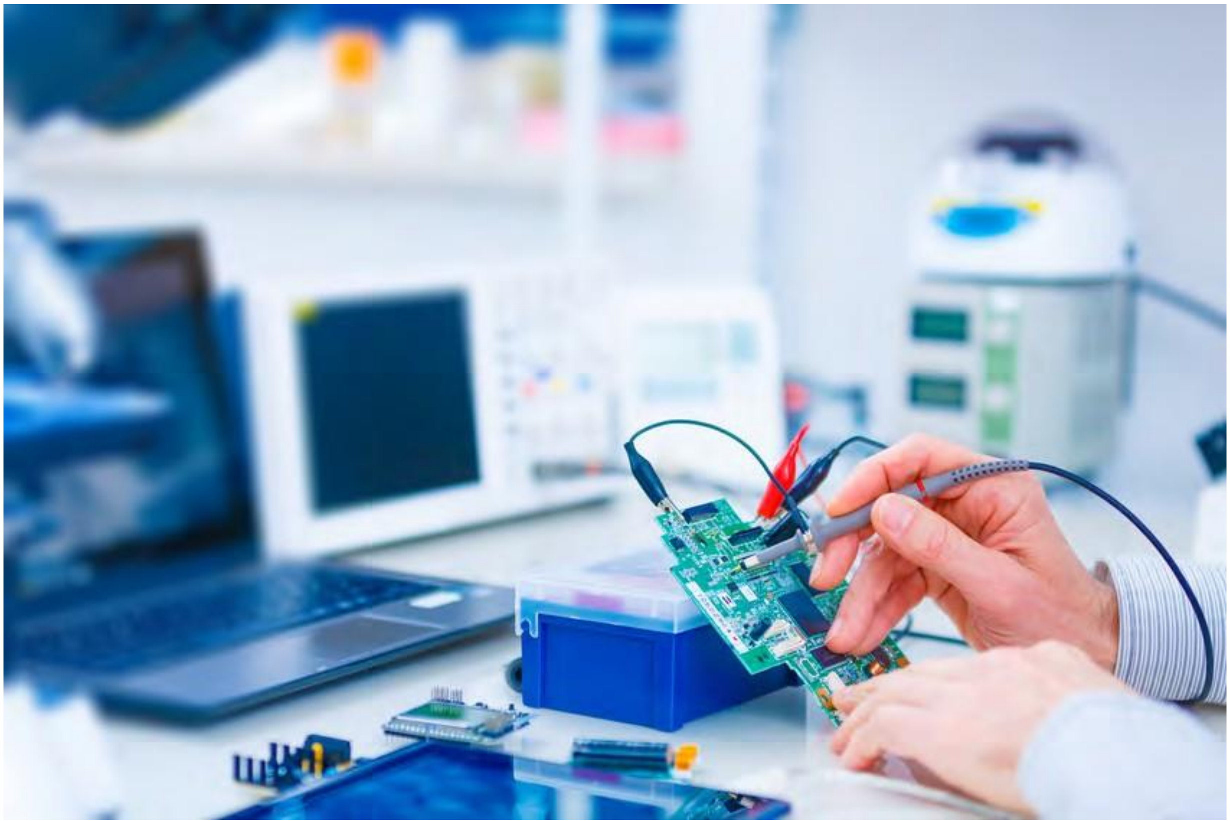


Overcoming Motor Driver Heat-Transfer Challenges in Robotic Applications

This paper is protected by copyright law. Individuals may reproduce and distribute this

white paper for individual, non-commercial use. All other uses require advance written permission from the authors. Please contact Soltex, Inc for more information.

The Soltex logo and Opticool Fluid are registered trademarks of Soltex, Inc.

DISCLAIMER: Although this white paper is designed to provide accurate and authoritative information with regard to the subject matter covered, the authors and their organizations accept no responsibility for errors and omissions.

