Wireless, GPS-Enabled Data Processing Architecture for Highway Work Zones

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ABSTRACT

A short-range, easily deployable data communication system enables numerous highway work zone applications. The Kansas Department of Transportation is currently funding a project to develop a delay notification system in rural construction zones. The objective of the project is to estimate the expected delay until the return of the pilot car and communicate that delay to motorists waiting in the queue. Since most rural construction zones are outside existing commercially available communications, such as cellular coverage, success of the project hinges primarily on the acquisition of a low-cost, easily deployable work zone data communication system. The prototype system relies on 900-Mhz radio transceivers integrated with GPS receivers and a microprocessor. These devices mount to signs, vehicles, and relay points and are programmed according to their function in the overall system. This low-cost approach not only enables the delay notification system, but also opens the door for other value-added applications within the work-zone. The same architecture can support construction vehicle tracking, notification of blow-bys (when vehicles fail to yield to traffic control), and field construction data reporting to centralized construction management systems. This paper reviews the communication architecture developed for the delay notification project and then casts that same communication system into scenarios to support value-added applications.

Key words: global positioning system—wireless communications—work zones

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INTRODUCTION AND BACKGROUND

The Kansas Department of Transportation (KDOT) performs routine roadway rehabilitation that requires traffic on two-lane rural highways to be narrowed to one lane. This operation involves the use of a pilot car to direct the flow of traffic. KDOT's construction policy limits driver wait time to a maximum of 15 minutes during pilot car operations. Even so, pilot car operations are a primary source of negative customer feedback for the agency. In 2002, KDOT began to investigate methods of informing the driving public of the expected wait time until the next pilot car. A preliminary study, based on surveys of the driving population conducted by KDOT and Kansas State University (KSU) in fall 2002, showed a sufficient desire from the driving public to be notified of the anticipated wait time when approaching a pilot car operation. Based on this information, KDOT sanctioned research into the pilot car notification system. Additionally, as the project was getting started in the fall of 2003, a letter was sent to the Governor of Kansas with regard to the above issue. In reply to this letter, the secretary of the Department of Transportation assured the writer that KDOT would look into the issue and address it in the best possible way.

The main objective of the subsequent research was to determine the best cost-effective method of informing drivers of delay time when approaching a pilot car operation at two-lane rural highway work zones. Several systems with similar intent have been developed as part of the intelligent transportation system (ITS) movement; however, these systems addressed high-traffic volume, high-cost, and long-term work zones (Garber and Srinivasan 1998; Dudek 1999). Rural work zones are a unique category, since such work zones have low traffic volumes, and are low cost (comparatively) and short duration. Although research on rural, pilot car-aided work zones is scant with regard to automatic traveler information systems, the work performed for urban areas has some applicability. Research conducted by the Oregon Department of Transportation revealed the following (Griffith and Lynde 2001):

- Motorists were willing to accept delays in the 5–10-minute range without expressing concerns that they would be upset or angry.
- Delays up to 15 minutes or longer were acceptable to many motorists as well, although in these cases information about length of the delay played a large role in their willingness to accept this length of time.

In 2003 and 2004, the KDOT-sponsored research effort scrutinized various alternatives to deliver wait time information to drivers in a queue waiting for a pilot car. In the summer of 2004, a system was prototyped and demonstrated to the public that made use of several mature technologies.

PILOT CAR WAIT TIME NOTIFICATION SYSTEM ARCHITECTURE

The architecture used to demonstrate the pilot car wait time notification in the fall of 2004 is illustrated in Figure 1. The pilot car was equipped with a GPS receiver, a 900-MHz serial data radio, and a laptop computer. The laptop computer received position, speed, and heading information from the GPS receiver. It ran an algorithm that determined the delay time to be displayed to the driver and then communicated that delay time via the 900-MHz radio. The sign was a standard warning approach sign equipped with an LED countdown timer display. A 900 MHz radio attached to the sign received the signals from the pilot car and displayed it accordingly.

