NAVIGATION USING LASER HEAT MARK TRACKING

ABSTRACT

A method is described for creating navigational landmarks using laser heating of surfaces adjacent to a mobile device which allow the device to track its orientation and position in the environment as it moves relative to the marks. This is accomplished by equipping the device with heat-inducing lasers and associated heat-sensing cameras. Orientation and position calculations are done by collating information about heat marks using various embodiments. Heat marks are distinguishable by temperature, pattern or color. The integration of the orientation and position changes allows the device to navigate its environment. The mobile device may be carried or contained within a vehicle that is autonomous or remotely controlled.

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CLAIMS

1. A mobile device equipped with one or more heat-inducing lasers and associated heat-sensing cameras by which the device tracks its orientation and position relative to surfaces within range of the lasers and visible to the cameras. A laser pulse heats an adjacent surface sufficiently to leave a thermal mark that is detectable by a camera. Heat marks are distinguishable by such means as temperature, pattern or color. A heat mark persists for an interval of time during which the camera locates the mark in its field of view and captures the location for subsequent processing. Changes in the device’s orientation and position within the interval are reflected by corresponding changes to the mark’s location within the camera’s field of view. Orientation and position changes are numerically calculated by processing the captured information about one or more heat mark locations by various means, depending on the embodiment. The integrated orientation and position changes allow the device to navigate its environment.

BACKGROUND OF THE INVENTION

Knowing the orientation and position of an object relative to some frame of reference is invaluable for navigation and mapping an environment. There are two general types of methods for determining orientation and position. Internal methods, also known as dead reckoning, rely on measuring internal variables, such as inertia changes. These techniques are subject to drift, an accumulating error over time. One remedy for this is to exert control over movements, such as performed by SLAM (Simultaneous localization and mapping). External methods, which are less prone to error accumulation, rely on obtaining information from the environment such as landmarks, images, and distances. Unfortunately, these sources of information are not always available. This invention leverages the availability of nearby surfaces upon which heat marks may be made by laser pulses. These marks then serve as temporary external landmarks for tracking orientation and position. The Appendix describes the feasibility of laser heating of surfaces for the purpose of marking.

FIELD OF THE INVENTION

The invention pertains to the field of navigation by tracking orientation and position with respect to an environment. In contrast to internal dead reckoning mechanisms, such as gyroscopes and accelerometers, the invention employs external information from laser pulse heating of surfaces to allow the calculation of orientation and position relative to the surfaces. The invention also deals with laser surface heating and the detection of such heating by heat-sensing cameras.

DESCRIPTION OF THE RELATED ART

US patent 5691921 specifies a laser marking method for locating moving objects having patterns applied to them that react in known ways to laser energy. US patent 4662756 is also a method for tracking pre-configured moving objects using detectable signals as the objects move within range of energy sources. Neither of these methods significantly overlap with the method of this invention, which is tracking the measuring device itself in an arbitrary environment.

REFERENCES

US 4662756: Motion tracking device

US 5691921: Thermal sensors arrays useful for motion tracking by thermal gradient detection

SUMMARY OF THE DISCLOSURE

There are a number of possible embodiments that use the method. The orientation and position tracking embodiments described below are examples of how the method is employed in a device.

Orientation tracking embodiment. A device equipped with an orthogonal array of heat-inducing pulsing lasers and associated heat-sensing cameras tracks its orientation relative to surfaces within range of the lasers and visible to the cameras. The orthogonal array consists of six laser/camera pairs pointing forward, backward, left, right, up and down in the frame of reference of the device. A laser pulse periodically heats an adjacent surface sufficiently to leave a temporary thermal mark that is detectable by a camera. This heat mark persists while cooling for a period of time such that a camera can detect and distinguish two marks made at the beginning and end of a time interval during which the orientation of the device may change. A change in orientation produces heat marks having identical positive directed distances between them as measured internally by cameras within the plane of rotation, and marks having zero separation between them on cameras outside of the plane. The angle between the heat marks necessary to produce the measured internal camera distance between them, combined with the rotation plane, yields the orientation change. Integrating the orientation changes calculates the current orientation of the device within its environment.