THIS WHITE PAPER IS PROVIDED "AS IS." THE LICENSOR, THE COPYRIGHT HOLDER AND THE CONTRIBUTORS TO THIS SPECIFICATION MAKE NO REPRESENTATIONS OR WARRANTIES (i) EXPRESS OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, TITLE

OR NON-INFRINGEMENT; (ii) THAT THE CONTENTS OF SUCH SPECIFICATION ARE FREE FROM ERROR OR SUITABLE FOR ANY PURPOSE; AND (iii) THAT IMPLEMENTATION OF SUCH CONTENTS WILL NOT INFRINGE ANY THIRD-PARTY PATENTS, COPYRIGHTS, TRADEMARKS OR OTHER RIGHTS. IN NO EVENT WILL THE LICENSOR, THE COPYRIGHT HOLDER AND THE CONTRIBUTORS TO THIS WHITE PAPER BE LIABLE TO ANY PARTY FOR ANY DIRECT, INDIRECT, SPECIAL OR CONSEQUENTIAL DAMAGES FOR ANY USE OF THIS WHITE PAPER, INCLUDING, WITHOUT LIMITATION, ANY LOST PROFITS, BUSINESS INTERRUPTION, LOSS OF PROGRAMS OR OTHER DATA ON YOUR INFORMATION HANDLING SYSTEM OR OTHERWISE, EVEN IF THE LICENSOR, THE COPYRIGHT HOLDER OR CONTRIBUTORS TO THIS WHITE PAPER IS EXPRESSLY ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

Introduction

Fig 1. Experimental Setup

A motor driver (sometimes called a motor controller) is an electronic device that acts as an intermediate device between a microcontroller, a power supply or batteries, and the motors in robotics applications (Figure 1).

The physical size and weight of a motor driver can vary significantly, from a device smaller than the tip of your finger to a large controller weighing several Kg. As robotic designs and technologies evolve in the future, more powerful motor drivers will be required to accommodate these advances. It is expected that miniaturization will play an increasingly important role in near-term robotic applications as well. As power requirements increases, motor drivers must be designed to manage parallel overheating issues, while also maintaining a smaller footprint overall. Liquid immersion cooling is one way to successfully manage these concerns [1].

An experiment was conducted to demonstrate how overheating

issues and limitations in contemporary motor drivers might be overcome with the introduction of liquid immersion cooling.

Discussion on Motor Driver Failure

Temperature management is a fundamental aspect of motor driver design due to its' direct relation with component availability, whereas power and operation are related to system efficiency. When discussing traditional processors, the failure rate λ may be defined as the number of components failing per unit time [2]. Thus, component thermal reliability with a constant failure rate is expressed as [3]:

$$R(t) = \exp(-\lambda t)$$

A temperature-related reliability model based on the mean time to failure (MTTF) for motor drivers is proposed where constant λ is as follows:

$$MTTF = \int_{!}^{!} R(t)dt = \int_{!}^{!} \exp(-\lambda t)\, dt = \frac{1}{\lambda}$$

The model above, derived from [4], is based on 5 component failure rates including the number of failures per million hours ($C_! \; and \; C_!$), temperature factors ($\pi_!$), quality factor ($\pi_!$), learning factor ($\pi_!$), and environmental factor ($\pi_!$), thus:

$$\lambda = (C_! \pi_! + C_! \pi_!)\pi_! \pi_!$$

As shown in the model above, temperature and environment each affect the overall reliability of motor drivers, with thermal behavior often influenced by robotic design.

Equipment Configuration and Setup


Fig 2. Syren 25A Motor Driver

There are a large number of motors that work in conjunction with motor drivers, microcontrollers, and power supplies.
These motors are used to move material, parts, tools, or specialized devices with various programmed motions in robotic units. For this experiment, a gear head motor with wheel operating at 45RPM/50mA @24VDC no load; 1A/7.5in- lb torque at stall was chosen.

The gear head motor was connected to a Syren 25A regenerative motor driver (Figure 2). The Syren 25A is one of the most versatile, efficient and easy to use dual motor drivers on the market. This motor driver can supply a single DC brushed motor with up to 25A continuously [5]. Syren 25A was the first synchronous regenerative motor driver in its class. The regenerative topology enables batteries to recharge whenever a robot is commanded to slow down or reverse. For the purposes of this experiment, power was added directly to the Syren 25A to power the motor using a variable power supply unit. Additionally, the motor driver has built-in thermistors that are designed to shut the motor driver off when input voltage exceeds 30VDC or the device gets too hot. For this experiment, a customized version of the device was used without thermistors so that a failure point could be established during overheating conditions. Prior to thermistor removal, the motor driver would regularly shut down when >24VDC input was introduced.

