Causal Chamber®

Configuration `lt_mk2_linked_leds_sigmoid`

```
config version : 1.0
 chamber model : Light Tunnel Mk2

changelog
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  1.0: Initial version
```

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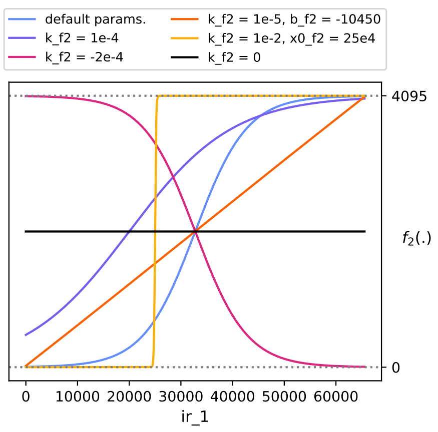
Description



This configuration exposes all variables of the Light Tunnel Mk2, excluding the camera. The motor control parameters (`mot_*_enabled`, `mot_*_steps` and `mot_*_max`) are kept fixed to ensure accurate positioning of the polarizers. The IR and UV LEDs (`led_*_ir`, `led_*_uv`) placed above each light sensor only turn on when the sensor is taking a measurement, eliminating their effect on the readings of the other light sensors. The chamber sets the values of `led_2_uv` and `led_3_uv` as

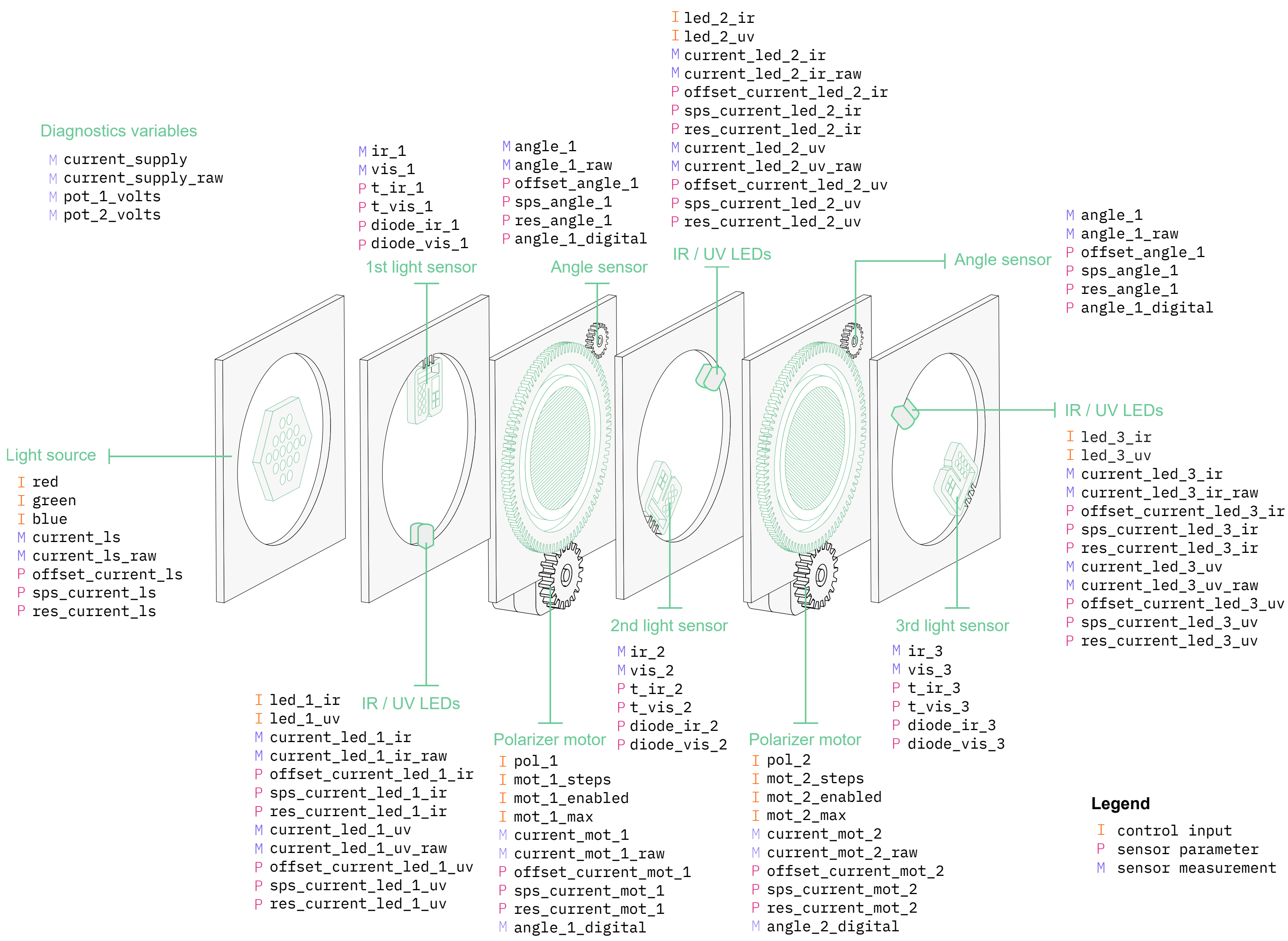
$$\texttt{led\_2\_uv} \leftarrow \text{clamp}[f_2(\texttt{ir\_1})] \text{ where } f_2(x) := \frac{\texttt{l\_f2}}{1+\exp(-\texttt{k\_f2}\cdot(x-\texttt{x0\_f2}))} + \texttt{b\_f2}, \quad (1)$$

