LiteTurn: Automated, Gesture-Controlled Cyclist Turn Lights Using Cheap and Efficient Consumer Devices

Kevin Yeh (kky226)
CS 386W: Wireless Networking
Fall 2014 | Austin, TX
kevinyeah@utexas.edu

Abstract**—**This paper presents LiteTurn, a new gesture-controlled turn-signaling system for cyclists that uses cheap consumer devices and energy-efficient Bluetooth 4.0 (BLE) to provide cyclists and motorists with better road awareness when sharing the road. Initially conceived at HackTX 2014, a large hackathon event at The University of Texas at Austin, the LiteTurn prototype was designed and developed over 24 hours and placed 3rd overall. The final product makes use of a variety of sensors found in commonplace consumer devices, along with a small wireless LED product, to detect cyclist states and automate turn light usage. In particular, the LiteTurn system consists of four major components:

a) Gesture Recognition using wrist wearable devices equipped with accelerometer and gyroscope sensors.

b) Turn Completion Detection using GPS-enabled smartphones.

c) Continuous LED updates for braking/rolling indicators.

d) Practical, cheap, and energy-efficient wireless LED hardware.

I Introduction

In a large number of major cities across the U.S., bicycling has seen a rise in popularity and use. Accompanying this rise in popularity has been an increased focus on bicycle safety and infrastructure, with government agencies frequently treading the line in order to satisfy both cyclists and motorists and accommodate both methods of transportation on the road safely and conveniently. Today, cyclists are still seen as secondary occupants on the road, and there has been a severe lack of adequate, readily-available accessories for cyclists that keeps them, and others sharing the road, aware of the conditions at hand, which can rapidly change in response to unpredictable or erratic behavior by cyclists and motorists alike. In particular, there have not been any cheap, readily-available turn signal products that are easy to use and are clearly visible to pedestrians, motorists, and cyclists traveling in a variety of different angles and directions.

Although consumer products have been developed to sell embedded lights sewn into clothing such as gloves, jackets, and helmets, these products have a high price point, require accessory clothing to be worn by the user, and require the user to make use of additional controls embedded in the clothing or attached to the handlebars to be effective. Some of these products also fail to improve visibility by a large amount; for example, the new Zackees turn-signal gloves requires users to hold a button on their glove to light up LEDs embedded in the gloves themselves, which are then deactivated as the rider holds the handlebars to start and complete the turn safely.

LiteTurn aims to solve all of these problems using cheap hardware, readily-available consumer devices with on-board accelerometer and gyroscopic sensors, and energy-efficient BLE wireless communication to provide cyclists with gesture-controlled turn signal lights that provide additional services beyond turn signaling. In addition to being able to signal a turn, the LiteTurn system will be able to provide custom lighting animations in neutral states and display braking. rolling, and hazard information in the form of acceleration-sensitive lighting.

Three main goals are targeted for improvement over traditional cyclist hand signals:

a) **Visibility**: At wide angles and in low-lit conditions, hand signals are not visible to motorists and other cyclists.

b) **Mobility**: Hand signals are impractical and unsafe when both hands need to be on the handlebars. In particular, approaching intersections at the top or bottom of a steep hill are targeted along with in-motion turning and signaling.

c) **Utility**: Although an officially-recognized braking hand signal is in effect within certain countries, it is often unsafe to use under normal conditions. As a result, there are no practical hand signals for indicating braking, rolling, and hazard status to motorists sharing the road.

By utilizing the official, recognized bicycle hand signals for turning and stopping, cyclists will not have to adapt to the new system -- the only requirement for cyclists is to download a mobile app on their smartphone and accompanying smartwatch, which will communicate with the cheap LiteTurn hardware mounted on their bicycle. In addition, this system is potentially compatible using any combination of smartphone and smart wearable device that provides orientation and GPS location sensor information, reducing the costs of the system significantly by using commonplace devices that many people already own and wear on a daily basis. The LiteTurn system can also replace the head and taillights commonly used on bicycles in low-lighting conditions, augmenting them with automated signaling and aesthetic capabilities at a fractional increase in price.

Figure 1: Illustrations of the four main cyclist hand signals. From left: left, right, right-alternate, and braking signals.