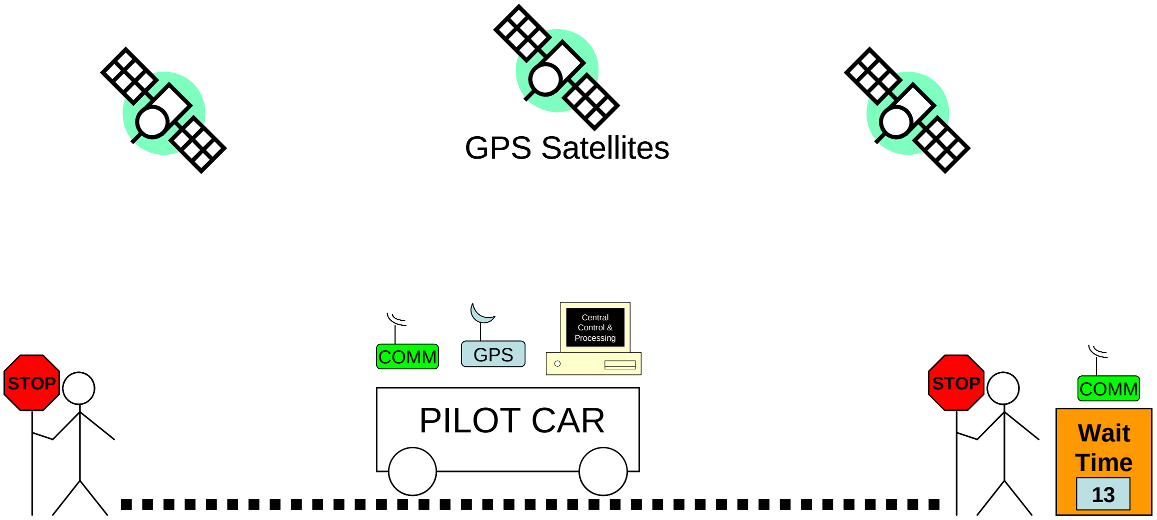

Figure 1. Initial architecture for pilot car wait time notification system, demonstrated fall 2004

A photograph of the sign system is shown in Figure 2. The demonstration took place during an overcast day along a relatively flat section of rural highway approximately four to five miles in length. The overcast conditions allowed for better visibility of the LED display. Note the large mast on the sign with an antenna mounted to the top and a radio module mounted on the mast just above the fabric. The mast was needed in the demonstration to provide connectivity with the pilot car throughout the work zone.

Figure 2. Photograph of instrumented sign during the fall 2004 demonstration

The system worked as designed during a two-hour test run in early October of 2004 at an actual work zone. The relatively flat terrain allowed the sign to receive data from the pilot car throughout the work zone. In late October, the system was demonstrated in a work zone in hillier terrain. The instrumented sign was located in a valley and quickly lost contact with the pilot car no more than a mile into the work zone. The timer algorithms in the system were not intelligent enough to estimate delay in the absence of a signal. Concerns over the weight of the sign, connectivity, and general robustness of the notification system led to a new operating concept that is schedule to be tested in 2005. The architecture for this concept is shown in Figure 3.

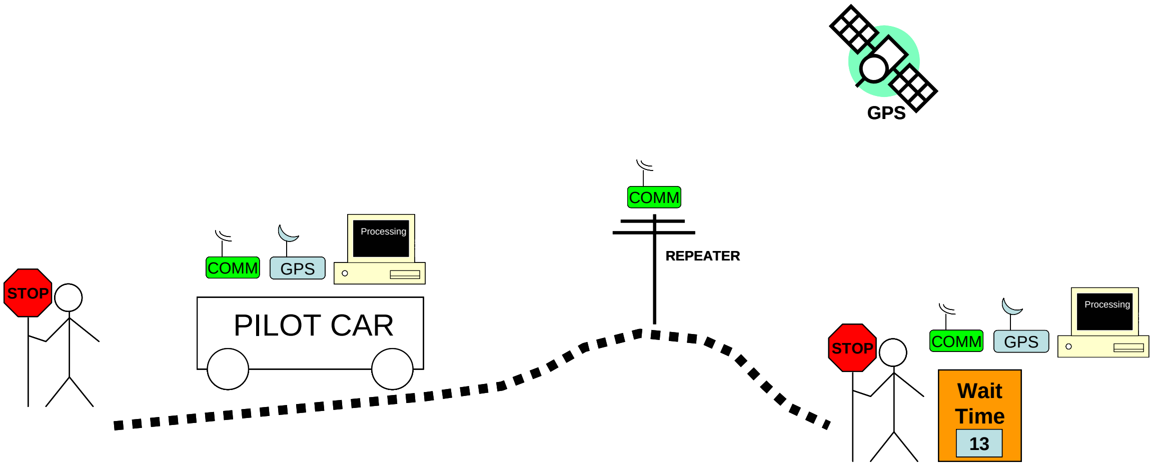

Figure 3. Target architecture for pilot car wait time notification system in 2005