$$\texttt{led\_3\_uv} \leftarrow \text{clamp}[f_3(\texttt{ir\_2})] \text{ where } f_3(x) := \frac{\texttt{l\_f3}}{1+\exp(-\texttt{k\_f3}\cdot(x-\texttt{x0\_f3}))} + \texttt{b\_f3}, \quad (2)$$

and where $\text{clamp}[x] := \max(0, \min(4095, x))$ clamps the output of f_i to $[0, 4095]$. The parameters `l_f2/3`, `k_f2/3`, `x0_f2/3`, and `b_f2/3` behave as additional manipulable chamber variables (see the variables table for their default value).

Chamber Diagram

See the variables table for a detailed description of each variable.



Variables Table

Some of the variable descriptions are adapted from Gamella et al. [2025, Appendix II]

Variable	Settable	Values	Default	Description
timestamp	No	float	–	The timestamp of the measurement, in seconds with respect to the system wall-clock.
counter	No	$\{i \in \mathbb{Z} : i \geq 0\}$	–	Measurement counter.
flag	Yes	float	0	User-defined flag.
intervention	No	{0,1}	–	Intervention flag. Has a value of 1 if this is the first measurement after a SET instruction, and 0 otherwise.
l_f2	Yes	float	4095	Sets the supremum of the values of f_2 in (1). Setting it to 0 disables the causal effect ir_1 $\rightarrow$ led_2_uv.
k_f2	Yes	float	2e-4	Controls the steepness of the sigmoid f_2 in (1). Larger absolute values correspond to larger steepness; negative values reverse the slope.
x0_f2	Yes	float	32768	The x value of the midpoint of the sigmoid f_2 in (1).
b_f2	Yes	float	0	Baseline (y-offset) of the clamped sigmoid transformation in (1).
l_f3	Yes	float	4095	Sets the supremum of the values of f_3 in (2). Setting it to 0 disables the causal effect ir_2 $\rightarrow$ led_3_uv.
k_f3	Yes	float	1e-3	Controls the steepness of the sigmoid f_3 in (2). Larger absolute values correspond to larger steepness; negative values reverse the slope.
x0_f3	Yes	float	5000	The x value of the midpoint of the sigmoid f_3 in (2).
b_f3	Yes	float	0	Baseline (y-offset) of the clamped sigmoid transformation in (2).
red	Yes	$\{0, \ldots, 255\}$	0	The brightness setting of the red LEDs on the main light source. Higher values correspond to higher brightness.
green	Yes	$\{0, \ldots, 255\}$	0	The brightness setting of the green LEDs on the main light source. Higher values correspond to higher brightness.
blue	Yes	$\{0, \ldots, 255\}$	0	The brightness setting of the blue LEDs on the main light source. Higher values correspond to higher brightness.
current_ls	No	float	–	The measurement of electric current drawn by the light source, in Amperes.
current_ls_raw	No	$\{-32768, \ldots, 32767\}$	–	The uncalibrated measurement, i.e., the raw ADC output, corresponding to the measurement current_ls.
offset_current_ls	Yes	$\{0, \ldots, 4095\}$	0	The reference voltage (offset) of the ADC producing the current_ls and current_ls_raw measurements. The actual reference voltage (in Volts) is given by $5 \times \frac{\texttt{offset\_current\_ls}}{4095}$. Because the signal from the current sensor is passed through an inverting amplifier and substracted from the reference voltage, higher values of offset_current_ls result in higher values of current_ls_raw.
sps_current_ls	Yes	$\{0, \ldots, 7\}$	7	The data rate of the ADC producing the current_ls and current_ls_raw measurements. Lower values mean the ADC accumulates more readings to produce a single measurement, reducing noise but also lowering the measurement speed. The actual data rates are (respectively) $8, 16, 32, 64, 128, 250, 475$ and 860 samples per second.
res_current_ls	Yes	$\{0, \ldots, 5\}$	0	The resolution of the ADC producing the current_ls and current_ls_raw measurements. Higher values mean a higher resolution, where a smaller voltage range is mapped to the ADC output range $\{-32768, 32767\}$. The voltage ranges are, respectively, $\pm 6.144, \pm 4.096, \pm 2.048, \pm 1.024, \pm 0.512$ and ± 0.256 Volts. The reading will saturate, i.e., clamp at -32768 or 32767, if the input voltage exceeds the set range.
pol_1	Yes	float $\in [-270, 270]$	0	The set position of the first polarizer, in degrees. The actual angle of the polarizer may slightly deviate from this setting due to the imperfect coupling of the mechanical pieces and the resolution of the motor (see mot_1_steps).

Table 1: Description of the variables produced by the chamber configuration lt_mk2_linked_leds_sigmoid. Settable variables can be manipulated by calling .set(<variable>,<value>). "float" corresponds to a 32-bit float.