II Previous Work

Although there has not been considerable research in the specific domain of automated turn light handling, various consumer products have been prototyped or released for use as cyclist turn lights.

a) DORA, LumaHelm: Two conceptual products that propose LED-embedded helmets in an attempt to address visibility issues. Many other helmets proposals have been released by various marketing and research labs, all with the same considerable problems regarding bulky accessory helmets and handlebar-mounted controls.

b) Zackees: A new LED-embedded glove product that activates using a circuit-completion paradigm between two metal rivets. The gloves are sold as a solution to low-lighting visibility issues, but fail to improve visibility in any situation where the user must place their hands on the handlebars for safety.

c) HelSTAR Helmet: Another helmet designed to communicate with the turn lights of motorcycle-based 12V navigation systems using RF communication.

d) MIT Labs Research: Sensor and LED-embedded jackets.

All of these products have major consumer usability and accessibility issues that prevent widespread use on the road. The introduction of novel accessory clothing embedded with sensors and LEDs limits the universal fit of the product for users of different body types, and requires the user to put in unnecessary work into wearing, washing, and taking care of unique clothing embedded with electronics. These devices also require additional learning by the user, introducing physical controllers embedded in the clothing or attached to the handlebars. Finally, all of these devices have projected and actual price points that are extremely high due to their novelty, selling as low as $80 for Zackees gloves and over $180 for the embedded helmets.

All three of the aforementioned problems are unnecessary complications to solve an otherwise basic and simple need: cheap, natural, and easy-to-use turn lights for cyclists to incorporate into their daily routine without interfering with it. With over 58% of American adults owning smartphones, and a growing number adopting the new wave of smartwatches and wrist wearables, the sensor technology for implementing reliable turn lights is already being carried by a significant portion of the cyclist population. The LiteTurn solution taps into the existing personal mobile sensor network to provide cheap, efficient, and available cyclist turn lights.

III Design

The focus for the first stage of LiteTurn was on accurate detection of turn signal gestures and turn completions, and the hardware used to display highly-visible lighting.

Gesture Recognition:

In a general system, turn signal gestures are detected using accelerometer and gyroscope sensory data interpreted into quaternions, which can be represented as yaw, pitch, and roll rotations around a center of mass. Detection of a turn occurs when the sensors are oriented at a 90-degree yaw from the rider with the correct roll (wrist rotation) orientation. Above a certain threshold, a larger pitch rotation indicates an inward turn, rather than an outward turn.

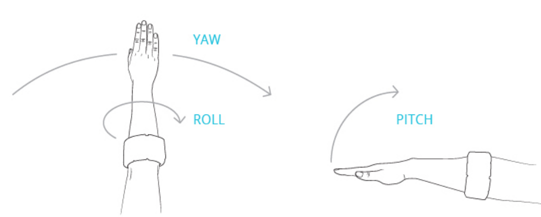

Figure 2: Illustrations of yaw, pitch, and roll rotation axes around the center of mass using accelerometer and gyroscope sensors attached to the cyclist’s wrist.

However, variations and inaccuracies in the sensors can produce noise within the readings, and this is often amplified when riding a fragile, physical piece of transport such as a bicycle. This is especially notable in the yaw rotation reading discrepancies that appear when transitioning from the outward turn signal to the inward, bent turn signal. Readings should therefore be transformed using a noise-reduction filter and sub-divided into discrete segments of 360-degree space along the dimensional plane. This sub-division makes it easy to define regions in 3-dimensional space where gestures can be identified within a window *w* of the perfect gesture.

The overarching gesture recognition system starts with the extraction of YPR world coordinates from accelerometer and gyroscope data. These coordinates are translated into relative coordinates using GPS location and temporal bearing calculations. In particular, the last known location bearing is used to correct the yaw coordinate. The resultant YPR relative coordinates in (0, 2pi) space are discretized into k segments of the degree spaces to get an integer range of [0, k) for each of the three orientation coordinates. A short delay is introduced into the gesture recognition module to reduce the number of false positives returned by the system. In preliminary experiments, requiring the cyclist to hold the gesture for 150 milliseconds was found to be a satisfactory compromise between turn recognition accuracy and false positive rate.

