Improvement of battery life of iPhones Inertial Measurement Unit by using edge computing

Application to cattle behavior

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***Abstract*—Smartphones, particularly iPhones, can be relevant instruments for researchers widely used around the world in multiple domains of applications such as animal behavior. iPhones are readily available on the planet, contain many sensors and require no hardware development. They are equipped with high performance inertial measurement units (IMU) and absolute positioning systems analyzing users movements, but they can easily be diverted to analyze likewise the behaviors of domestic animals such as cattle. Using smartphones to study animal behavior requires the improvement of the autonomy to allow the acquisition of many variables at a high frequency over long periods of time on a large number of individuals for their further processing through various models and decision-making tools. Storing, treating data at the iPhone level with an optimal consumption of energy to maximize battery life was achieved by using edge computing on the iPhone. It reduced the size of the raw data by 42% on average by eliminating redundancies. The decrease in sampling frequency, the selection of the most important variables and postponing calculations to the cloud allowed also an increase in battery life by reducing of amount of data to transmit.**

Keywords—cattle behavior, iPhone, IMU, Edge computing, IoT

I. Introduction

Classifying animal behavior requires to measure its movements and displacements. But, often the best parameters to sample and their frequency to accurately identify a behavior is unknown before adequate models are developed. Hence, researchers want to be able to measure a large quantity of high-frequency parameters in order not to miss out any valuable information. Moreover, researchers do not have the time to develop tailor-made sensors to measure these different parameters. The iPhone provides a simple way to quickly measure a multitude of settings at an affordable price.

iPhones are widely widespread around the world and are equipped of several sensors such as a location and global positioning system (GPS), an inertial measurement unit (IMU) from which signals are easily extractable for the user, saving long hardware developments. Sensor Data[a] is such an application available on Apple Store allowing to acquire 41 parameters up to 100 Hz rate. The signals recorded come from the IMU that contains a 3-axis accelerometer, a 3-axis gyroscope and a magnetometer (digital triaxial compass). The accelerometer is used to measure inertial acceleration. The gyroscope measures angular rotation. The magnetometer improves the precision of the gyroscopic measurements by correcting the drift of the magnetic pole [6].

For such reasons, i-Phones are used in various applications from different domains such as human posture and movement for upper arm [1], human body position [2], sports monitoring [3][4], cattle behavior monitoring [5].

In the latter, the IMU data collected during specific movements is related to the filmed behaviors of the animals in order to identify the parameters that make it possible to identify the behavior and their amplitude of variation. When large amount of data must be processed, it can be collected and processed in an architecture as proposed in [6] allowing the collection and the sharing of data from all over the world in order to develop global behavioral models.

To help scientists specialized in animal behavior in using simple devices as I-Phones in their research needs instead of alternative tailored-made measuring devices, we assessed the reproducibility of the measurements with different models of phones. We also checked the impact of data sampling rate as

[a] Edited by Wavefront Labs and available in the Apple App store: https://itunes.apple.com/us/app/sensor-data/id397619802?mt=8

well as the amount of data that collected according to the iOS version on battery life.

II. MATERIAL

iPhones 4s and 5s are compared with the latest version supported of iOS on each device (see Table I). On each iPhone version sensor Data release 1.26 is installed and iOS version has been updated to the last release. Table II presents parameters logged by Sensor Data. All other applications are removed to eliminate interferences in the measurement of the battery life.

TABLE III. TESTED DEVICES [7][8]

iPhone	Configuration	
	iOS version	***IMU***
4s	8.3	STMicro 8134 33DH 00D35: 3D axis accelerometer; STMicro AGD8 2135 LUSDI: 3 axis gyroscope
5s	10.3	Bosch Sensortech BMA220: 3 axis accelerometer; STM B329: 3 axis gyroscope; AKM AK8963 compass 3 axis

III. METHODOLOGY

The precision of both iPhones was evaluated by attaching an iPhone 4s with an iPhone 5s using elastics. The two-solidarized iPhone were placed on an animal in order to compare possible variations in the IMU measurements. The accuracy of the accelerometer, gyroscope and location sensor was evaluated with a displacements table and a checker. These instruments allow respectively mastered movements and 3D - acceleration and 3D - rotation.

The autonomy of the battery of new iPhone 4s and 5s is evaluated at different sampling frequency: 1, 2, 3, 5, 10, 20, 30, 50, 100 Hz with all the 41 parameters and replicate 5 times. The lowest frequencies (1 to 5 Hz) should cover most kinds of movements imprinted by an animal. The frequencies 10, 20, 30 et 50 Hz are a tenfold increase in previous sampling rates allowing a good representation of phenomenon as used in most animal behavior applications although in theory according Shannon/Nyquist the double of the frequency of the studied phenomenon should be enough. Finally, 100 Hz frequency is the maximum rate supported by the device. In a second time, the same measurements were redone with measured parameters only and replicated 3 times. The replication of the measurements allowed to evaluate standard deviation.

