SmartDeviceLink Application to Intelligent Climate Control

Oleg Gusikhin, Omar Makke, Jeffrey Yeung and Perry MacNeille
Research and Advanced Engineering, Ford Motor Company, 20300 Rotunda Drive, 48121, Dearborn, Michigan, U.S.A.

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Abstract: SmartDeviceLink (SDL) is an open-source software development kit (SDK) that enables a smart-device to connect to the vehicle, providing functions for safe and easy access to the vehicle human-machine interface (HMI) and the ability to programmatically control vehicle functions. This paper discusses a framework for developing intelligent control applications that implement personalized and context-aware features for automotive climate control systems. There is also a discussion of integration of wearables, internet-of-things (IoT) sensors, cloud and mobile machine learning.

1 INTRODUCTION

Connected cars and Internet of Things (IoT) technologies are at the frontier of the automotive industry innovation (Lu, 2014; Swan, 2015). In recent years, significant progress has been made in the area of brought-in connectivity. The increasing ubiquity of smartphones created a need to provide a safe and easy access to smartphone apps while driving. Ford Motor Company's SYNC™ Applink was the first wide scale implementation of such technology followed by the rest of the industry generating a multitude of different solutions. This situation presented a significant challenge for the app development community as it requires adaptation of a given app to each automaker's interface.

To address this challenge, Ford contributed Applink to the open source SmartDeviceLink project to promote the development of an industry wide standard. MirrorLink is another phone linking open standard that has been developed in parallel with Applink. It projects the app's display of a MirrorLink enabled phone to MirrorLink enabled vehicle head unit. This standard, however; is not universally adopted by OEMs and phone providers. For instance, iOS does not support MirrorLink, leaving out the iPhone users who are a substantial portion of the addressable market.

Apple and Google also introduced their phone projection technologies, CarPlay and Android Auto respectively, that provide in-car access to selected approved apps through a familiar Android and iPhone display (Shelly, 2015). In contrast, SDL allows seamless integration of mobile apps into the vehicle head unit while maintaining the look and feel of the given OEM human machine interface (HMI) design. In addition, SDL implements the capability to programmatically manage the vehicle sub-system settings, including radio, climate control, navigation and other user-configurable infotainment and convenience features. Consequently, it provides a powerful platform for cyber-physical systems that integrate wearables, IoT sensors and cloud data into the intelligent vehicle control (Smirnov, 2016). The paper discusses the opportunities for the SDL application with automotive climate control.

Climate comfort in the vehicle cabin is achieved through a system of integrated heating, ventilation and air conditioning (HVAC), either controlled manually or automatically (Daly, 2011). The basic HVAC system maintains a manually set temperature and speed of air flowing from the ventilation system. On the other hand, an automatic climate control keeps a set temperature within the space of the cabin by regulating a blower speed and direction based on temperature, humidity and sun-load sensors. The state of the art automotive climate control features multi-zone automatic climate control. Many high end vehicles include separate climate control for driver, front passenger and rear passenger zones. A number of luxury vehicles have a four-zone automatic climate control system with infrared sensors that monitor occupants' surface temperature. Further advancement of climate control systems includes the development of air quality control. Many automakers have now begun to install air quality sensors in the vehicle that

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measure different pollutants in the outside air, such as $PM_{2.5}$ (particulate matter less than 2.5 micron in diameter), carbon monoxide (CO), and hydrocarbons (HC). When a high level of pollution is detected, climate control switches to recirculation mode to prevent polluted air from entering the cabin.

Factory-installed climate control equipment is an automotive grade system that must meet a wide range of requirements for safety, robustness, and manufacturability. Automotive grade components withstand significant physical forces, function under a wide range of ambient conditions, and have a lifespan substantially longer than typical consumer devices. The ability to effectively integrate consumer devices into vehicle control systems not only reduces the cost of the feature, but also ensures that customers can leverage the latest technological innovations available in the market. For example, biometrics from wearable devices could provide more accurate prediction of the perceived comfort levels of the passengers.

The IoT revolution is a game changer for the control approach. Home climate control has seen such changes with products like the Nest Learning Thermostat that implement model predictive control (MPC) algorithms. IoT technology provides significant opportunities and challenges for automotive control applications. Potentially significantly advances in personalization and intelligence are achieved more rapidly and at lower cost than development of the automotive grade technology. It supports the trend in mobility for on-demand transportation and a shared car economy, as personalization is not tied to the vehicle but stays with a user's smartphone and can be dynamically integrated into vehicle control. The ability to collect and analyse data in the cloud can provide new data from crowdsourcing of environment information, remote prognostics and diagnostics and provide new insights into consumers' behaviour and climate control usage. However, it raises a number of concerns regarding security, safety and robustness of the applications that rely on external information.