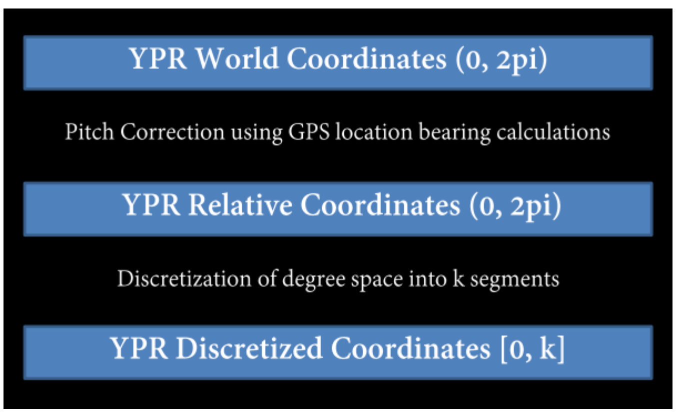

Figure 3: Gesture Recognition Module Pipeline for coordinate conversion.

Turn Completion Detection:

Turn completion can be broadly detected using GPS location bearings, which provides degrees along a cardinal directional system. Since most turns are roughly right turns or u-turns, detecting 90-degree and 180-degree changes within a small threshold of error will accurately provide evidence of an ended turn. Bearing readings should be taken once per some distance window, which should be large enough to avoid false positives, but short enough to be responsive to the user's activities. In practical experiments, 1s/10m was chosen as a good polling interval for GPS coordinates.

A short running history of GPS bearings is kept to reduce the effects of multiple precise bearing updates occurring during the motion of a single turn. On completion of the turn, the bearing history is cleared to prevent introduction of repeated detections.

The use of a location-based turn completion module provides both upsides and downsides. The use of a minimum distance polling method prevents small position changes from triggering false positives, allowing cyclists to wait out a turn on their bicycle with small localized movement at the intersection. However, two specific occurrences are missed by this basic implementation.

Lane changes indicated by a turn gesture are not covered by the basic 90-degree threshold implementation. Instead, more precise measures must be used to cover this case. In particular, accelerometer data used in conjunction with bearing calculations may be sufficient for detecting local and momentary horizontal movement while traveling in a globally tangential direction.

Gentle turns, e.g. forks and road cutoffs, introduce a much more difficult problem. Distinguishing between making a gentle turn onto another road and traveling forwards along a curved road is a much more complex to resolve. Increasing the turn tolerance will provide more angular leeway into what is considered a turn, but is highly fragile as a solution and can introduce false positives into the system. Instead, a more robust solution may come in the form of a linear or exponentially increasing timeout for turn signals. This can result in immediate recognition of a sharp 90-degree turn, while still allowing small turns to be completed after a small timeout.

Braking / Rolling Signals:

Braking and rolling signals can be directly implemented using streaming accelerometer values from the cyclist's smartphone. Localized movement from the physical act of pedaling will be drowned out by the larger global movement of the bicycle in physical space, allowing raw accelerometer values to be extracted, and the vector component of the traveling direction to be determined using the last known bearing. The magnitude of this vector is used to interpolate the color of the light, which is sent as an RGB value over BLE or WiFi to the microcontroller controlling the LEDs. A smaller update interval can be used over BLE due to the smaller latency of a direct paired connection between the smartphone and microcontroller.

IV Initial Implementation and Experiments

At HackTX 2014, a prototype consumer LiteTurn product was developed using a Myo gesture-recognition armband, a Spark Core micro-controller, and a 24-Neopixel LED ring. The product used Myo gesture and orientation sensors to detect turn signal gestures, Android GPS bearing information to detect end of turns, and a wireless core hooked up to the Neopixel ring, which acted as turn signal lights. Thse three major components combined to become the fully-functional product that was demoed and, ultimately, placed 3rd overall in the hackathon.

(a) A Myo gesture-recognition armband

(b) A 24-Neopixel RGB LED ring and 2200mAh LiPo battery wired to a contained Spark Core micro-processor with embedded WiFi chip.

Figure 4: The hardware for LiteTurn version 1. (a) The Myo armband contains an accelerometer, gyroscope, and EMG muscle activity sensors to detect activities such as fingers spread, closed fist, and directional hand waving. (b) The LiPo battery powers the core with 5V, which sends data to a digitally-addressable ring of current-controlled LEDs.

The first component involved grabbing gesture and orientation data from the Myo's accelerometer, gyroscope, and EMG muscle activity sensors to detect when the cyclist signals for a turn (Figure 3a). Although Myo gestures (FIST, FINGERS SPREAD) worked as a precautionary filter to prevent false positives from coming through, it required extra knowledge and adaptation by the cyclist to understand the required pose to activate the lights.