Several system enhancements are included in the new architecture. The need for a communications repeater in hilly terrain was evident. It has the secondary benefit of drastically reducing the power and mass requirements on the notification sign. With a repeater nearby, a simple six- to eight-inch whip antenna can be used on the sign, reducing its height and mass and increasing its crash worthiness. The repeater can be strategically located to maximize connectivity, such as at the crest of the first hill in the direction of the work zone. The repeater can be located well away from the travel way, limiting its exposure to traffic. Power requirements of the system are dominated by the transmit cycle of the radios. If the repeaters provide most of the high-power transmit capability, the battery requirements on the signs can also be minimized.

Also notice in Figure 3 that GPS and processing capability are available at the sign as well as in the pilot car. The ultimate design will also have GPS and processing at the repeater station; however, in a limited demonstration planned for 2005, they are not needed. Other enhancements in the architecture are also targeted for 2005, but are less physically prominent. These enhancements deal with the processing algorithm for estimating delay time. In the absence of a signal from the pilot car, the sign will intelligently estimated the wait time through some type of countdown mechanism. The processing capability at the sign enables intelligent action in the absence of communication. The GPS at the sign also enables automatic configuration. If the system understands the location of all of its assets, the determination of the appropriate display time is greatly simplified. It is the combination of the communication module, location module, and processing module into a reprogrammable unit that opens the door to a wide variety of applications within the work zone.

MULTI-FUNCTION COMMUNICATION, LOCATING, AND PROCESSOR PLATFORM

Through the process of refining the delay notification system, it became evident that the core unit that provided for communications, locating, and processing was the key element in efficiently enabling and managing not only the delay notification system, but also many other work zone systems. The key to a viable delay notification system is cost. The cost includes not only the initial up-front equipment charge, but also the day-to-day cost of personnel to deploy and run the equipment. The latter is more critical in the long run. Engineering the equipment to decrease the time to deploy and operate as well as lower the qualifications needed to manage the system would provide substantial cost benefit in the long run. Unlike the suburban and urban counterparts, rural work zones are a relatively low-margin business. Contractors will resist systems, even inexpensive systems, that require extra manpower to operate. Ideally, any new system will not only provide the useful data for the traveling public, but also provide a cost advantage for the contractor. The basic communication, locating, and processing subsystem that enables the wait-time notification application can also enable other work zone applications that may reduce overall road construction costs, either through efficiency or cost avoidance.

The basic architecture of the communication, locating, and processing (CLP) subsystem is shown in Figure 4. The GPS unit provides global locating in the form of spatial coordinates of latitude, longitude, and elevation. GPS also provides a high-quality time standard as well as velocity information for mobile platforms. The processing unit is the reprogrammable brain of the CLP subsystem. It queries the GPS unit for location and processes any requests that arrive from the wireless communications. The processing section is the module that contains custom algorithms appropriate for the application. In the case of the pilot car notification system, the processing unit is programmed differently, depending on whether the unit resides on the pilot car or on the sign. In most cases, all the algorithms for a specific application can be contained within a single unit. The unit is then switched to take on the appropriate "personality," depending on its location within the system. The CLP subsystem on a sign and in the pilot car will behave differently, but share the same physical hardware architecture.

