent application, Lau, 2003

- Tracker (100) transmits orthogonally polarized interferometer beam (310)
- 6DOF sensor (150) has beam splitter (320) in front of retro-reflector (330)
- One component is focused by 340 on to 2D sensor detecting pitch and yaw
- Other component further split by 220 to separate the polarized components of the beam (230,240) from which roll angle is estimated at 250
- Main return from retro at 330 provides the 3D element

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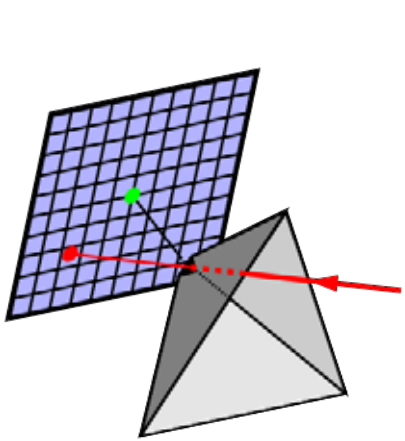
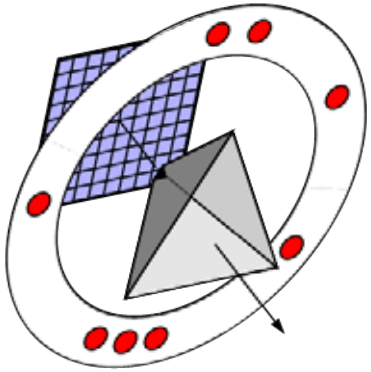
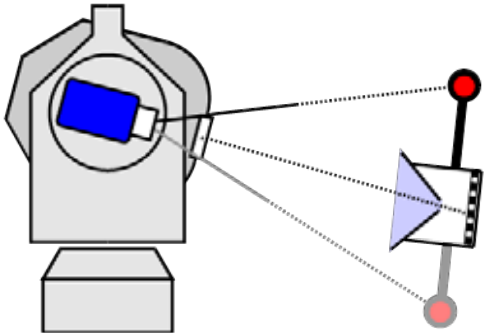
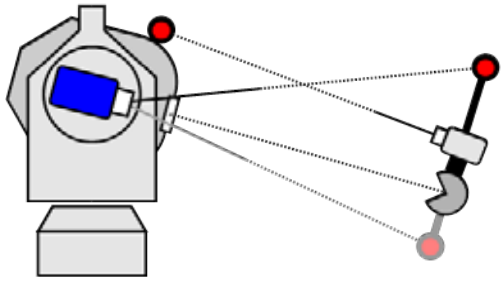
Pitch, yaw and roll by other means









- Pinhole prism determines pitch and yaw by sensing part of tracker beam passing through apex
  (See Boeing, Leica patents)
- Potential to get missing roll from image of additional targets around prism?
- Concept shows API's video camera locating a pinhole prism with single offset target for full roll angle measurement
- Second offset target potentially improves roll measurement
- Camera probe provides alternative pitch and yaw measurement

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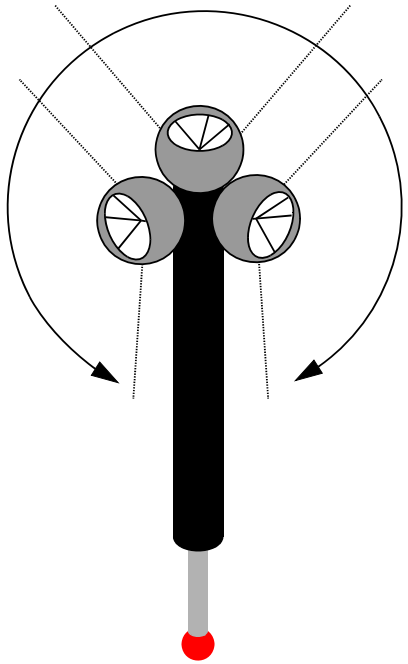
Full 6DOF from prism, dynamic target switching



- Technical University of Vienna developed in-beam 6DOF in 90s
- Tracker return beam taken to CCD chip where reflector edges cast a shadow
- From line orientations the full prism orientation is calculated
- Possible range limitation ~ 4m?
  Potential angle accuracy 10" = 50µm at 1m probe tip offset
- Concept referenced in FARO patent application and FARO also have "instant" ADM
- Instant ADM tolerates beam breaks but could switch prisms if 6DOF known
- *With in-beam 6DOF, a prism cluster and target switching you get some interruptions but potentially flexible handling*