Variable	Settable	Values	Default	Description
mot_1_steps	No	{3200, 1600, 800, 400, 200}	3200	The steps-per-revolution of the stepper motor controlling the first polarizer. Higher values mean a higher motor resolution, i.e., more precise positioning. At low current levels mot_1_max and/or step values below 800, the motor may lose torque and start missing steps, resulting in a mismatch between the set position pol_1 and the actual polarizer angle.
mot_1_enabled	No	{0,1}	1	Enables (1) or disables (0) the motor of the first polarizer. If the motor is disabled (0), setting pol_1 will have no effect on the actual position of the polarizer.
mot_1_max	No	$\{0, \ldots, 4095\}$	3000	Regulates the maximum current drawn by the motor controlling the first polarizer. At low current levels and/or mot_1_steps values below 800, the motor may lose torque and start missing steps, resulting in a mismatch between the set position pol_1 and the actual polarizer angle.
current_mot_1	No	float	–	The measurement (in Amperes) of the electric current drawn by the motor controlling the first polarizer.
current_mot_1_raw	No	$\{-32768, \ldots, 32767\}$	–	The uncalibrated measurement, i.e., the raw ADC output, corresponding to the measurement current_mot_1.
offset_current_mot_1	Yes	$\{0, \ldots, 4095\}$	0	The reference voltage (offset) of the ADC producing the current_mot_1 and current_mot_1_raw measurements. The actual reference voltage (in Volts) is given by $$5 \times \frac{\texttt{offset\_current\_mot\_1}}{4095}.$$ Because the signal from the current sensor is passed through an inverting amplifier and substracted from the reference voltage, higher values of offset_current_mot_1 result in higher values of current_mot_1_raw.
sps_current_mot_1	Yes	$\{0, \ldots, 7\}$	7	The data rate of the ADC producing the current_mot_1 and current_mot_1_raw measurements. Lower values mean the ADC accumulates more readings to produce a single measurement, reducing noise but also lowering the measurement speed. The actual data rates are (respectively) $8, 16, 32, 64, 128, 250, 475$ and 860 samples per second.
res_current_mot_1	Yes	$\{0, \ldots, 5\}$	0	The resolution of the ADC producing the current_mot_1 and current_mot_1_raw measurements. Higher values mean a higher resolution, where a smaller voltage range is mapped to the ADC output range $\{-32768, 32767\}$. The voltage ranges are, respectively, $\pm 6.144, \pm 4.096, \pm 2.048, \pm 1.024, \pm 0.512$ and ± 0.256 Volts. The reading will saturate, i.e., clamp at -32768 or 32767, if the input voltage exceeds the set range.
angle_1	No	float	–	The position (in degrees) of the first polarizer as measured by the analog angle sensor.
angle_1_raw	No	$\{-32768, \ldots, 32767\}$	–	The uncalibrated angle measurement for the first polarizer, i.e., the raw ADC output corresponding to angle_1.
offset_angle_1	Yes	$\{0, \ldots, 4095\}$	0	The reference voltage (offset) of the ADC producing the angle_1 and angle_1_raw measurements. The actual reference voltage (in Volts) is given by $$5 \times \frac{\texttt{offset\_angle\_1}}{4095}.$$
sps_angle_1	Yes	$\{0, \ldots, 7\}$	7	The data rate of the ADC producing the angle_1 and angle_1_raw measurements. Lower values mean the ADC accumulates more readings to produce a single measurement, reducing noise but also lowering the measurement speed. The actual data rates are (respectively) $8, 16, 32, 64, 128, 250, 475$ and 860 samples per second.
res_angle_1	Yes	$\{0, \ldots, 5\}$	0	The resolution of the ADC producing the angle_1 and angle_1_raw measurements. Higher values mean a higher resolution, where a smaller voltage range is mapped to the ADC output range $\{-32768, 32767\}$. The voltage ranges are, respectively, $\pm 6.144, \pm 4.096, \pm 2.048, \pm 1.024, \pm 0.512$ and ± 0.256 Volts. The reading will saturate, i.e., clamp at -32768 or 32767, if the input voltage exceeds the set range.
angle_1_digital	No	$\mathbb{Z}$	–	The position (in degrees) of the first polarizer as measured by the rotary encoder.