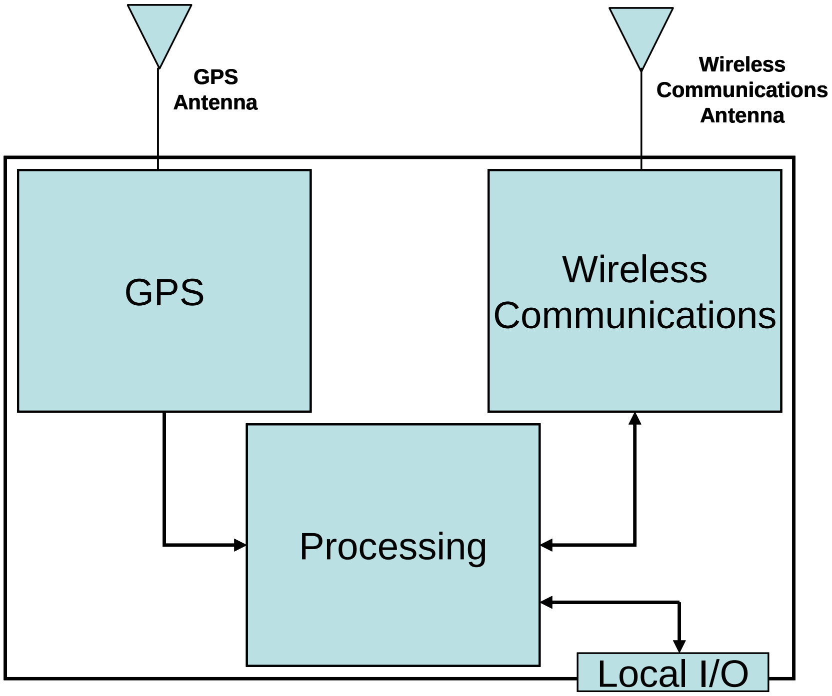

Figure 4. Subsystem architecture for communications, locating, and processing

Processing is typically accomplished with a micro-controller or PIC processor. Most of these devices are inherently capable of standard serial communications such as RS-232. A broad range of capability exists within this class of controller. On the low end are devices that simply monitor a sensor and pass the data via a serial communications channel. On the high end are devices that rival the power, flexibility, and storage capacity of desktop computers. The tradeoff in capability also comes with a tradeoff in physical dimensions, power consumption, and cost. For these reasons, it is important to size the processor appropriately for the application.

The last unit in the CLP subsystem is the wireless communications module. The wait time application utilized a 900-MHz system whose base communication standard was serial data communications. The candidates for the wireless system include both the 900-MHz and 2.4-GHz regions. The lower frequency has better signal propagation characteristics, though both are primarily line-of-sight. The lower frequency has greater tolerance for moderate foliage and for filling in between hills. The primary difference, though, is in the speed of data transmission and the resulting requirements placed on the processor. Both the 900-Mhz and 2.4-GHz bands are license-free. Although multiple protocols can be used in these bands, the 2.4-GHz band is dominated by the IEEE 802.11 standards, commonly referred to as WiFi. In this configuration, the data capacity is between 2 to 10 Mbits. WiFi is the dominant technology used to provide laptops and other computing devices with a wireless broadband internet connection in places such as airports and hotels. The 900-Mhz frequency is more typically found in voice applications and serial data applications. The 900-Mhz technology was chosen in the wait time notification system for a number of reasons. Its propagation properties were an advantage. The other modules in the system had native serial communications capabilities, so the serial nature of the 900-Mhz technology integrated well. The higher bandwidth systems also require more power as well as more processing capability, both of which were critical factors in the current application.

With the exception of the antennas for the GPS and wireless communications, the system is a self-contained unit. A common power source (either internal or external battery) services all modules. This unit is the basis for every part of the system. The sign uses it to receive location information from the pilot car, assess its own position in relation to the pilot car, and calculate and display the appropriate wait time. The LED display timer itself communicates through a serial port to the processor (local I/O). On the pilot car, the unit has no local I/O. All critical components are contained within the subsystem. The same is true if the subsystem is used for the repeater. The programming in the processor is changed appropriately, and the external power supply will need to be greater due to the increased transmit duty cycle. However, the same CLP physical subsystem remains completely intact for all three functions. A picture of the physical unit developed for the wait-time notification project is shown in Figure 5.

Several advantages exist with having the GPS unit in every module, apart from the apparent need of location information in calculating expected delay. Asset tracking becomes nearly automatic. Another module, the management module, could exist in the system. Its purpose is to keep track of all the assets. It could query all devices in the system and display them appropriately in a map of the work zone. If the CLP module is mounted on construction vehicles, these assets could be tracked as well. For the wait time notification project, note that the complete system will include multiple signs (at least one on each approach to the work zone), multiple repeaters as dictated by the terrain, and a module for the pilot car. The basic unit discussed will service all devices.