SDL allows integration of IoT technology in a safe and secure way. It also ensures that the OEM is in control of what application is used within the system.

This paper examines the way wearable devices, IoT sensors, personal smart mobile devices and cloud information can be integrated into automotive climate control using SDL. These examples show how the IoT approach can implement intelligent control for basic HVAC units or augment the existing automatic climate control system with additional sensory input and personalization. In the next section, we describe the SDL APIs relevant to build climate control apps. Section 3 provides an example of the intelligent climate control integrating wearables and machine learning. Section 4 describes air quality control leveraging brought-in sensors and cloud data. Section 5 provides a summary and discussion of benefits.

2 SmartDeviceLink FOR VEHICLE CLIMATE CONTROL

SmartDeviceLink is an open source project under GENIVI Alliance. It comprises head unit software and mobile SDKs for Android and iOS, as well as cloud configuration. It supports several transport protocols: Bluetooth, WiFi and USB. SmartDeviceLink supports both media and non-media apps. Media apps are dedicated to audio streaming and provide alternative user interface (UI) to the native media UI, which usually include FM/AM/XM, and CD. Non-media apps normally read vehicle data and provide added functionality to the driver. The head unit defines four states called HMI_LEVEL for each app: FOREGROUND, LIMITED, BACKGROUND, and NONE.

When the app is selected from the head unit, it opens a UI and is put in FOREGROUND state, which gives the app all its permissions. Once opened, the driver may switch to a different screen on the head unit, such as the navigation screen, which puts the app in LIMITED, and thus limiting some of the app's permissions.

An app in NONE state is idle and is only allowed to be discovered and started. The app is put in BACKGROUND state if its functionality interferes with a higher priority function, such as an incoming phone call during audio streaming, and can be treated as a temporary NONE state for many cases. Mobile applications can communicate with SDL core once they implement the SDL software development kit (SDK), which is available for Android and iOS platforms. The SDK makes the app discoverable by the vehicle's head unit. It exposes a set of remote procedure calls (RPCs) through a defined set of application programming interface (API).

In brief, the app instantiates an instance of SDL proxy class which handles the communication between the app and the vehicle. The RPCs are methods of the proxy class. Moreover, the proxy class intercepts the vehicle's notifications and makes them available for the mobile app.

The proxy class also allows the app to query the head unit for capabilities, since the app can be

Table 1: SDL API's for reading and writing module parameters.

API	Parameters	Description
`getInteriorVehicleCapabilities()`	Zone	Returns supported modules the vehicle is equipped with (Radio, Climate Unit…).
`getInteriorVehicleData()`	Zone, Module	Reads module data. Modules are obtained from `getInteriorVehicleCapabilities`.
`setInteriorVehicleData()`	Zone, Module, Data	Control API. Sets the data of the Module for the specified zone

running on different vehicles designed by different OEMs with different capabilities. Although the RPC implementation is not directly exposed to the app developer, it is worth noting that the RPC protocols are implemented as JSON strings.

A remote control extension for SDL is created and is available in the public repository. The extension consists of additions to SDL core inside the vehicle and to the mobile SDK for Android and iOS. Three major RPC's responsible for remote control, and their corresponding APIs are shown in Table 1. These APIs provide enough abstraction for mobile apps to control vehicle modules with different capabilities inside vehicles by different OEMs.

SDL opens new opportunities to bring IoT to the vehicle using remote control APIs. Figure 1 shows a general configuration of how this can be achieved. Two consumer grade sensors are brought by the driver: the mobile device hosting the mobile application, and the optional sensors. The sensors may be embedded directly on the device hosting the mobile application, such as an accelerometer or skin temperature sensor on a wearable, or it may be a completely separate device, such as a $PM_{2.5}$ sensor, which can broadcast its values over Bluetooth.

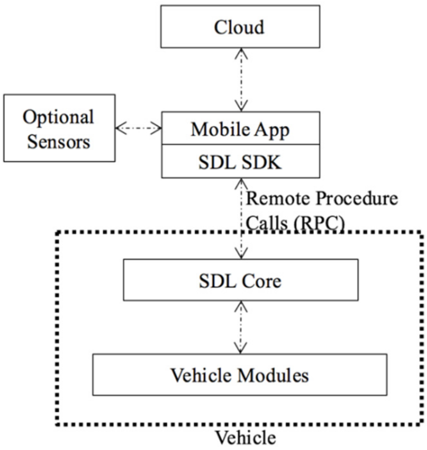

Figure 1: SDL-based sensor integration.

