MIT 6.S062 2018 – Mobile and Sensor Computing
Midterm Exam

There are 20 questions and 9 pages in this quiz booklet. To receive credit for a question, answer it according to the instructions given. *You can receive partial credit on questions.* You have **90 minutes** to answer the questions.

Don't forget to write your name on this cover sheet NOW!

Some questions may be harder than others. Attack them in the order that allows you to make the most progress. If you find a question ambiguous, be sure to write down any assumptions you make. Be neat. If we can't understand your answer, we can't give you credit!

THIS IS A CLOSED BOOK QUIZ.
YOU MAY USE TWO DOUBLE-SIDED PAGE OF NOTES.

Do not write in the boxes below

1-5 (20)	6-7 (10)	8-10 (13)	11-12 (9)	13-14 (9)
15 (5)	**16-17 (9)**	**18-19 (10)**	**20 (5)**	**Total (90)**

Name: SOLUTIONS

Starters

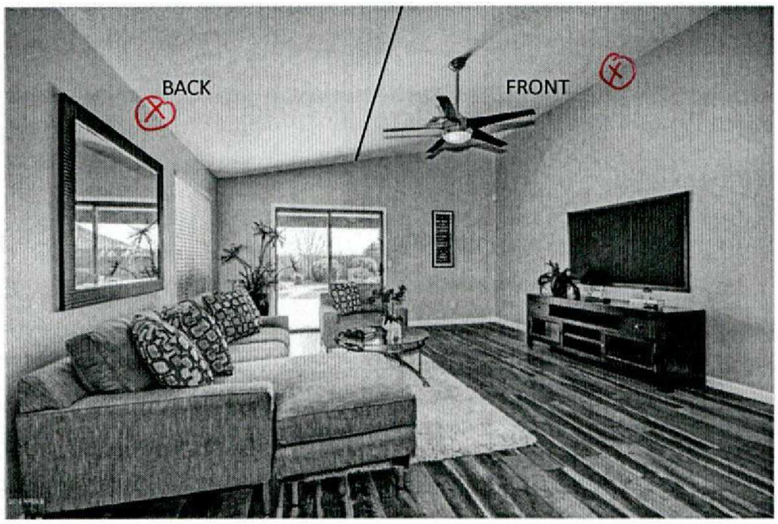
For each of the questions below, select True or False. There may be more than one True answer for every statement.

1. *(4 points)* Which of these sensors uses the Coriolis effect? (Circle True or False for each choice.)
   (a) True / False GPS
   (b) True / False Accelerometer
   (c) True / False Gyroscope
   (d) True / False Magnetometer (compass)
2. *(4 points)* Circle True or False for each statement below about the MIT ID card, as discussed in the RFID lecture.
   (a) True / False It uses a passive RFID tag.
   (b) True / False It uses inductive coupling for power.
   (c) True / False The coils of the tag and the reader need to be aligned.
   (d) True / False The coils of the tag and the reader need to be orthogonal.
3. *(4 points)* Circle True or False for each of these statements about the Farmbeats paper.
   (a) True / False It duty cycles the farm's White Spaces base station to adapt to weather conditions.
   (b) True / False It uses weather forecasts to plan the base station's duty cycling.
   (c) True / False It uses UAVs (drones) to provide backup Internet access to the farm.
   (d) True / False It uses spatial and visual smoothness in its learning model.
4. *(4 points)* The Google Loon project, which we discussed during the lecture on Farmbeats, has the following characteristics:
   (a) True / False It uses two balloons to change its altitude.
   (b) True / False It uses wind currents to assist its movement.
   (c) True / False It operates mainly in the stratosphere.
   (d) True / False It was used to bring Internet access to Puerto Rico after the hurricanes in 2017.
5. *(4 points)* The medium access control (MAC) protocol for RFIDs discussed in class has the following properties:
   (a) True / False It uses slotted Aloha.
   (b) True / False If the number of tags is known and fixed, its efficiency is higher than 90%.
   (c) True / False It reaches a deadlock if there is more than one RFID tag in the environment.
   (d) True / False An RFID tag transmits messages only when queried by an RFID reader.

Cricket

6. *(4 points)* Eager B. Eaver is deploying beacons from the Cricket location system in the room shown below. He would like to use the system to distinguish between the two halves of the room, "FRONT" and "BACK". The part of the room near the large TV is the "FRONT", while the part of the room with the couch and plants is the "back". Where should he place beacons to accomplish this task using the design described in the Cricket paper? Mark your placement of beacons clearly in the picture below, aiming to place as few beacons as possible. Each beacon's range is the entire room. Briefly (in one sentence) explain your answer.