10VDC was initially supplied to each motor driver to determine which components on the device get hottest during standard operation. A thermal imaging camera was utilized to determine the motor driver’s *IC hotspot* (Figure 3).

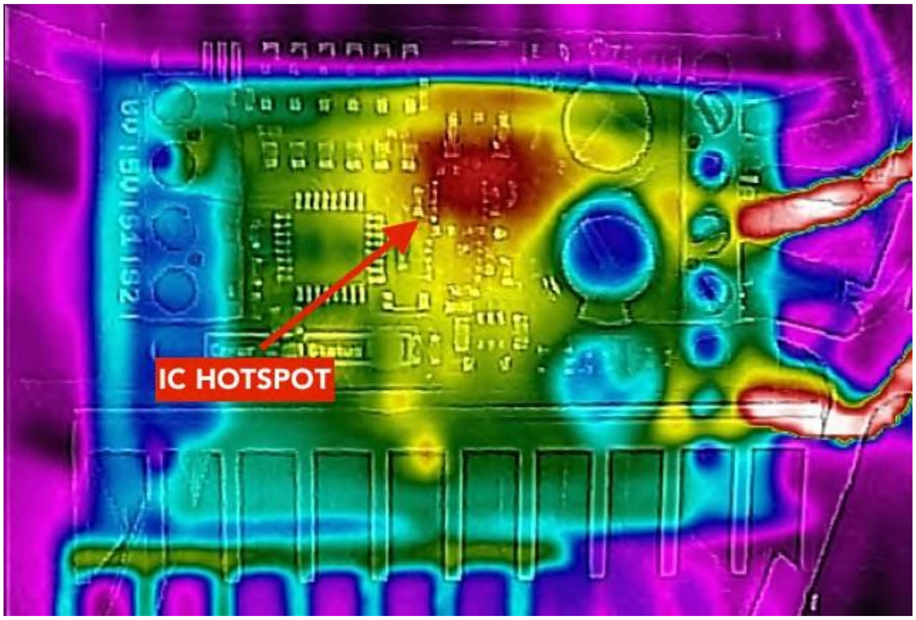


Fig 3. Thermal Image - Syren 25A Motor Driver Powered Up

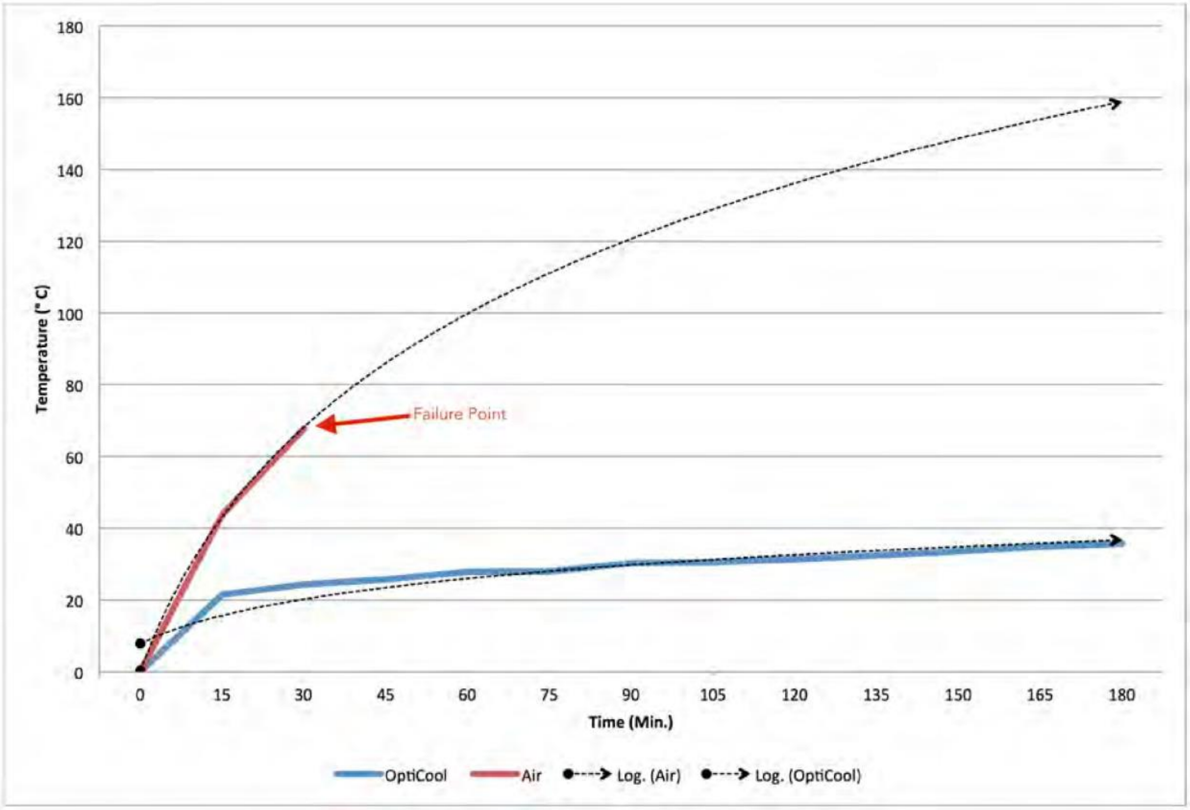
Testing Procedures

Input voltage was introduced and maintained at 30VDC to an un-submerged motor driver (Motor Driver 1) and submerged motor driver (Motor Driver 2) during testing. Temperature levels of the IC hotspot and operation were monitored and recorded over a 3-hour period.

Results

The Syren 25A motor driver was designed to operate optimally with 6-24VDC input at a maximum threshold of 30VDC. Removal of the motor drivers' thermal protection enabled us to continuously input this 30VDC threshold while monitoring temperature and operation to failure. Input voltage was maintained at 30VDC while recording the temperature of Motor Driver 1 and monitoring operation. Lab temperature was maintained at 20-20.28°C during testing. As input voltage was maintained, component temperature continued to increase, eventually leading to motor driver failure. At the 29-minute mark, Motor Driver 1 ceased to operate thereby cutting off the motor and wheel rotation. At this point, the motor driver was smoking and the device emitted a burned component smell. Decreasing the input power and waiting until the device cooled down did not turn the motor driver back on.

Motor Driver 2 was immersed in dielectric cooling fluid and 30VDC input voltage was applied at startup. Fluid temperature remained constant at 20.1°C. 30VDC input was maintained for a period of three hours reaching a maximum temperature of 35.7°C. During this 3-hour period, temperatures were recorded and operation was monitored. Although the voltage input was at the devices threshold, temperature of the device remained relatively constant during testing, thereby enabling continued operation in the device. There was no significant change in wheel rotation or motor stress over time.