Through experimentation, we found that the orientation data itself was a satisfactory indicator of the user's intentions, and that noisy data could be filtered naively by delaying the signal until the position was held for a short time. As a result, this step could be done at a much lower cost by using any sort of existing consumer smart watch or armband that the user already wears with less overall bulk. By doing so, the required calibration of the Myo is also avoided entirely. A rider who wishes to use the LiteTurn system but does not own an appropriate wearable can, in theory, strap the phone to their wrist and achieve the same effect, although this is unwieldy and should generally be regarded as less safe.

The second component involved hooking a Spark Core up to a Neopixel 24-LED RGB ring (Figure 3b) and providing a simple web API to send commands. A simple LiPo battery provided power to the micro-controller. Since the Spark Core requires a WiFi connection, cost and battery drain can easily be reduced by replacing the core with a simple micro-controller and bluetooth chip to pair directly with the user's phone. To work around this limitation at HackTX, we connected the smartphone to a 4G network and set up a wireless hotspot for the core to connect to.

The final component was the companion Android app, which brought both pieces together and added additional aesthetic features. Using GPS location bearings, we were able to determine when the user makes a turn or u-turn. Instead of combining accelerometer and magnetometer sensors, which is used in the Google Maps application to provide very precise measurements, we used GPS location changes to detect bearings. This doesn't work over short distances, but the large distances traveled on bicycles makes it a perfect fit, with the added benefit that small, sudden turn changes won't affect the turn readings. For example, if the user rides around the car in front of them, the combination of GPS location bearings and a 10 meter minimum distance for detection will prevent a false positive.

Fig 5: User-facing companion Android application to display sensor readings, control light status, and track user location.

V Final Experimental Implementation and Evaluation

In the final experimental setup, the Thalmic Myo armband was replaced with a Samsung Galaxy S3 placed into a glove and tied in place with a rubber band, simulating a smartwatch with the screen facing outwards. In addition, the companion application was updated with a location tracker that marked each location update along with the points of gesture and turn completion detection.

A testbed was set up in the Austin North Campus region with 16 turns and a variety of road conditions. The path involves short and long stretches of road, flats, steep uphills and downhills, potholes and bumps, and occasional rain. Three trials were run for each test, varying the gesture recognition delay, gesture threshold windows, and location polling intervals.

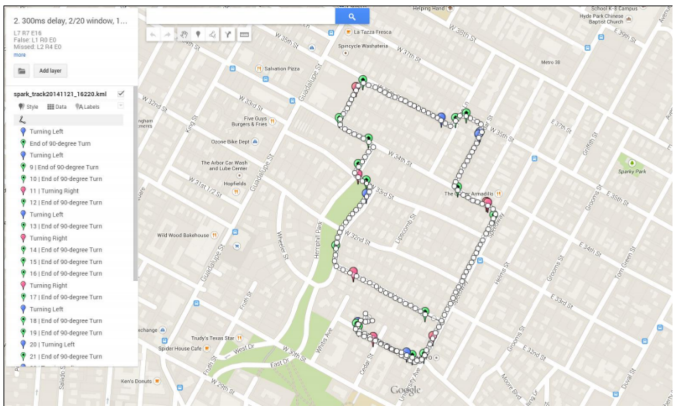

Figure 6: The 16-turn testbed set up in Austin's North Campus region.

Gesture Recognition Delay: First, we look at the accuracy and false positive rate of gesture recognition and turn completion detection at varying magnitudes of recognition delay. It is important to introduce an amount of delay into the system to abort turn recognition when the user does not hold the gesture for a long period of time, as false positives may then be reduced. Three tests were done at 0ms, 150ms, and 300ms delays. We observed an average false positive rate of 32.29% when no delay is in the system, with a 21% reduction after increasing to 150ms. A further increase to 300ms reduces the rate by approximately 5.5%, but coincides with a gesture recognition accuracy drop of 19%.

	0ms	150ms	300ms
Turn Recognition Accuracy	86.25%	84%	65.63%
End Recognition Accuracy	100%	100%	93.75%
False Positive Rate	32.29%	11.45%	5.88%

Figure 7: Gesture Recognition Delay versus Accuracy and False Positive Rates across 9 different trials.