Position tracking embodiment. In addition to the laser/camera array specified in the orientation tracking embodiment, the position tracking embodiment requires the equipage of distance measuring lasers which optionally are embodied in the same physical laser components. A translation in position along an axis produces laser heat marks having consistent positive distances between them on cameras orthogonal to the axis, which combined with distance measurements to the marks yields the translation along the axis. Integrating the position changes calculates the current position of the device within its environment.

An alternative embodiment. By means of a distinguishable pattern of heat marks on a surface, orientation and position changes in the device may be tracked by how the marks change location within the camera’s field of view using geometric means.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram of the device changing orientation. FIG. 2 is a diagram of the device translating position. FIG. 3 is a diagram depicting the calculation of orientation and position change within the device.

DETAILED DESCRIPTION

Refer to the orientation and position tracking embodiments. FIG. 1 depicts device orientation tracking while rotating. The device is shown with four laser/camera pairs aligned on a plane of rotation with the remaining two laser/camera pairs not shown. At time *T1* four heat marks have been make by laser pulses on adjacent surfaces. At time *T2* the device has rotated clockwise by some angle and new heat marks have been made that are denoted as “hot”. The heat marks from *T1* are now shown as “warm” marks. The two unshown laser/camera pairs will have superpositioned respective marks.

FIG. 2 depicts a position tracking while translating to the right from time *T1* to *T2*. At *T2* pairs of heat marks on the axis of translation are shown as superpositioned; marks on the axis orthogonal to the axis of translation are shown with distinguishable separations.

For the orientation tracking calculation, refer to FIG. 3 as applied to the scenario of FIG. 1. Sides *A* and *B* are lines to the heat marks that are visible to a camera whose focal lens is shown. *D* is the distance between the marks. Let α be the angle between *A* and *B*, which is also the rotation within the given plane. Within the camera a triangle similar to *A*-*B*-*D* is formed as *a*-*b*-*d*, with α the angle between *a* and *b*. The internal quantity *d* is calibrated to the value of α. Note that for orientation tracking, it is not necessary to know the lengths of *A*, *B*, or *D*.

For the position tracking calculation, consider one of the cameras detecting a positive distance between the marks. Here laser distance measuring comes into use to detect the lengths of *A* and *B*. The similar triangle *a*-*b*-*d*, whose lengths are all known, allow the computation of *D*, which is the translation along the axis.