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Variable	Settable	Values	Default	Description
`pol_2`	Yes	float $\in [-270, 270]$	0	The set position of the second polarizer, in degrees. The actual angle of the polarizer may slightly deviate from this setting due to the imperfect coupling of the mechanical pieces and the resolution of the motor (see `mot_2_steps`).
`mot_2_steps`	No	{3200, 1600, 800, 400, 200}	3200	The steps-per-revolution of the stepper motor controlling the second polarizer. Higher values mean a higher motor resolution, i.e., more precise positioning. At low current levels `mot_2_max` and/or step values below 800, the motor may lose torque and start missing steps, resulting in a mismatch between the set position `pol_2` and the actual polarizer angle.
`mot_2_enabled`	No	{0,1}	1	Enables (1) or disables (0) the motor of the second polarizer. If the motor is disabled (0), setting `pol_2` will have no effect on the actual position of the polarizer.
`mot_2_max`	No	$\{0, \ldots, 4095\}$	3000	Regulates the maximum current drawn by the motor controlling the second polarizer. At low current levels and/or `mot_2_steps` values below 800, the motor may lose torque and start missing steps, resulting in a mismatch between the set position `pol_2` and the actual polarizer angle.
`current_mot_2`	No	float	–	The measurement (in Amperes) of the electric current drawn by the motor controlling the second polarizer.
`current_mot_2_raw`	No	$\{-32768, \ldots, 32767\}$	–	The uncalibrated measurement, i.e., the raw ADC output, corresponding to the measurement `current_mot_2`.
`offset_current_mot_2`	Yes	$\{0, \ldots, 4095\}$	0	The reference voltage (offset) of the ADC producing the `current_mot_2` and `current_mot_2_raw` measurements. The actual reference voltage (in Volts) is given by $$5 \times \frac{\texttt{offset\_current\_mot\_2}}{4095}.$$ Because the signal from the current sensor is passed through an inverting amplifier and substracted from the reference voltage, higher values of `offset_current_mot_2` result in higher values of `current_mot_2_raw`.
`sps_current_mot_2`	Yes	$\{0, \ldots, 7\}$	7	The data rate of the ADC producing the `current_mot_2` and `current_mot_2_raw` measurements. Lower values mean the ADC accumulates more readings to produce a single measurement, reducing noise but also lowering the measurement speed. The actual data rates are (respectively) $8, 16, 32, 64, 128, 250, 475$ and 860 samples per second.
`res_current_mot_2`	Yes	$\{0, \ldots, 5\}$	0	The resolution of the ADC producing the `current_mot_2` and `current_mot_2_raw` measurements. Higher values mean a higher resolution, where a smaller voltage range is mapped to the ADC output range $\{-32768, 32767\}$. The voltage ranges are, respectively, $\pm 6.144, \pm 4.096, \pm 2.048, \pm 1.024, \pm 0.512$ and ± 0.256 Volts. The reading will saturate, i.e., clamp at -32768 or 32767, if the input voltage exceeds the set range.
`angle_2`	No	float	–	The position (in degrees) of the second polarizer as measured by the analog angle sensor.
`angle_2_raw`	No	$\{-32768, \ldots, 32767\}$	–	The uncalibrated angle measurement for the second polarizer, i.e., the raw ADC output corresponding to `angle_2`.
`offset_angle_2`	Yes	$\{0, \ldots, 4095\}$	0	The reference voltage (offset) of the ADC producing the `angle_2` and `angle_2_raw` measurements. The actual reference voltage (in Volts) is given by $$5 \times \frac{\texttt{offset\_angle\_2}}{4095}.$$
`sps_angle_2`	Yes	$\{0, \ldots, 7\}$	7	The data rate of the ADC producing the `angle_2` and `angle_2_raw` measurements. Lower values mean the ADC accumulates more readings to produce a single measurement, reducing noise but also lowering the measurement speed. The actual data rates are (respectively) $8, 16, 32, 64, 128, 250, 475$ and 860 samples per second.
`res_angle_2`	Yes	$\{0, \ldots, 5\}$	0	The resolution of the ADC producing the `angle_2` and `angle_2_raw` measurements. Higher values mean a higher resolution, where a smaller voltage range is mapped to the ADC output range $\{-32768, 32767\}$. The voltage ranges are, respectively, $\pm 6.144, \pm 4.096, \pm 2.048, \pm 1.024, \pm 0.512$ and ± 0.256 Volts. The reading will saturate, i.e., clamp at -32768 or 32767, if the input voltage exceeds the set range.

Table 1: Description of the variables produced by the chamber configuration `lt_mk2_linked_leds_sigmoid`. Settable variables can be manipulated by calling `.set(<variable>,<value>)`. "float" corresponds to a 32-bit float.