Table II shows data acquirable and calculable with SensorData on iPhones based on the accelerometer, gyroscope, magnetometer, location and proximity sensors. Only acceleration on x,y,z [g], Euler angles (pitch, roll, yaw), magnetic data, magnetic and true heading, latitude [°], longitude [°], altitude [m] are real measure data. All the other parameters are calculated from the previous ones.

An application in Xamarin[b] was developed in order to measure the compressibility of data by reducing of precision. All raw data are logged with a decimal precision of 6 digits. The compression of raw data by eliminating of redundancies has been done. The level of compression has also evaluated on truncate data to 3, 4 and 5 decimal digits.

[b] https://www.xamarin.com

TABLE IV. PARAMETERS ACQUIRED

Sensors	Table Column Head	Unit
Accelerometer	Acceleration on x, y, z	g[c]
Gyroscope	Euler angles (pitch, roll, yaw)	radian
	Attitude quaternion on x, y, z	radian
	Rotation matrix (3x3)	-
	Gravitational component of acceleration	g
	User component of acceleration	g
	Rotation rate	rad.s^{-1}
Magnetometer	Magnetic data	µTesla
	Magnetic and true heading	°
Location	Latitude and longitude	°
	Altitude and accuracies	m
	Course	°
	Speed	m.s^{-1}
Proximity Sensor	Proximity	[0,1]

IV. RESULTS

Both iPhones 4s and 5 solidarized and placed on animal gave the similar results in terms of accelerometric, gyroscopic and magnetic measurements. These measurements were confirmed by imposing controlled movements and vibrations on both iPhones. The both iPhones measured correctly controlled movements with a precision of 10^{-3}.

As shown on Table 3, the compression of data reduces by 43,5% on average the size of the raw data by eliminating redundancies. The truncation of raw data respectively to 5, 4 and 3 digits and the elimination of redundancies reduces up to 44,5% on average the size of data to store. The small decrease on average the size of data with 6, 5, 4 and decimals can be explained by the combination of parameters inside groups that limit the possibilities of compression.

The evolution of the compression rate is not significant on groups of data by opposition to individual data. The compressibility on individual parameters are very variable because it depends on one hand of the precision of sensors that are contained in the IMU, and on the other hand of the activity of the animal. Furthermore, the acquisition rate of sensors are different and therefore the variability in data also.

Table 4 shows the mean autonomy time of batteries for two models of iPhone obtained with different sampling frequency for 15 et 41 parameters, respectively.

[c] Gravitational acceleration

TABLE III. COMPRESSION RATE OBTAIN BY TRUNCATURE OF RAW DATA

Individual data	Compression rate [%] on individual data				Mean Compression rate [%] by group			
	6 decimal	5 decimal	4 decimal	3 decimal	6 decimal	5 decimal	4 decimal	3 decimal
Acceleration in the X axis	46,02	46,02	83,56	96,16	4,26	4,26	4,26	4,27
Acceleration in the Y axis	55,81	55,81	86,93	97,64				
Acceleration in the Z axis	61,76	61,76	86,93	92,77				
Euler angles of the device (Roll)	30,38	61,28	90,44	98,49	24,13	24,13	24,13	24,13
Euler angles of the device (Pitch)	27,10	46,62	86,10	97,84				
Euler angles of the device (Yaw)	24,64	28,93	57,16	93,75				
Attitude quaternion in the X axis	27,85	51,73	91,22	98,97	24,13	24,13	24,13	24,47
Attitude quaterniion in the Y axis	27,77	51,34	90,77	98,99				
Attitude quaternion in the Z axis	26,06	39,83	81,40	98,01				
Attitude quaternion in the W axis	25,94	39,54	81,10	98,01				
Rotation matrix (element 11)	25,66	37,49	80,69	98,01	24,13	24,13	24,13	24,15
Rotation matrix (element 12)	25,73	37,94	80,90	98,01				
Rotation matrix (element 13)	27,83	50,20	87,98	98,57				
Rotation matrix (element 21)	26,12	40,43	81,29	98,01				
Rotation matrix (element 22)	25,89	39,10	81,00	98,01				
Rotation matrix (element 23)	30,52	61,69	90,68	98,60				
Rotation matrix (element 31)	26,09	40,98	84,59	98,26				
Rotation matrix (element 32)	26,11	40,98	84,72	98,31				
Rotation matrix (element 33)	31,43	66,12	94,94	99,37				
3D Gravitational acceleration (X)	27,79	50,20	87,98	98,57	24,13	24,13	24,23	32,02
3D Gravitational acceleration (Y)	30,49	40,43	90,68	98,60				
3D Gravitational acceleration (Z)	31,40	39,10	94,94	99,37				
3D User acceleration (X)	31,29	62,49	90,49	98,10	24,13	24,13	24,13	24,25
3D User acceleration (Y)	29,62	58,60	90,09	98,19				
3D User acceleration (Z)	30,90	62,41	91,73	98,56				
Rotation rate in the X axis	25,70	62,02	76,10	91,65	24,13	24,13	24,13	24,13
Rotation rate in the Y axis	25,62	36,76	73,97	89,75				
Rotation rate in the Z axis	25,53	35,90	69,75	84,94				
Magnetic Heading	68,40	68,43	68,63	70,87	0,01	0,01	0,01	0,01
True Heading	68,25	68,28	68,51	70,78				
Heading Accuracy	100,00	100,00	100,00	100,00				
Magnetometer data in the X axis	79,31	82,22	94,79	97,86	60,82	60,83	60,84	60,86
Magnetometer data in the Z axis	98,22	98,22	98,22	98,22				
Magnetometer data in the Z axis	72,40	72,40	75,67	88,68				
Latitude	99,93	99,99	100,00	100,00	99,85	99,94	99,99	100,00
Longitude	99,92	99,98	100,00	100,00				
Position Accuracy	100,00	100,00	100,00	100,00				
Course	99,96	99,96	99,96	99,96	99,75	99,75	99,75	99,75
Speed	99,85	99,85	99,85	99,87				
Altitude	99,99	99,99	99,99	99,99	99,99	99,99	99,99	99,99