The remote control SDK allows reading and controlling the parameters shown in Table 2 (except for ambient temperature which is read only) for the climate control unit. Other modules, such as radio, also have defined set of parameters which can be read and controlled. For each and every parameter, permissions to read and write to the parameters are controlled by the OEM through a cloud server.

Table 2: SDL parameters for climate control.

Parameter	Description
`acEnable`	Toggles AC ON/OFF
`desiredTemp`	User input (the set temperature in the head unit).
`fanSpeed`	Blower speed in %
`currentTemp`	Outside Ambient Temperature
`temperatureUnit`	Unit of the temperatures
`circulateAirEnable`	Air recirculation ON/OFF
`autoModeEnable`	Auto mode value ON/OFF
`defrostZone`	Front, Rear defrost ON/OFF
`dualModeEnable`	Dual mode is ON/OFF for units supporting zone control

In order to provide control over which apps can be discovered by SDL and what the app can execute, the OEM implements a policy table in the cloud. Each approved app is assigned an application ID (App ID) by the OEM. Each App ID is associated with an explicit set of RPCs which the app can execute in each of the four HMI_LEVEL states of the app. If the app attempts to execute an RPC that is in incorrect state, it will be denied. The policy table contains this information for every approved app in the cloud. When an SDL app connects to a new vehicle, it will send its App ID, and the vehicle will search its local policy table for it. If the App ID is not found, the vehicle requests the mobile app (the mobile software development kit specifically) to obtain encrypted policy information specifically for the App ID. This request is also initiated regularly to update the local policy table for all discovered apps which give the OEM ultimate control of permissions.

3 PERSONALIZED CLIMATE CONTROL

The goal of intelligent climate control is to maintain the comfort level of the user with minimal user interactions. Most existing automatic climate control systems maintain a preset temperature by blowing hot or cold air until the temperature reaches the preset level. This mode is designed to work for the vast majority of the population. However, user climate comfort preferences vary based on physiological and psychological factors and may change during driving (Rosenfeld, 2015). In Kuang, 1995, the authors have demonstrated the perception of comfortable temperature correlates more with skin temperature rather than with the ambient temperature of the cabin. The paper describes experimental control system that uses an IR sensor to obtain skin temperatures. Nowadays, we can leverage many wearable devices, such as the Seraphim Sense Angel Sensor (Seraphim, 2016), that provide a real-time reading of skin temperature among other biometrics. SDL-enabled application integrating wearable's data can be written to personalize climate settings using cloud services and machine learning algorithms.

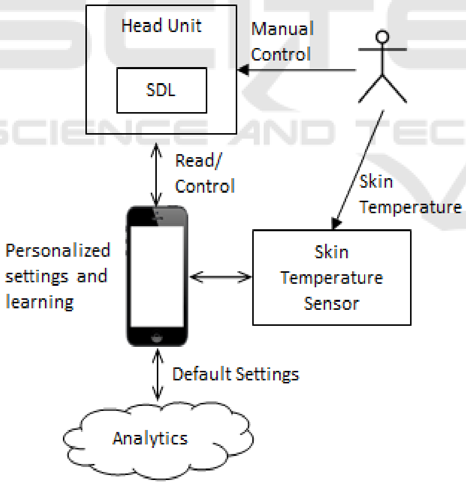

Figure 2: Personalized climate control.

Figure 2 shows the main components of such a system. It has been demonstrated that neural networks have been an efficient and effective approach to implement complex non-linear models for personalized climate control (Thomas, 2007; Kajino, 2000). The modern smartphone's hardware provides sufficiently powerful computational platform to implement machine learning, and neural networks in particular. Lane, 2015, discusses a feasibility of implementation of low power consumption cloud-free deep neural networks for smartphones for audio processing.

Recently, Google open-sourced its TensorFlow™ engine, which can be used to implement deep learning and neural networks on many platforms, including locally on smartphones.

The proposed system implementation diagram is shown in Figure 3. The input includes vehicle climate control parameters shown in Table 2 which are obtained via SDL, combined with the skin temperature from the wearable device, and the output is the target temperature, which can be set via SDL. With a proper learning model, the cabin settings could be adjusted seamlessly to the user's desires without user input.

