Inferior vena cava tracking in spontaneously breathing patients

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Inferior vena cava tracking in spontaneously breathing patients
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emergency medicine
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emergency medicine
emergency medicine
burns
stroke
sepsis
trauma
heart disease
catastrophic injuries
multiple organ failure
leading causes of death
emergency medicine
burns

5 stroke

4 sepsis

1 trauma
catastrophic injuries
multiple organ failure
multifaceted injuries
emergency medicine
burns
stroke
sepsis
trauma
heart disease
catastrophic injuries
multiple organ failure
multiple echelons of care
emergency medicine
burns
stroke
sepsis
trauma
catastrophic injuries
multiple organ failure
$260 billion per year
emergency medicine
Inferior vena cava tracking in spontaneously breathing patients, or How to tell just how full the Holy Grail of emergency medicine is
How to tell just how full
the Holy Grail
How to tell just how full the Holy Grail our abc’s
How to tell just how full the Holy Grail airway breathing circulation
How to tell just how full the Holy Grail airway breathing circulation
pH
PaO₂
hematocrit
stroke volume
venous pressure
arterial pressure
heart rate
circulation
pH
PaO₂
hematocrit
stroke volume
venous pressure
arterial pressure
heart rate
cardiac output
cardiac output
cardiac output
Cardiac Output (CO)  

CO = SV x HR

Stroke Volume (SV)  
SV = EDV - ESV

- End Diastolic Volume
- Preload
- Filling Time

Venous Return

Heart Rate (HR)

- Afterload
- Venous Pressure
- Sympathetic Nerve Stim.

intrathoracic pressure

- Tissue-Fluid Volume
- Breathing

- Skeletal Muscle Pump
- Venous Compliance

Hormones

- Contractility
- Vasodilation/Vasoconstriction

Autonomic Innervation

Atrial Reflex

Cardiac output  
venous return
cardiac output
venous return
Increased contractility

Decreased contractility

Normal operating point of the heart

Increased blood volume

Mean systemic pressure

Right atrial pressure [mmHg]
End diastolic volume [mL]
Cardiac preload [mmHg]
how do we find this?
blood volume
blood volume
intravascular volume status
intravascular volume status
intravascular volume status

hypovolemia: hemorrhaging dehydration
intravascular volume status
hypervolemia:
congestive heart failure
end stage renal disease
intravascular volume status
how much fluid do you give?
intravascular volume status
how much fluid do you take?
intravascular volume status
how do you measure it?
Inferior vena cava tracking in spontaneously breathing patients, or
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How to tell
How to tell: Physical exam

2,500 years old…
...still a 50/50 bet
How to tell: Central line invasive difficult tells half the story
How to tell: Passive leg raise a great method until you’re the one lifting
How to tell: **SVV/PPV** limited testing in healthy subjects
How to tell: ideally non-invasively, dynamically, and in as many environments as possible
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Inferior vena cava tracking
Inferior vena cava tracking
Inferior vena cava tracking, the pros
ultrasound is cheap
acquisition is quick
rapid POC across environments
Inferior vena cava tracking, the cons
operator-dependent
patient-dependent
morbidity-dependent
Inferior vena cava tracking
Inferior vena cava tracking
detect
match
track
feature detection
feature detection

skills of the doctor

verification of the engineer
feature detection

also Harris corners

\[ A = \sum_{(i,j) \in W} w(i,j) \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} \]
feature matching
feature matching

\[ I(x, y) * k(x, y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} I(u, v)k(x-u, y-v) \]

\[ I(x, y) * k(x, y) = \sum_{i=0}^{W-1} \sum_{j=0}^{H-1} I(i, j)k(x-i, y-j) \]

\[ I(x, y) \circ k(x, y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} I(u, v)k(x+u, y+v) \]