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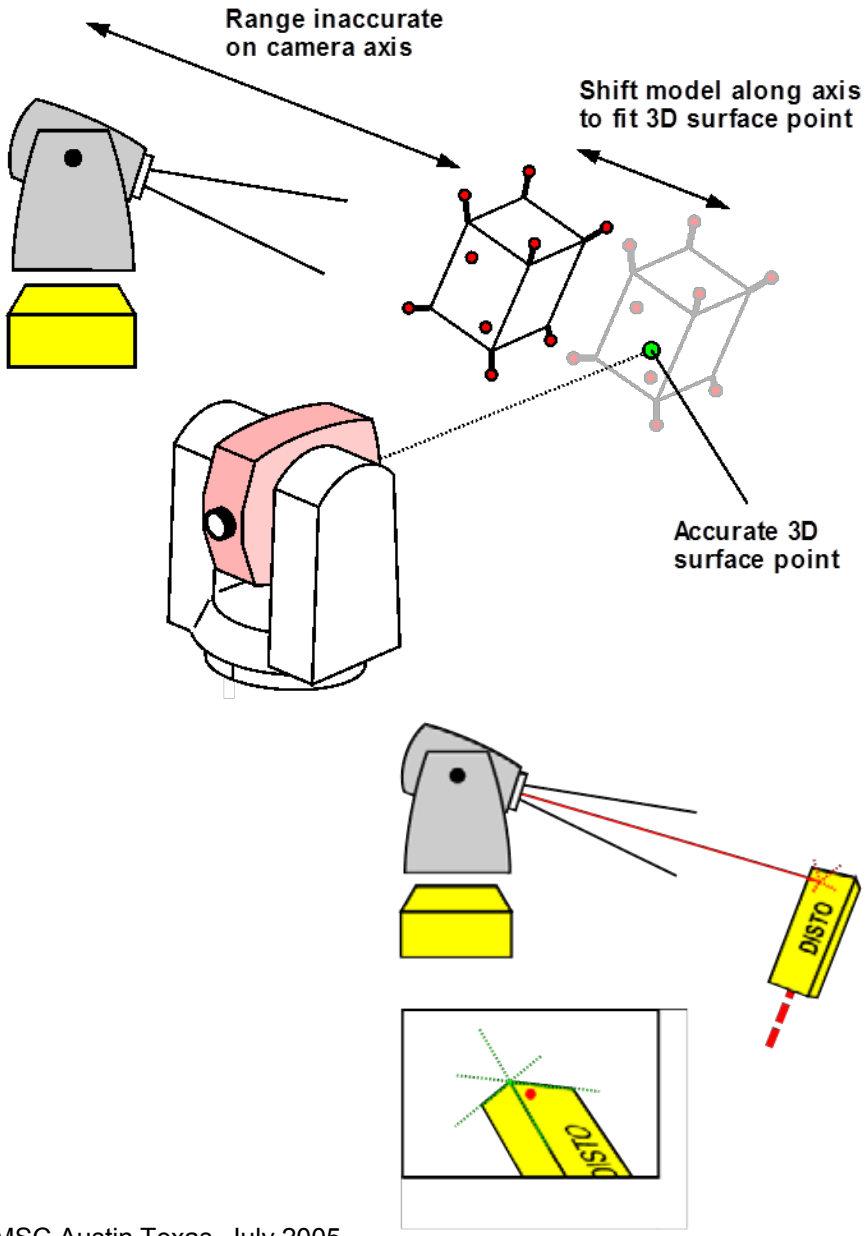
Combinations with surface ranging



- Ranging to a general surface point permits the target probe to make large rotations
- Upper example shows a video theodolite locating a target probe by resection
- Weak range on camera axis is fixed by separate ranging measurement to surface (T-Cam + LR200?)
- In lower example an imaging Total Station calculates 5DOF from line images. Range to general surface point gives final 6DOF
- Concepts need the development of accurate, high-speed surface ranging to create real-time probing