YPR Divisions and Recognition Window: Second, we examine the recognition accuracy and false positive rate of the system under various orientation divisions and gesture window allowances. It is important to find a satisfactory balance between precision and natural allowance of the gesture when performing the physical act of cycling. Figure 8 shows the results of three division and window setups. At a 2-segment window within a 20-division space, each gesture is allowed a 72-degree allowance within which they can be detected. However, due to the precision required by the right-turn gesture, the recognition module performs at a poor 78% accuracy rate. When increasing the number of segments to 3, the accuracy improves across the board but coincides with a 17% increase in false positive rate. A compromise of 5 segments within 40 divisions provides a satisfactory 90% average recognition accuracy with a 13.45% false positive rate.

	2/20	3/20	5/40
Left Turn Recognition	85.70%	93%	81.25%
Right Turn Recognition	78%	100%	100%
False Positive Rate	11.44%	28.85%	13.45%

Figure 8: Recognition Windows versus Accuracy and False Positive Rate across 9 different trials.

Location Polling Interval: Finally, we observe the system effects of increasing the polling interval for GPS location coordinates. At a baseline of once per second and a minimum of 10 meters traveled, a 90% recognition accuracy and 13.45% false positive rate is achieved. At both 1.5s/15m and 2s/20m, the recognition accuracy and false positive rate both plummet by approximately 15%. However, it is more desirable in consumer safety products to achieve high accuracy rates, as false positives will not be as detrimental to the safety of the user as a missed turn.

	1s/10m	1.5s/15m	2s/20m
Turn Recognition Accuracy	90.63%	75%	71.88%
End Recognition Accuracy	100%	94%	96.88%

False Positive Rate	13.45%	0%	2.94%

Figure 9: Location Polling Interval versus Accuracy and False Positive Rate across 9 different trials.

False Positives

As Figure 7 and Figure 8 indicate, with some amount of recognition delay and a moderate window of 5/40, false positives can be limited greatly to approximately 10%. Common confounding actions performed naturally by cyclists while riding are allowed by the delay and orientation windows as long as these parameters are not too relaxed. These actions include repositioning of hands along the handlebars, riding one-handed or hands-free, and resting hands on the top tube of the bicycle. However, along stretches of steep hills, the elevation can alter pitch readings dramatically and set off unwanted turn recognition. Although this work does not account for this fact, solutions are considered in section VI.

Missed Turns

On the other end of the scale are missed turns, reducing the overall accuracy of the system. In all test cases, the gesture recognition module missed turns in one of the two small stretches of road, where turns came in quick succession and ran ahead of location polling. Due to the low resolution of location updates, the gesture recognition module must adjust orientation readings using outdated user bearings, resulting in misaligned yaw axis and a missed turn.

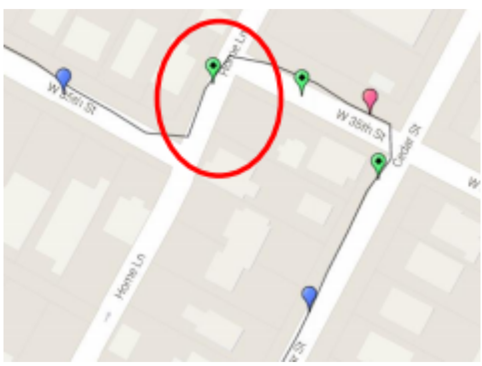

Figure 10: A precise section of road that introduces problems for the gesture recognition module. Green markers represent the end of a turn, while blue and pink markers represent the recognition of a turn gesture. A pink marker is missed within the area identified by the red circle.

VI Future Work

Several challenges and issues arose during development of the LiteTurn product, and a number of these challenges are similar to those brought up in the RisQ paper for smoking gesture dectection[1]. In addition, there is a lot of room for the system to grow and further improve road awareness for both cyclists and motorists.

1. Robust, Extensive Testing:

The trials presented in this work are limited in both scope and size due to the resources available at the time. Smaller parameter variations should be tested for optimal values, and larger sample sizes are required for the results outlined in section V to be significant. In addition, testing should be done using different test individuals to measure the adaptability of the system to various styles of riding and hand signaling. Furthermore, the system should be tested in denser urban areas, where tall, reflective buildings may confound GPS location coordinates and affect the accuracy of location bearings, which is depended upon in most aspects of the system. Finally, power use must be tested for system efficiency measurements.