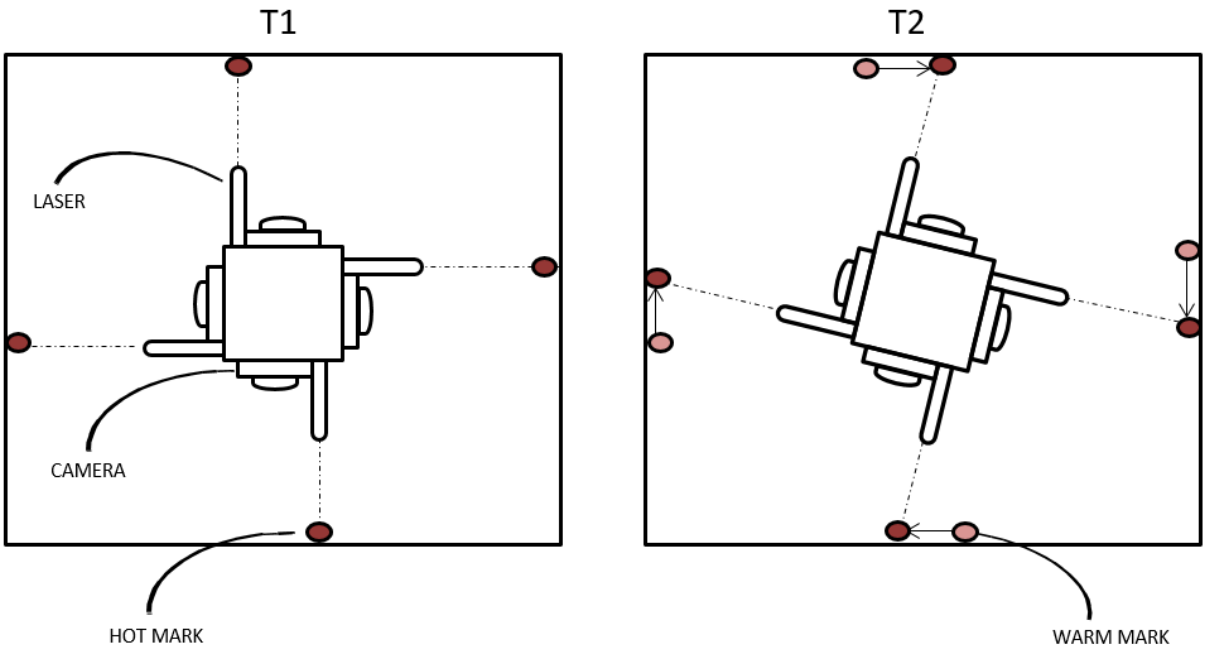

FIG. 1 – ORIENTATION TRACKING

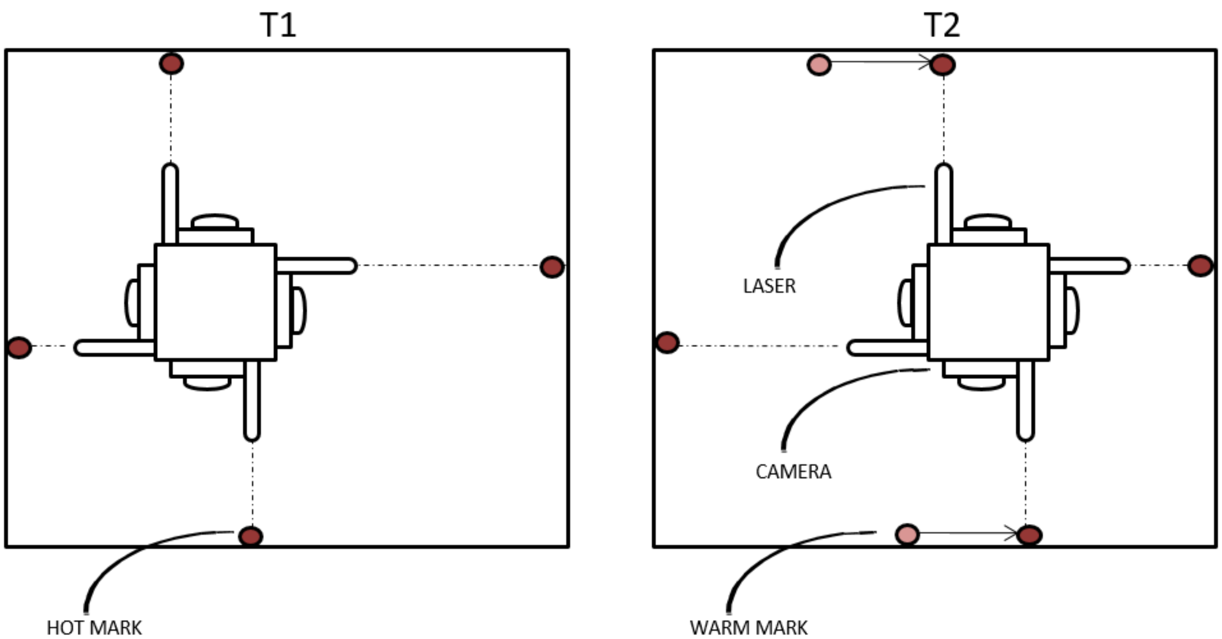

FIG. 2 – POSITION TRACKING

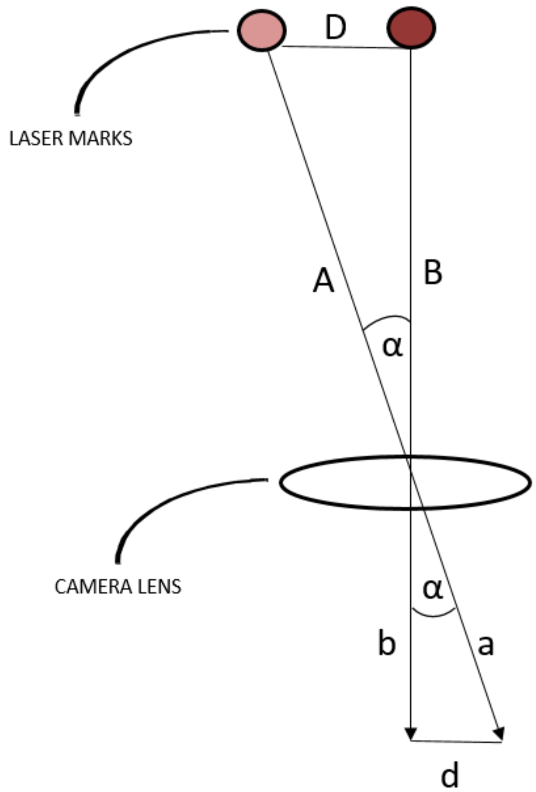

FIG. 3 – TRACKING GEOMETRY

APPENDIX – FEASIBILITY OF LASER HEATING OF A SURFACE

This report investigates the feasibility of surface heating using a battery powered laser. Due to the large amount of changeable parameters, simplifications are made and all terms are left as variables. Ideally, the entire system would be solved by constructing a partial differential equation that combines conduction and radiative heat transfer. The problem is simplified by breaking it into stages.

Part 1 – Laser Heating

In simple terms, the problem can be described as an energy balance. Assuming that we are using an efficient laser with a power of P, pointed at a surface (with an absorptivity α, heat capacity c_p, and a density ρ) for a duration t, over a volume estimated to be a cylinder with a cross sectional area A representing the emitting area of the laser and a thickness estimated by h, the specific heat equation can be written as:

$$\rho A h c_p \Delta T = P t \alpha \eta$$

with η being a general efficiency fudge factor.

With this equation, the change in temperature can be calculated from a pulse of laser. Below is an example of a plausible set of values:

Parameter	**Value**	**Source**
ρ	10 lb/gal	Paint
A	1 mm^2	Estimate for area of laser dot
h	0.1 mm	Estimate for thickness of paint
c_p	0.4 cal/gK	Paint
P	10.5 W	Pulse laser