Variable	Settable	Values	Default	Description
angle_2_digital	No	$\mathbb{Z}$	–	The position (in degrees) of the second polarizer as measured by the rotary encoder.
ir_1	No	$\{0,\ldots,65535\}$	–	The uncalibrated infrared intensity measurement produced by the first light sensor, placed in front of both polarizers (wrt. the light source).
vis_1	No	$\{0,\ldots,65535\}$	–	The uncalibrated visible-light intensity measurement produced by the first light sensor, placed in front of both polarizers (wrt. the light source).
ir_2	No	$\{0,\ldots,65535\}$	–	The uncalibrated infrared intensity measurement produced by the second light sensor, placed between the two polarizers.
vis_2	No	$\{0,\ldots,65535\}$	–	The uncalibrated visible-light intensity measurement produced by the second light sensor, placed between the two polarizers.
ir_3	No	$\{0,\ldots,65535\}$	–	The uncalibrated infrared intensity measurement produced by the third light sensor, placed after both polarizers (wrt. the light source).
vis_3	No	$\{0,\ldots,65535\}$	–	The uncalibrated visible-light intensity measurement produced by the third light sensor, placed after both polarizers (wrt. the light source).
t_ir_1	Yes	{0,1,2,3}	3	The exposure time of the first sensor during an infrared intensity measurement. Higher values correspond to longer exposure, increasing the sensitivity of the sensor.
t_vis_1	Yes	{0,1,2,3}	3	The exposure time of the first sensor during a visible-light intensity measurement. Higher values correspond to longer exposure, increasing the sensitivity of the sensor.
t_ir_2	Yes	{0,1,2,3}	3	The exposure time of the second sensor during an infrared intensity measurement. Higher values correspond to longer exposure, increasing the sensitivity of the sensor.
t_vis_2	Yes	{0,1,2,3}	3	The exposure time of the second sensor during a visible-light intensity measurement. Higher values correspond to longer exposure, increasing the sensitivity of the sensor.
t_ir_3	Yes	{0,1,2,3}	3	The exposure time of the third sensor during an infrared intensity measurement. Higher values correspond to longer exposure, increasing the sensitivity of the sensor.
t_vis_3	Yes	{0,1,2,3}	3	The exposure time of the third sensor during a visible-light intensity measurement. Higher values correspond to longer exposure, increasing the sensitivity of the sensor.
diode_ir_1	Yes	{0,1,2}	2	The photodiode used by the first light sensor when taking an infrared measurement, corresponding to the small (0), medium(1) and large (2) photodiodes. Larger values increase the sensitivity of the sensor.
diode_vis_1	Yes	{0,1}	1	The photodiode used by the first light sensor when taking a visible-light measurement, corresponding to the small (0) and medium (1) photodiodes. Larger values increase the sensitivity of the sensor.
diode_ir_2	Yes	{0,1,2}	2	The photodiode used by the second light sensor when taking an infrared measurement, corresponding to the small (0), medium (1) and large (2) photodiodes. Larger values increase the sensitivity of the sensor.
diode_vis_2	Yes	{0,1}	1	The photodiode used by the second light sensor when taking a visible-light measurement, corresponding to the small (0) and medium (1) photodiodes. Larger values increase the sensitivity of the sensor.
diode_ir_3	Yes	{0,1,2}	2	The photodiode used by the third light sensor when taking an infrared measurement, corresponding to the small (0), medium (1) and large (2) photodiodes. Larger values increase the sensitivity of the sensor.
diode_vis_3	Yes	{0,1}	1	The photodiode used by the third light sensor when taking a visible-light measurement, corresponding to the small (0) and medium (1) photodiodes. Larger values increase the sensitivity of the sensor.
led_1_ir	Yes	$\{0,\ldots,4095\}$	0	The brightness setting of the infrared (IR) LED above the first light-intensity sensor. Higher values correspond to higher brightness.
led_1_uv	Yes	$\{0,\ldots,4095\}$	0	The brightness setting of the ultraviolet (UV) LED above the first light-intensity sensor. Higher values correspond to higher brightness.
led_2_ir	Yes	$\{0,\ldots,4095\}$	0	The brightness setting of the infrared (IR) LED above the second light-intensity sensor. Higher values correspond to higher brightness.

Table 1: Description of the variables produced by the chamber configuration lt_mk2_linked_leds_sigmoid. Settable variables can be manipulated by calling .set(<variable>,<value>). "float" corresponds to a 32-bit float.