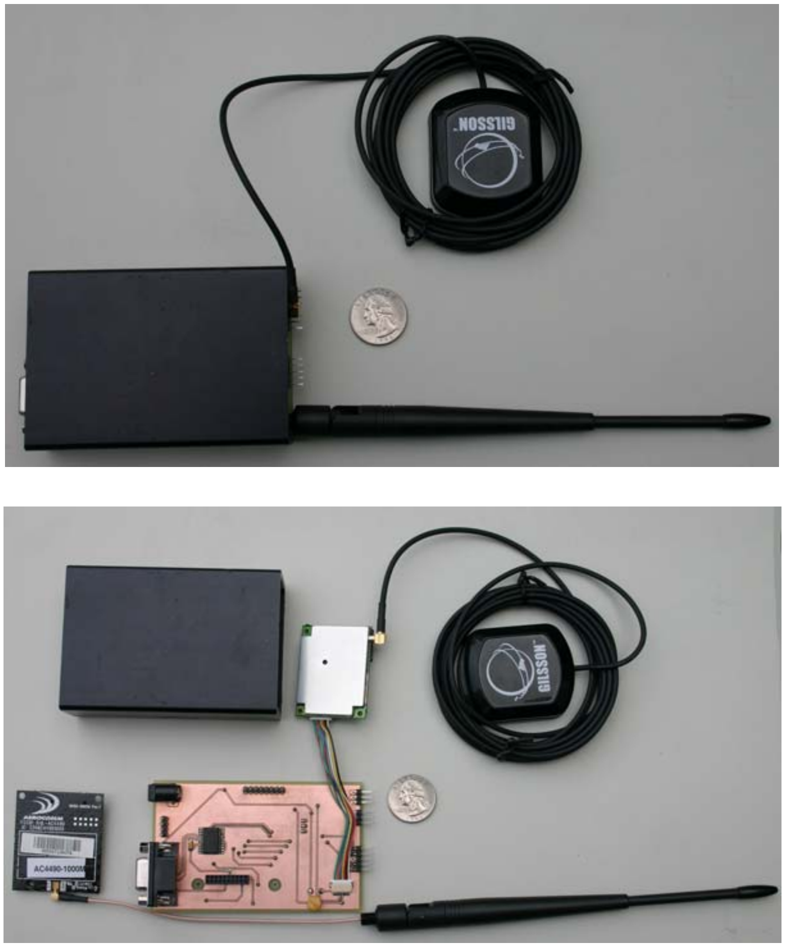

Figure 5. Fully assembled CLP subsystem built for pilot car delay notification project (top) and individual components within the unit (bottom)

ADDITIONAL WORK ZONE APPLICATIONS ENABLED BY ARCHITECTURE

Cost is the primary driver in any application. The added burden of manpower for a new public information system could quickly create undue overhead for the contractor that is passed onto the taxpayer through increased bids for construction. In addition to equipment and manpower costs, liability is also a primary driver. Any system that increases or decreases the overall safety of the system will also increase or decrease the overall liability costs proportionally. The remainder of the paper is dedicated to investigating a number of concepts in which the basic CLP module architecture could be used to enable additional work zone applications, and the impact that such applications could have on project costs.

Blow-by and Other User Action Monitoring

Work zones continue to be one of the areas of great risk both for highway workers as well as the traveling public. Many systems have been employed to alert drivers of upcoming construction zones, monitor their speed, and sound alarms signaling impending danger. Figure 6 shows a concept of a networked approach to such sensors and alarms enabled by the architecture previously discussed.