t	100 × 150 ns	Pulse laser (100 pulses)
α	0.89	White paint
η	0.8	Estimate

The change in temperature ΔT can then be calculated to be around 0.6 K, which is a reasonable temperature for detection. Moreover, the resulting temperature is directly proportional to the duration of the laser emission, which can be easily tuned for its specific application.

Part 2 – Cooling of Heated Point

The second part of the analysis is determining how long it takes the heated dot to cool back down to ambient temperature. There are three factors to consider here – conduction to the surrounding material, convection to the air, radiation to air. For simplicity, the radiation term is ignored because the temperatures are relatively low. The conduction to the surrounding material will be treated as an interface heat transfer problem. This way, both conduction and convection can be modelled using Newton's law of cooling:

$$\frac{dT}{dt} = -\frac{h_{\text{conv}}}{h_{\text{cond}}}\Delta T$$

where $\frac{h_{\text{conv}}}{h_{\text{cond}}}$ is the Biot number of the system. Checking the values for the two types of heat transfer:

Parameter	**Value**	**Source**
$\boldsymbol{h}_{\textbf{conv}}$	1.5 W/(m^2 K)	Free convection gas
$\boldsymbol{h}_{\textbf{cond}}$	0.17 W/(m K) / 0.1 mm	Paint over its thickness

It can be seen that the heat transfer is completely dominated by conduction. Solving the differential equation:

$$\frac{dT}{dt} = -8.8 \times 10^{-4}\,T, \qquad T_{t=0} = 0.6\ \text{K}$$

Results in:

$$T = 0.6\ \text{K}\ e^{-8.8\times10^{-4}t}$$