2. Concurrent activities and confounding gestures:

More work should be done in filtering noise from the various sensors. In particular, the orientation readings should undergo a low-pass filter and an averaging of the most recent window of values to smoothen the overall analog readings with little increase in latency. More precise orientation threshold combinations can reduce false positives due to less common poses while riding, such as one-handed riding, waving, or high-fiving.

3. Robust, Adaptive Turn Completion:

By using GPS location bearings, the LiteTurn product is able to determine when a turn has ended by checking the degrees between the current bearing and previous bearings in recent memory. However, not all turns are within some small threshold of 90 or 180 degrees; in particular, forked roads and lane-change signals will go undetected as small or even unchanged bearing readings. More precise sensors, such as accelerometers, can be used to detect momentary horizontal acceleration for lane changes, and a more robust system of detection, such as an adaptive timeout based on the change in bearings from one time step to the next, may be required to accommodate small-angled turns. Using Google Maps to infer road topology may also be an option for these types of turns.

4. Pitch Correction:

As previously mentioned, steep hills can affect the accuracy of pitch orientation readings. Elevation information should be extracted from gyroscope readings or Google Maps cached data to offset this error.

5. Better coverage of motorist and cyclist activities:

In addition to automatic handling of braking and rolling signals, the user may feel more comfortable using the braking hand signal, as it is an officially recognized gesture and should be detected by the LiteTurn system. The system should be able to detect this signal and react accordingly.

6. Methods of Activation:

Although we focused on gesture recognition as a non-invasive, natural extension of the officially-recognized cycling hand signals, it can be unnecessarily involved for riders who have not committed these gestures to physical memory. Other methods of hands-free activation are possible and may be more comfortable to the user, such as voice commands and more precise hand gestures like swiping and fist formation.

7. Consumer Aesthetics:

The LiteTurn system in its neutral state has the potential to provide customized lighting aesthetics and animations due to the 24 individually-addressable RGB LED Neopixel lights installed. Although this is unnecessary for the general LiteTurn system, a more expensive consumer line could sell these Neopixel lights for cyclists who wish to have more aesthetically pleasing hardware.

8. Implementation Revisited

As is, the LiteTurn system takes advantage of a limited-use $150 Myo product and a $40 robust Spark Core micro-controller with an embedded WiFi chip. These components can be easily replaced by any of the increasingly popular smartwatches or wristband products and a combination of a cheap, sub-dollar micro-controller and bluetooth low energy chip to provide lower energy usage, lower costs, and more accessibility. The final form-factor should be small, energy-efficient, and cost approximately $10-20 to produce, at most. In addition, any GPS-capable smartphone device should be adaptable into a Liteturn system controller.

9. Road Safety Extensions:

Although the Liteturn system is already capable of replacing head and tail lights in favor of an all-in-one solution that provides all of the capabilities of turn lights installed in motorized vehicles, sensors have become smaller over the years and are more accessible for mobile consumer use than ever before, opening the possibilities for further automation and improvement of road awareness. Distance sensors can be installed on the rear end of bicycles to alert the rider of oncoming vehicles, and video sensors can be installed to process lane definitions and detect when the user is veering or has entered a turn lane.

VII Conclusion

Personal mobile sensor networks are becoming more viable and accessible for a large number of consumers as sensors become smaller and smaller. These networks can play a major role in improving and automating road safety and awareness for cyclists and motorists alike. This paper explored a single possibility, using commonplace mobile devices to recognize natural hand gestures and detect turn completions automatically without any thought or learning curve for cyclists. The Liteturn system was developed with accessibility and ease of use in mind, providing riders with a fully hands-free and automated way to signal their intentions to other travelers on the road without any cumbersome clothing or accessories to wear or take care of. In the future, we plan to make the Liteturn system even cheaper, more lightweight, and more energy-efficient by reducing the hardware down to its core components and relying on BLE to reduce the power footprint of our devices.

V References

[1] A. Parate, M. Chiu, C. Chadowitz, D. Ganesan, E. Kalogerakis. 'RisQ: Recognizing Smoking Gestures with Inertial Sensors on a Wristband.' Proc. 12th Annual Int. Conf. Mobile Systems, Applications, and Services, New York, NY, USA, June 2014.