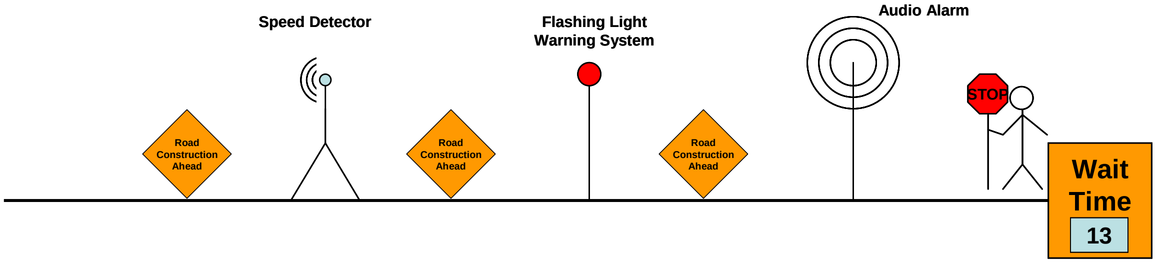

Figure 6. Inattentive driver detection and warning concept

Figure 6 depicts extra sensors and actuators on the approach to a construction zone. The speed detector, flashing light, and audio alarm each have at their base the CLP subsystem. The speed detector monitors the velocity of the approaching traffic. If the speed exceeds a certain threshold, a message is sent to the unit controlling the red flashing light. If the speed is above an even greater threshold (or another detector further into the work zone indicates that the driver has not slowed down) an additional audio alarm or other type of reactive measure may be triggered through the system. Since devices are communicating through a common wireless network, the system would be easy to deploy and configure with new sensors or actuators. Furthermore, since each device has a GPS unit, the speed detector need not be programmed with knowledge of the warning light or audio alarm. The speed detector communicates the hazard and location and the devices within the appropriate vicinity react accordingly. A central monitor can chart the location of all assets (even signs) and ensure they are deployed in agreement with governing standards.

Construction Fleet Monitoring

Knowing the exact timing of delivery can increase efficiency and safety. A CLP unit in each construction vehicle, or possibly on all construction personnel, can enhance the observation of the entire operation and thus create opportunities for increased efficiency and safety. Many vehicles have electronic interfaces for monitoring critical components, such as fuel, tire pressure, or mechanical failures. If a CLP unit is designed to interface with the vehicle, the diagnostic information becomes available centrally, allowing for better planning and deployment of resources.

Field Data Entry

Much of the construction practice is governed by standards and methods that require periodic data entry or material sampling. Direct entry of the data into electronic format on the job reduces transcription, thus reducing opportunity of error. The availability of GPS (including the exact time of data collection and location of samples) provides a method for automatic labeling. Figure 7 depicts one such scenario. The production sample (such as aggregate or asphalt) is logged electronically by an application running on a common personal data assistant (PDA). The intelligent hard hat has the CLP subsystem embedded. It allows the worker to be tracked for safety reasons, but also communicates to the PDA to provide location information to be logged with the data entry. A complete copy of the data can then be transmitted across the wireless network to a central server. Once at the server, project inspectors and owners would have instantaneous feedback concerning the quality or pace of the project.

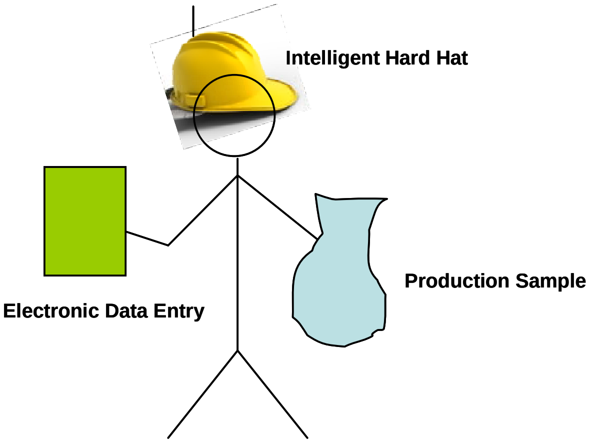

Figure 7. Field data entry concept

CONCLUSION

Wireless data communications, GPS technology, and portable processing can combine to create an opportunity to develop spatially rich applications that are easily deployable and manageable. Highway construction zones can benefit greatly by using spatially enabled applications to increase safety, deliver traveler information, and increase construction efficiency. The application currently under development at KSU for KDOT communicates the expected wait time at rural construction zones to drivers. The project utilizes a core module consisting of a GPS receiver, a 900-MHz wireless data transceiver, and a PIC processor. This module is designed to be replicated to each element in the system and forms the core of the application. The module interfaces with local devices such as the LED sign on the approach to the work area. The modules differ only by the algorithm running in the processor to perform the local task. The manpower requirements of the wait time notification system are minimized, since initialization is automated using the location data of each asset in the field. The generic framework provides a foundation to begin to automate other tasks in the work zone. Asset tracking, data collection, and inattentive driver detection are a sample of the applications that could be enabled using a similar architecture.

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