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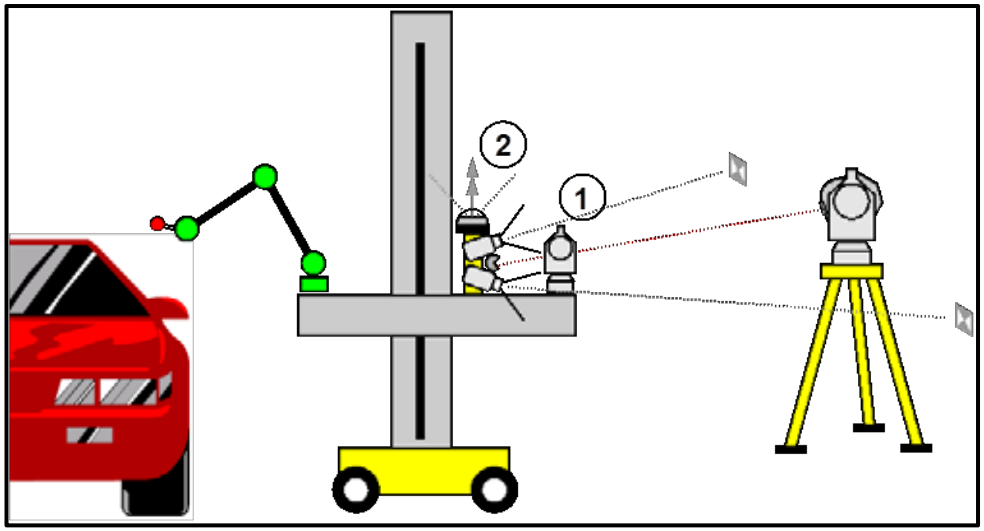
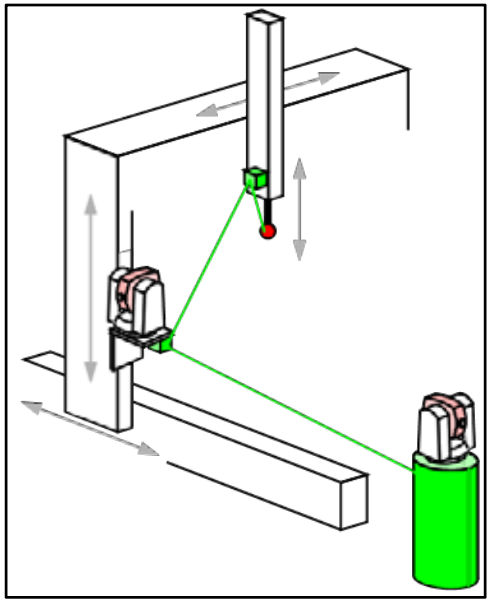
Improving the reach, automating the handling





- Hand-held probes are short :– you need a portable CMM arm to reach inside an aircraft wingbox
- A long reach probe also needs accurate orientation measurement :– 10" or better (100µm at 2m or better)
- Motorized pan and tilt targets might achieve this, or perhaps levelled cameras or camera clusters
- If you can achieve a few arc seconds in 6DOF then "cascaded trackers" can be used to build large CMMs, or large CMM arms with laser beams for links

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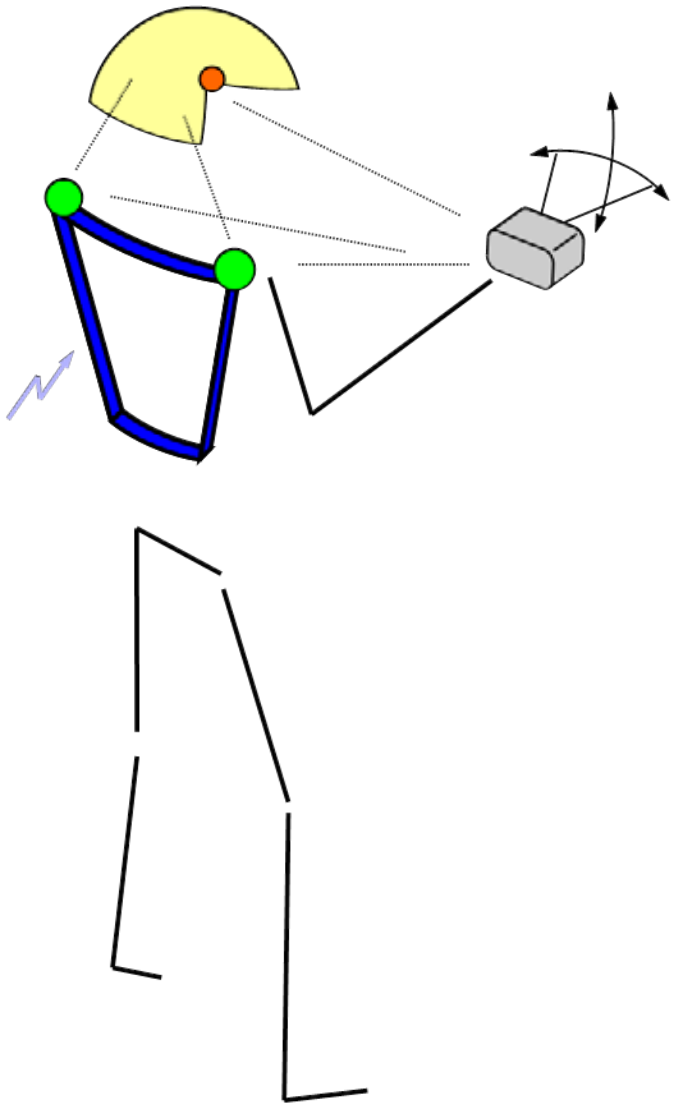
Cascaded tracking for hand-held freedom