Discussion

Device failure experienced during Motor Driver 1 testing was expected due to thermal overload. This is indicative of the problems associated with overheating in robotics applications today, and the reason that thermistors are required on devices like the one utilized in this test. Alternatively, the results of Motor Driver 2 testing indicate that liquid immersion cooling is a viable thermal management option in robotics applications. Liquid immersion cooling has been proven to maintain operation and reliability in a similar fashion in other types of electronics devices [1]. This demonstrates a reliable method of overcoming thermal management challenges and increased power demands in future robotic development efforts. Additionally, liquid cooling can be used to increase maximum input/output thresholds of motor drivers thereby enabling more powerful robotic designs.

Reference

[1] J. Carr and D. Sundin, Minimizing CPU overheating with liquid immersion cooling. Electronics Protection Magazine, 2014.

[2] EPMSA, Guidelines to Understanding Reliability Prediction, 2005.

[3] JEDEC, Failure Mechanisms and Models for Semiconductor Devices, JEP122F, 2010.

[4] Assessing the Corrosion Effect and Materials Compatibility of Electronics in Liquid Cooled Immersion Applications*, 2015. soltexinc.com.*

[5] SyRen 10/Syren 25 motor driver user's guide: Dimension Engineering, July 2007.

Opticool Fluid

OptiCool Fluid is an isoparaffin-based dielectric heat transfer fluid manufactured by Soltex, Inc.
OptiCool has been used for over 10-years to cool electrical circuitry in transformers, RF and microwave transmission devices and computer systems.

OptiCool Fluid is a colorless, odorless, food grade isoparaffin oil. With a very low viscosity and high thermal conductivity, OptiCool Fluid has extremely high heat transfer coefficients, making it ideal for removing heat from circuitry with high heat flux densities.

Contact Soltex to find out more about OptiCool Fluid and its electronics cooling applications.

soltexinc.com
mailto:sales@dsiventures.com
Tel: 281-587-0900