Variable	Settable	Values	Default	Description
led_2_uv	No	$\{0,\ldots,4095\}$	0	The brightness setting of the ultraviolet (UV) LED above the second light-intensity sensor. Higher values correspond to higher brightness. In each measurement cycle, the chamber first measures ir_1 and then sets led_2_uv following (1), before proceeding to measure ir_2, current_led_2_uv and current_led_2_uv_raw.
led_3_ir	Yes	$\{0,\ldots,4095\}$	0	The brightness setting of the infrared (IR) LED above the third light-intensity sensor. Higher values correspond to higher brightness.
led_3_uv	No	$\{0,\ldots,4095\}$	0	The brightness setting of the ultraviolet (UV) LED above the third light-intensity sensor. Higher values correspond to higher brightness. In each measurement cycle, the chamber first measures ir_2 and then sets led_3_uv following (2), before proceeding to measure ir_3, current_led_3_uv and current_led_3_uv_raw.
current_led_1_ir	No	float	–	Measurement (in Amperes) of the current drawn by the IR LED above the first sensor.
current_led_1_ir_raw	No	$\{-32768,\ldots,32767\}$	–	The uncalibrated measurement, i.e., the raw ADC output, corresponding to the measurement current_led_1_ir.
offset_current_led_1_ir	Yes	$\{0,\ldots,4095\}$	0	The reference voltage (offset) of the ADC producing the current_led_1_ir and current_led_1_ir_raw measurements. The actual reference voltage (in Volts) is given by $$5 \times \frac{\texttt{offset\_current\_led\_1\_ir}}{4095}.$$ Because the signal from the current sensor is passed through an inverting amplifier and substracted from the reference voltage, higher values of offset_current_led_1_ir result in higher values of current_led_1_ir_raw.
sps_current_led_1_ir	Yes	$\{0,\ldots,7\}$	7	The data rate of the ADC producing the current_led_1_ir and current_led_1_ir_raw measurements. Lower values mean the ADC accumulates more readings to produce a single measurement, reducing noise but also lowering the measurement speed. The actual data rates are (respectively) $8, 16, 32, 64, 128, 250, 475$ and 860 samples per second.
res_current_led_1_ir	Yes	$\{0,\ldots,5\}$	0	The resolution of the ADC producing the current_led_1_ir and current_led_1_ir_raw measurements. Higher values mean a higher resolution, where a smaller voltage range is mapped to the ADC output range $\{-32768, 32767\}$. The voltage ranges are, respectively, $\pm6.144, \pm4.096, \pm2.048, \pm1.024, \pm0.512$ and ±0.256 Volts. The reading will saturate, i.e., clamp at -32768 or 32767, if the input voltage exceeds the set range.
current_led_1_uv	No	float	–	Measurement (in Amperes) of the current drawn by the UV LED above the first sensor.
current_led_1_uv_raw	No	$\{-32768,\ldots,32767\}$	–	The uncalibrated measurement, i.e., the raw ADC output, corresponding to the measurement current_led_1_uv.
offset_current_led_1_uv	Yes	$\{0,\ldots,4095\}$	0	The reference voltage (offset) of the ADC producing the current_led_1_uv and current_led_1_uv_raw measurements. The actual reference voltage (in Volts) is given by $$5 \times \frac{\texttt{offset\_current\_led\_1\_uv}}{4095}.$$ Because the signal from the current sensor is passed through an inverting amplifier and substracted from the reference voltage, higher values of offset_current_led_1_uv result in higher values of current_led_1_uv_raw.
sps_current_led_1_uv	Yes	$\{0,\ldots,7\}$	7	The data rate of the ADC producing the current_led_1_uv and current_led_1_uv_raw measurements. Lower values mean the ADC accumulates more readings to produce a single measurement, reducing noise but also lowering the measurement speed. The actual data rates are (respectively) $8, 16, 32, 64, 128, 250, 475$ and 860 samples per second.
res_current_led_1_uv	Yes	$\{0,\ldots,5\}$	0	The resolution of the ADC producing the current_led_1_uv and current_led_1_uv_raw measurements. Higher values mean a higher resolution, where a smaller voltage range is mapped to the ADC output range $\{-32768, 32767\}$. The voltage ranges are, respectively, $\pm6.144, \pm4.096, \pm2.048, \pm1.024, \pm0.512$ and ±0.256 Volts. The reading will saturate, i.e., clamp at -32768 or 32767, if the input voltage exceeds the set range.
current_led_2_ir	No	float	–	Measurement (in Amperes) of the current drawn by the IR LED above the second sensor.

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Variable	Settable	Values	Default	Description
current_led_2_ir_raw	No	$\{-32768, \ldots, 32767\}$	–	The uncalibrated measurement, i.e., the raw ADC output, corresponding to the measurement current_led_2_ir.
offset_current_led_2_ir	Yes	$\{0, \ldots, 4095\}$	0	The reference voltage (offset) of the ADC producing the current_led_2_ir and current_led_2_ir_raw measurements. The actual reference voltage (in Volts) is given by $$5 \times \frac{\texttt{offset\_current\_led\_2\_ir}}{4095}.$$ Because the signal from the current sensor is passed through an inverting amplifier and substracted from the reference voltage, higher values of offset_current_led_2_ir result in higher values of current_led_2_ir_raw.
sps_current_led_2_ir	Yes	$\{0, \ldots, 7\}$	7	The data rate of the ADC producing the current_led_2_ir and current_led_2_ir_raw measurements. Lower values mean the ADC accumulates more readings to produce a single measurement, reducing noise but also lowering the measurement speed. The actual data rates are (respectively) $8, 16, 32, 64, 128, 250, 475$ and 860 samples per second.
res_current_led_2_ir	Yes	$\{0, \ldots, 5\}$	0	The resolution of the ADC producing the current_led_2_ir and current_led_2_ir_raw measurements. Higher values mean a higher resolution, where a smaller voltage range is mapped to the ADC output range $\{-32768, 32767\}$. The voltage ranges are, respectively, $\pm 6.144, \pm 4.096, \pm 2.048, \pm 1.024, \pm 0.512$ and ± 0.256 Volts. The reading will saturate, i.e., clamp at -32768 or 32767, if the input voltage exceeds the set range.
current_led_2_uv	No	float	–	Measurement (in Amperes) of the current drawn by the UV LED above the second sensor.
current_led_2_uv_raw	No	$\{-32768, \ldots, 32767\}$	–	The uncalibrated measurement, i.e., the raw ADC output, corresponding to the measurement current_led_2_uv.
offset_current_led_2_uv	Yes	$\{0, \ldots, 4095\}$	0	The reference voltage (offset) of the ADC producing the current_led_2_uv and current_led_2_uv_raw measurements. The actual reference voltage (in Volts) is given by $$5 \times \frac{\texttt{offset\_current\_led\_2\_uv}}{4095}.$$ Because the signal from the current sensor is passed through an inverting amplifier and substracted from the reference voltage, higher values of offset_current_led_2_uv result in higher values of current_led_2_uv_raw.
sps_current_led_2_uv	Yes	$\{0, \ldots, 7\}$	7	The data rate of the ADC producing the current_led_2_uv and current_led_2_uv_raw measurements. Lower values mean the ADC accumulates more readings to produce a single measurement, reducing noise but also lowering the measurement speed. The actual data rates are (respectively) $8, 16, 32, 64, 128, 250, 475$ and 860 samples per second.
res_current_led_2_uv	Yes	$\{0, \ldots, 5\}$	0	The resolution of the ADC producing the current_led_2_uv and current_led_2_uv_raw measurements. Higher values mean a higher resolution, where a smaller voltage range is mapped to the ADC output range $\{-32768, 32767\}$. The voltage ranges are, respectively, $\pm 6.144, \pm 4.096, \pm 2.048, \pm 1.024, \pm 0.512$ and ± 0.256 Volts. The reading will saturate, i.e., clamp at -32768 or 32767, if the input voltage exceeds the set range.
current_led_3_ir	No	float	–	Measurement (in Amperes) of the current drawn by the IR LED above the third sensor.
current_led_3_ir_raw	No	$\{-32768, \ldots, 32767\}$	–	The uncalibrated measurement, i.e., the raw ADC output, corresponding to the measurement current_led_3_ir.
offset_current_led_3_ir	Yes	$\{0, \ldots, 4095\}$	0	The reference voltage (offset) of the ADC producing the current_led_3_ir and current_led_3_ir_raw measurements. The actual reference voltage (in Volts) is given by $$5 \times \frac{\texttt{offset\_current\_led\_3\_ir}}{4095}.$$ Because the signal from the current sensor is passed through an inverting amplifier and substracted from the reference voltage, higher values of offset_current_led_3_ir result in higher values of current_led_3_ir_raw.