- The most convenient arm is the human arm
- The concept diagram shows a cascaded link from an off-diagram tracking system to a target backpack (blue), then to a probing device (grey, e.g. single point tactile, optical or a scanner)
- Local sensing on the back pack directly locates the hand-held probe (e.g. dual camera vision metrology system, acoustic 6DOF sensor, etc)
- External tracking system could be VICON'S motion capture system, GSI's VSTARS/M, Arc Second's indoor GPS or even a motorized, self-pointing 6DOF target for a laser tracker.
- Backpack offers good target spread for the triangulation systems
- Local sensing could route via helmet if error build-up is acceptable

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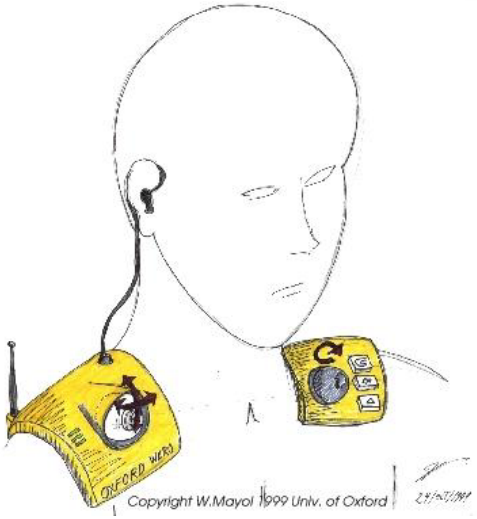
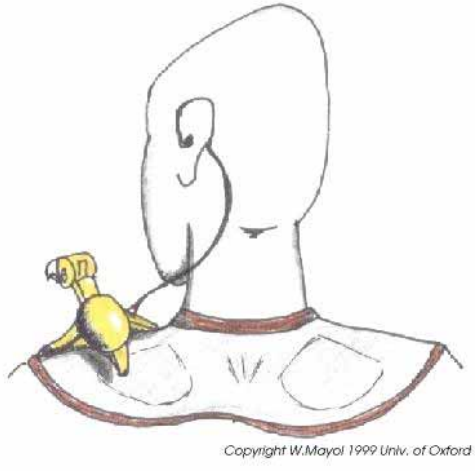
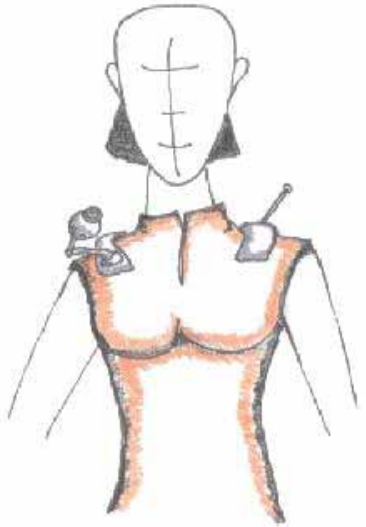
Wearing the sensors is not a new idea

Shape Tape from www.measurand.com





Wearable camera concepts from Oxford Robotics Group



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Conclusions

- 6DOF probing could be cheaper with
  - Video theodolites or imaging Total Stations
  - Orientation sensing at the target
- Orientation sensing at the target can achieve independence from laser trackers and open up prospects for 3rd. party developers or the independent software suppliers (SpatialAnalyzer, Verisurf, etc)
- A gravity-oriented camera is worth investigation as a tracker probe
- There is scope for closer integration of trackers and arms
- This presentation uses ideas which are essentially known, but there are other more speculative options for 6DOF tracker probes - *discussion welcome*

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