The 15 parameters are those actually measured by the IMU. The 41 parameters are measured and calculated parameters on basis of the 15 measured parameters.

TABLE V. AUTONOMY IN HOURS FOR DIFFERENT SAMPLING FRENQUENCY OF ALL 41 PARAMETERS AND 15 PHYSICALS PARAMETERS

Frequency (Hz)	41 parameters		15 parameters	
	iPhone 4s	iPhone 5s	iPhone 4s	iPhone 5s
1	5.47 (±1.72)	7.68 (±1.83)	5.10 (±1.90)	7.95 (±1.89)
2	6.37 (±2.20)	10.30 (±2.29)	7.50 (±3.16)	9.47 (±2.38)
3	7.21 (±2.62)	9.16 (±1.86)	6.58 (±2.49)	9.32 (±2.00)
5	5.84 (±2.22)	8.44 (±2.23)	5.95 (±2.32)	8.48 (±2.03)
10	5.26 (±1.72)	7.75 (±1.74)	5.26 (±1.82)	7.80 (±1.78)
20	5.24 (±1.76)	7.59 (±1.87)	5.24 (±1.82)	7.87 (±1.78)
30	5.15 (±1.80)	7.68 (±1.82)	5.23 (±1.78)	7.80 (±1.84)
50	5.09 (±1.81)	7.80 (±1.95)	5.24 (±1.83)	7.47 (±1.74)
100	5.15 (±1.78)	7.65 (±1.77)	5.11 (±1.73)	7.56 (±1.80)

Table 3 and Figure 1 show that the iPhone 5s has a battery life 50% longer on average compared to the iPhone 4s. The improvement in autonomy can notably be explained by the presence of a co-processor in the iPhone 5s. Otherwise, Table 3 doesn't show significant changes whether 41 or 15 parameters are recorded.

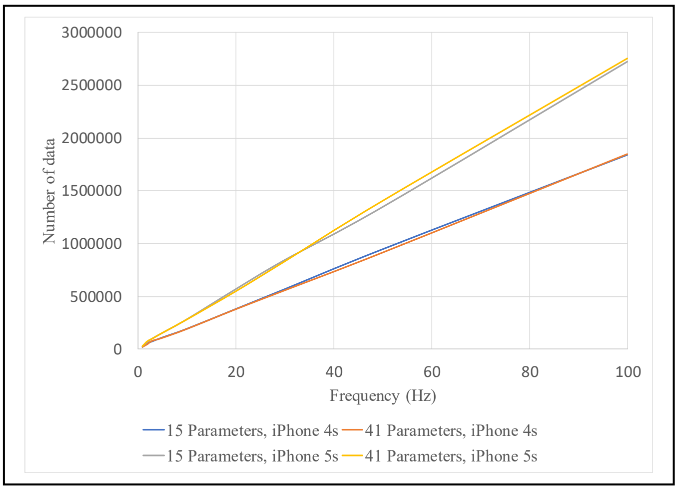

FIGURE 1: NUMBERS OF DATA COLLECTED FOR DIFFRERENTS FREQUENCIES

V. CONCLUSION

A comparison between two generation of iPhone has been proposed. In terms of precision both iPhone models give the same results on animals and with experimental measures obtained with table of displacements and checker. The autonomy of iPhone 5s is 50% higher than iPhone 4s. This improvement can notably be explained by the presence of a coprocessor on the iPhone 5s.

The compressibility of data massively acquired can be reduced in mean of 43,5% and this can hardly be improved any further. By opposition, we have shown that individual parameters can be highly compressible. In the future when the most explicative parameters will be selected for a given research application, the compressibility of data will be improved. Finally, applying edge computing during the massive collection of data is not interesting.

In future works, we will compare iPhone 4s and 5s with more recent models such as iPhone SE, 6s and 7s. SensorData can be used to collect 41 parameters from the IMU of the iPhone at a frequency up to 100 Hz. However, it is not possible to switch off the screen during the acquisition phase, autonomy of the iPhone. The use of other software such as PowerSense[d] which operates in the background will undoubtedly significantly increase the acquisition time of the data.

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