4 CABIN AIR QUALITY CONTROL

Air quality is increasingly becoming a concern particularly as urban areas continue to grow. It is typically described by an Air Quality Index (AQI), which is a measure of the concentration of various gases and particulates in the air over a specific time span and an indicator of the health impact of the air. Cabin air quality can be improved through proper management of the climate control system (Müller, 2011). For instance, if the external air quality is poor, the vehicle should recirculate internal air. However, recirculating air too long can cause fogging of windows and drowsiness.

Conversely, if the internal air quality is poor, the cabin air should be purged with external air by turning recirculation off and increasing the air blower speed. Since this air is processed through the vehicle's air filter, this will improve the air in the cabin even if the external air is not clean.

With a growing interest in cabin air quality management, automakers are actively seeking implementation of internal and external air quality sensors with the climate control system. While there is substantial progress in the development of air quality sensors for the consumer market, their availability for automotive applications is currently limited. In lieu of an embedded system, SDL offers an efficient and effective approach leveraging brought-in consumer sensors and cloud-based AQI data.

In the prototype, we used a sensor from ChemiSense (ChemiSense, 2016) that detects several analytes using proprietary sensor arrays and machine learning, including: NO_2, NH_3, CO, CHOH (Formaldehyde), Humidity, VOCs (volatile organic

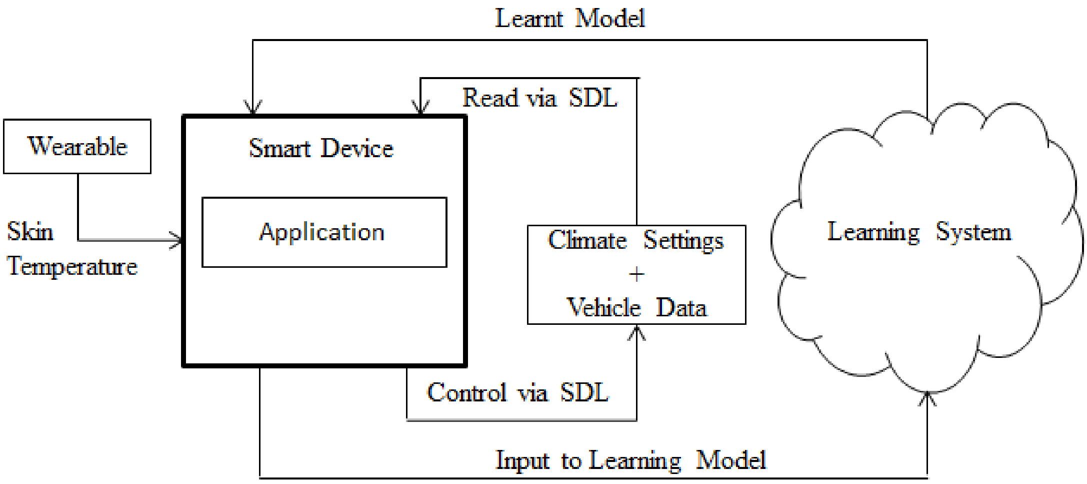

Figure 3: Architecture of intelligent climate control.

compounds); temperature with a thermistor, and PM$_{2.5}$ with an IR smoke detector. An AQI value is determined by calculating the indices for CO and PM2.5. The higher value is taken as overall internal cabin AQI.

The brought-in air quality sensor is not necessarily tied to any particular provider, except that the sensor must communicate with a mobile device or the HMI with a low-energy radio such as Bluetooth LE to reduce power draw so the device can be self-standing. In fact, this platform can work with any many air quality sensors, provided it meets sufficient standards for reaction time, for specificity and accuracy. The interface with the AQI value from the in-vehicle sensor (and the sensor itself) built with Applink is shown in Figure 4.

Figure 4: Air Quality Index App and Sensor.

Estimation of the air quality outside the vehicle was done using the API provided by AirNow (AirNow, 2016), a website operated by the U.S. EPA to provide real-time and forecasted data on the air quality in the U.S. This API provides the calculated AQI for O_3, PM$_{2.5}$, and PM$_{10}$. The AQI values are also assigned a category, ranging from "Good" to "Hazardous".

For the purposes of this application, we are focused on PM$_{2.5}$, since this is of the most interest in China. Thus, wherever AQI is concerned for the external (outside) readings, it is based solely on PM$_{2.5}$. AirNow uses weather stations scattered throughout the U.S. to provide their measurements. The API determines the closest station to the latitude and longitude coordinates requested, which we determine from the GPS of our device. For deployment in China, a similar governmental service can be used instead. Obtaining data from AirNow or similar government data services in other regions is easy and reliable. However, it is not sufficiently granular for effective air quality management.