Table 1: Description of the variables produced by the chamber configuration lt_mk2_linked_leds_sigmoid. Settable variables can be manipulated by calling .set(<variable>,<value>). “float” corresponds to a 32-bit float.

Variable	Settable	Values	Default	Description
sps_current_led_3_ir	Yes	$\{0,...,7\}$	7	The data rate of the ADC producing the current_led_3_ir and current_led_3_ir_raw measurements. Lower values mean the ADC accumulates more readings to produce a single measurement, reducing noise but also lowering the measurement speed. The actual data rates are (respectively) $8, 16, 32, 64, 128, 250, 475$ and 860 samples per second.
res_current_led_3_ir	Yes	$\{0,...,5\}$	0	The resolution of the ADC producing the current_led_3_ir and current_led_3_ir_raw measurements. Higher values mean a higher resolution, where a smaller voltage range is mapped to the ADC output range $\{-32768, 32767\}$. The voltage ranges are, respectively, $\pm 6.144, \pm 4.096, \pm 2.048, \pm 1.024, \pm 0.512$ and ± 0.256 Volts. The reading will saturate, i.e., clamp at -32768 or 32767, if the input voltage exceeds the set range.
current_led_3_uv	No	float	–	Measurement (in Amperes) of the current drawn by the UV LED above the third sensor.
current_led_3_uv_raw	No	$\{-32768,...,32767\}$	–	The uncalibrated measurement, i.e., the raw ADC output, corresponding to the measurement current_led_3_uv.
offset_current_led_3_uv	Yes	$\{0,...,4095\}$	0	The reference voltage (offset) of the ADC producing the current_led_3_uv and current_led_3_uv_raw measurements. The actual reference voltage (in Volts) is given by $$5 \times \frac{\texttt{offset\_current\_led\_3\_uv}}{4095}.$$ Because the signal from the current sensor is passed through an inverting amplifier and substracted from the reference voltage, higher values of offset_current_led_3_uv result in higher values of current_led_3_uv_raw.
sps_current_led_3_uv	Yes	$\{0,...,7\}$	7	The data rate of the ADC producing the current_led_3_uv and current_led_3_uv_raw measurements. Lower values mean the ADC accumulates more readings to produce a single measurement, reducing noise but also lowering the measurement speed. The actual data rates are (respectively) $8, 16, 32, 64, 128, 250, 475$ and 860 samples per second.
res_current_led_3_uv	Yes	$\{0,...,5\}$	0	The resolution of the ADC producing the current_led_3_uv and current_led_3_uv_raw measurements. Higher values mean a higher resolution, where a smaller voltage range is mapped to the ADC output range $\{-32768, 32767\}$. The voltage ranges are, respectively, $\pm 6.144, \pm 4.096, \pm 2.048, \pm 1.024, \pm 0.512$ and ± 0.256 Volts. The reading will saturate, i.e., clamp at -32768 or 32767, if the input voltage exceeds the set range.
current_supply	No	float	–	The current drawn by the chamber and all its components, including the onboard computer and server. Used for diagnosis.
current_supply_raw	No	$\{0,...,1023\}$	–	The uncalibrated measurement, i.e., the raw ADC output, corresponding to the measurement current_supply.
pot_1_volts	No	float	–	The raw voltage (in volts) of the first angle sensor. Used for diagnosis.
pot_2_volts	No	float	–	The raw voltage (in volts) of the second angle sensor. Used for diagnosis.

Table 1: Description of the variables produced by the chamber configuration lt_mk2_linked_leds_sigmoid. Settable variables can be manipulated by calling .set(<variable>,<value>). “float” corresponds to a 32-bit float.