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feature matching

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\[ I(x, y) \circ k(x, y) = \sum_{i=0}^{W-1} \sum_{j=0}^{H-1} I(i, j) k(x_i, y_j) \]
feature tracking
Kanade-Lucas-Tomasi feature tracking
Kanade-Lucas-Tomasi feature tracking

\[ \epsilon(d) = \epsilon(d_x, d_y) = \sum_{x=u_x-w_x}^{u_x+w_x} \sum_{y=u_y-w_y}^{u_y+w_y} (I_1(x, y) - I_2(x + d_x, y + d_y))^2 \]

\[ \frac{\partial \epsilon(d)}{\partial d} = 0 = -2 \sum_{x=u_x-w_x}^{u_x+w_x} \sum_{y=u_y-w_y}^{u_y+w_y} (I_1(x, y) - I_2(x + d_x, y + d_y)) \begin{bmatrix} \frac{\partial I_2}{\partial x} \\ \frac{\partial I_2}{\partial y} \end{bmatrix} \]

\[ \frac{1}{2} \left[ \frac{\partial \epsilon(d)}{\partial d} \right]^T \approx \sum_{x=u_x-w_x}^{u_x+w_x} \sum_{y=u_y-w_y}^{u_y+w_y} \left( d \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} - \begin{bmatrix} \delta I \\ \delta I \end{bmatrix} \right) \]
Kanade-Lucas-Tomasi feature tracking

\[\epsilon(d) = \epsilon(d_x, d_y) = \sum_{x=u_x-w_x}^{u_x+w_x} \sum_{y=u_y-w_y}^{u_y+w_y} (I_1(x, y) - I_2(x + d_x, y + d_y))^2\]

define error as a function of displacement

\[\frac{\partial \epsilon(d)}{\partial d} = 0 = -2 \sum_{x=u_x-w_x}^{u_x+w_x} \sum_{y=u_y-w_y}^{u_y+w_y} (I_1(x, y) - I_2(x + d_x, y + d_y)) \left[ \frac{\partial I_2}{\partial x} \quad \frac{\partial I_2}{\partial y} \right]\]

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Kanade-Lucas-Tomasi feature tracking

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find a stable error

\[ \frac{1}{2} \left[ \frac{\partial \epsilon(d)}{\partial d} \right]^T \approx \sum_{x = u_x - w_x}^{u_x + w_x} \sum_{y = u_y - w_y}^{u_y + w_y} \left( d \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} - \begin{bmatrix} \delta I_x \\ \delta I_y \end{bmatrix} \right) \]
Kanade-Lucas-Tomasi feature tracking

\[ \epsilon(d) = \epsilon(d_x, d_y) = \sum_{x=u_x-w_x}^{u_x+w_x} \sum_{y=u_y-w_y}^{u_y+w_y} \left( I_1(x, y) - I_2(x + d_x, y + d_y) \right)^2 \]

define error as a function of displacement

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find a stable error

\[ \frac{1}{2} \left[ \frac{\partial \epsilon(d)}{\partial d} \right]^T \approx \sum_{x=u_x-w_x}^{u_x+w_x} \sum_{y=u_y-w_y}^{u_y+w_y} \left( \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} - \begin{bmatrix} \delta I_x \\ \delta I_y \end{bmatrix} \right) \cdot \left( \begin{bmatrix} I_x \\ I_y \end{bmatrix} \right) \]

use image gradients to simplify things
\[ \frac{1}{2} \left[ \frac{\partial \epsilon(d)}{\partial d} \right]^T \approx \sum_{x=u_x-w_x}^{u_x+w_x} \sum_{y=u_y-w_y}^{u_y+w_y} \left( d \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} - \begin{bmatrix} \delta I_x \\ \delta I_y \end{bmatrix} \right) \]

\[ b \doteq \sum_{x=u_x-w_x}^{u_x+w_x} \sum_{y=u_y-w_y}^{u_y+w_y} \begin{bmatrix} \delta I_x \\ \delta I_y \end{bmatrix} \]

\[ G \doteq \sum_{x=u_x-w_x}^{u_x+w_x} \sum_{y=u_y-w_y}^{u_y+w_y} \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} \]

\[ d_{opt} = G^{-1} b \]

simplify things
d_{opt} = G^{-1}b \quad \text{simplify things}
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spontaneously breathing patients

euvolemic
spontaneously breathing patients

hypovolemic
spontaneously breathing patients

hypervolemic
47 patients mildly ill (in ER)

subcostal US measurements made by certified sonologists
measurements

\[ C.I. = \frac{D_{\text{max}} - D_{\text{min}}}{D_{\text{max}}} \]
can now find this
how full
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