Figure 5 provides the results of the field test conducted in a Bay Area. During the field test we identified 3 areas with elevated level of pollution corresponding to poor air in an AQI chart. At Dumbarton Bridge (1), a pungent smell similar to rotting fish and sulfur was noticed. Near the San Francisco International Airport (2), the air quality worsened. In downtown San Francisco (3), measurements were taken on a street by street basis to formulate a true air quality map during a high-traffic period. Note that the entire region listed as good air quality on AirNow even though large areas of noxious odors were observed.

One way to capture the fixed local areas of elevated pollution is to remember GPS coordinates of those areas during repeated drives. These coordinates can be used to switch to recirculation. Furthermore, combining government air quality data from the fixed sources and crowdsourcing from the vehicles together with weather, traffic, maps, machine learning and comprehensive analytics can enable development of granular and accurate air quality maps that can be used for air quality management. Even for vehicles with external air quality sensors, this map can provide significant benefits: it can provide advance warning to close windows, start recirculation in advance vs reacting to AQI reading that due to delay may cause some polluted air entering the cabin, and provide an advice on the least polluted routes.

5 CONCLUSIONS

The paper discusses the opportunities to augment automotive climate control with a SmartDeviceLink enabled smartphone app.

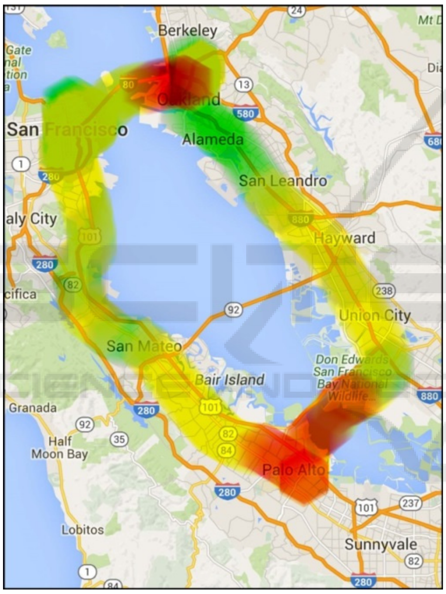

Figure 5: SF Bay Area Air Quality Test.

Such an approach leverages cloud data, IoT sensors, and wearable devices with opportunities for intelligent algorithms personalized to individual drivers. This paper reviews two potential applications: integration of wearable devices to enable personalization of climate control and an air quality management system based on brought-in air quality sensors.

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Integration of wearables that measure biometric data adds a new dimension to climate control by implementing a passive feedback loop requiring minimal user input. Many wearable devices today monitor skin temperature in real-time. With this data, along with information about the current climate control settings and external weather data, the system can learn the user's preferences. For example, when the user increases the cabin temperature, it may relate to their skin temperature being cold. After this occurs several times, the system can learn this preference and automatically increase the cabin temperature when the wearable detects a cold skin temperature. Combining this with machine learning, we can create an intelligent, personalized climate control system.

Correlation of other parameters monitored by wearables, including metabolic rate, heart rate, stress levels, breathing, or even blood oxygen levels can give insight into how climate control affects patients with chronic illnesses such as asthma.

Cabin air quality management is gaining attention especially in regions with high pollution levels, such as China. Despite the innovation of consumer air quality sensors in recent years, the availability of automotive grade sensors remains limited. The proposed solution augments the climate control system with consumer-grade sensors, cloud-based information, and applications that manage air recirculation and refresh.

SDL's ability to dynamically integrate consumer devices with vehicle climate control makes this approach effective within emergent mobility models, such as car sharing and on-demand ride services. Passenger preferences are readily passed between vehicles as they are carried between vehicles on the passenger's mobile device. With on-demand services such as Uber or Lyft, the commuter's mobile device can send climate comfort preferences with other information like location and destination. The driver's SDL enabled application would modify vehicle climate control settings to precondition passenger zone. A remote control feature of SDL allows the backseat passenger to manage climate settings using personal device directly paired with the vehicle electronics.

Other opportunities arise from cloud connectivity where data collected from sensors and wearables enables cloud analytics. There is the opportunity for crowdsourcing of air quality sensor data continuously from vehicles at many locations to improve real-time air quality maps. Finally, insights from climate control usage patterns under different contexts will facilitate future advances leading to optimization of climate control system design.

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