Causal Ground Truth

The graph below can be interpreted as a causal ground truth, where an edge $X \rightarrow Y$ signifies that an intervention on X will change the distribution of subsequent measurements of Y. This causal interpretation is formalized in Gamella et al. [2025, Appendix V]. Note that the absence of an edge between two variables does not preclude the existence of a causal effect between them. As with most real systems, effects between observed variables may exist beyond what we know or can validate through experimentation, e.g., due to a lack of statistical power. Furthermore, there may be confounding effects where unmeasured external variables simultaneously affect some of the variables in the chamber, such as ambient pressure or lighting conditions. For more details, we refer the reader to Gamella et al. [2025, Appendix V].

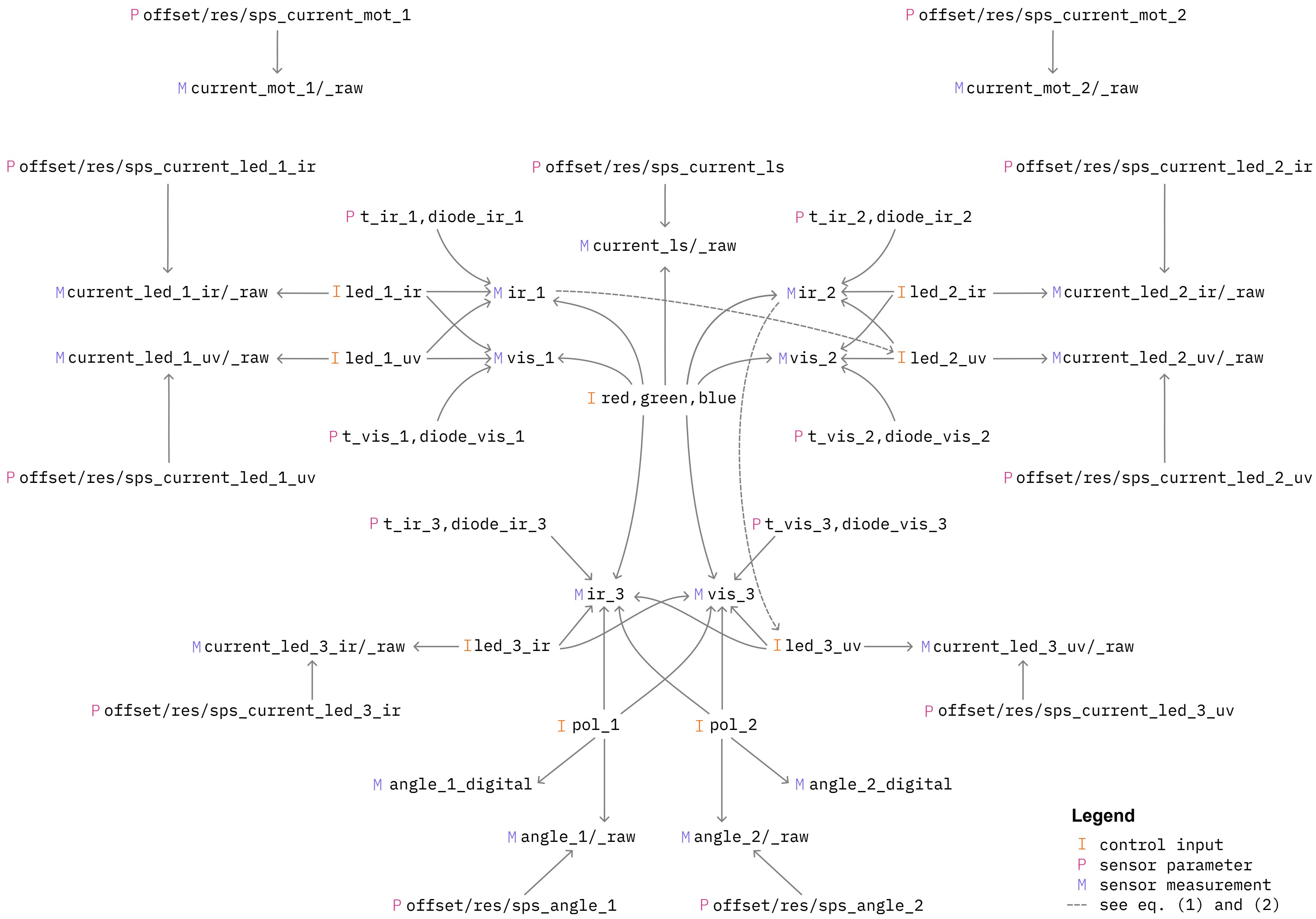

Figure 1: Graph representation of the known effects between the variables of the chamber. We use some shorthand notation to simplify the graph: node labels separated by a comma correspond to independent nodes with the same incident edges, e.g., a node `var_1,var_2` corresponds to two separate nodes `var_1` and `var_2`. Similarly, a node `a/b/c_var` is shorthand notation for the separate nodes `a_var`, `b_var`, and `c_var`.

References

Juan L. Gamella, Jonas Peters, and Peter Bühlmann. Causal chambers as a real-world physical testbed for AI methodology. *Nature Machine Intelligence*, 2025. doi: 10.1038/s42256-024-00964-x.