Cricket uses TOF.
We need two beacons to find the difference in distances.
The two beacons need to be roughly equidistant from the center line.



7. *(6 points)* Eager sets the radio bit rate to 20 kbit/s and the size of the radio message sent from each beacon to 75 bytes (600 bits). He must now configure the ultrasonic transmitter and receiver to ensure that the maximum distance traversed by an ultrasonic signal before it is undetectable at a listener is no more than D meters. Calculate D, assuming that the speed of sound is 330 meters per second. Show your work.

$$\Delta t = \frac{600 \text{ bits}}{20 \text{ kbit/s}} = 30 \text{ ms}$$

$$D = c_{sound}\,\Delta t = (330 \text{ m/s})(30 \text{ ms}) = 9.9 \text{ m}$$

RF localization and WiTrack

8. *(6 points)* Ben Bitdiddle has an idea to estimate the distance from an RF transmitter to an object when there is no noise and no multipath using only one transmit and one receive antenna co-located on the same device. He transmits a sinusoidal waveform at frequency f Hz and then computes the **phase** of the reflected signal. The radio signal travels at c meters per second. He finds that he can make this approach work as long as the distance to the object is less than some value, D meters. What is D in terms of the parameters provided? Explain your answer.

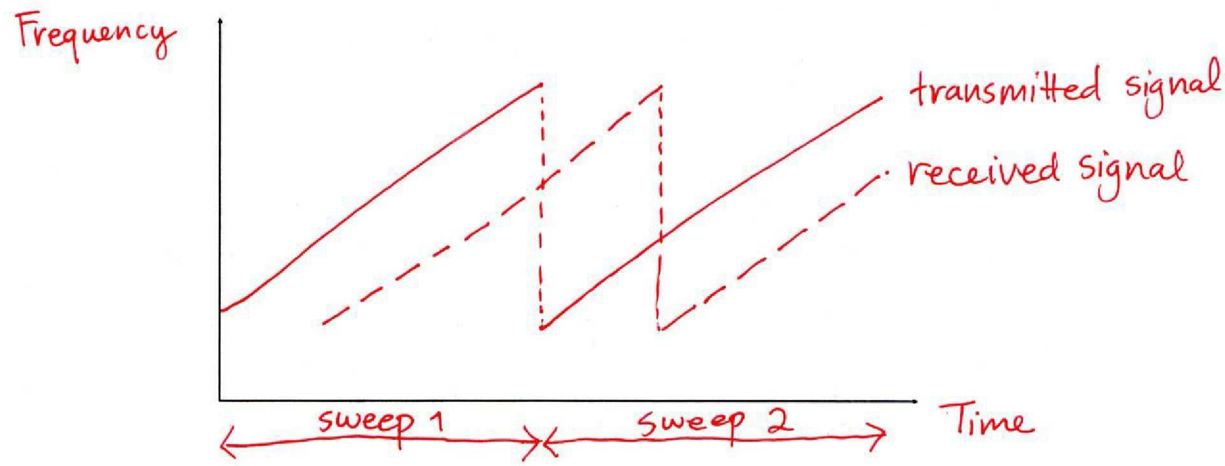
There is no phase ambiguity if $\Delta\phi < 2\pi$

$$\Delta\phi = \frac{2\pi}{\lambda}\Delta x = \frac{2\pi f}{c}\Delta x < 2\pi \Rightarrow \Delta x < \frac{c}{f}$$

Δx: total distance traveled $= 2D$ (transmitter → object → receiver)

$$\therefore D = \frac{\Delta x_{max}}{2} = \frac{c}{2f}$$

9. *(4 points)* Now consider the WiTrack system discussed in class, which uses a frequency-modulated continuous wave (FMCW). There is no multipath and no noise and a single reflector. Sketch the frequency of the ideal FMCW transmitted signal as a function of time. On the same graph, also sketch the received signal as a function of time. Label the axes.



10. *(3 points)* Suppose that the bandwidth allowed for the WiTrack FMCW frequency sweep is 75 MHz. What is the distance resolution, i.e., the minimum distance between two objects so that they may be located separably? Assume that the transmit and receive antennas are co-located. The speed of the radio signal is 3×10^8 m/s.

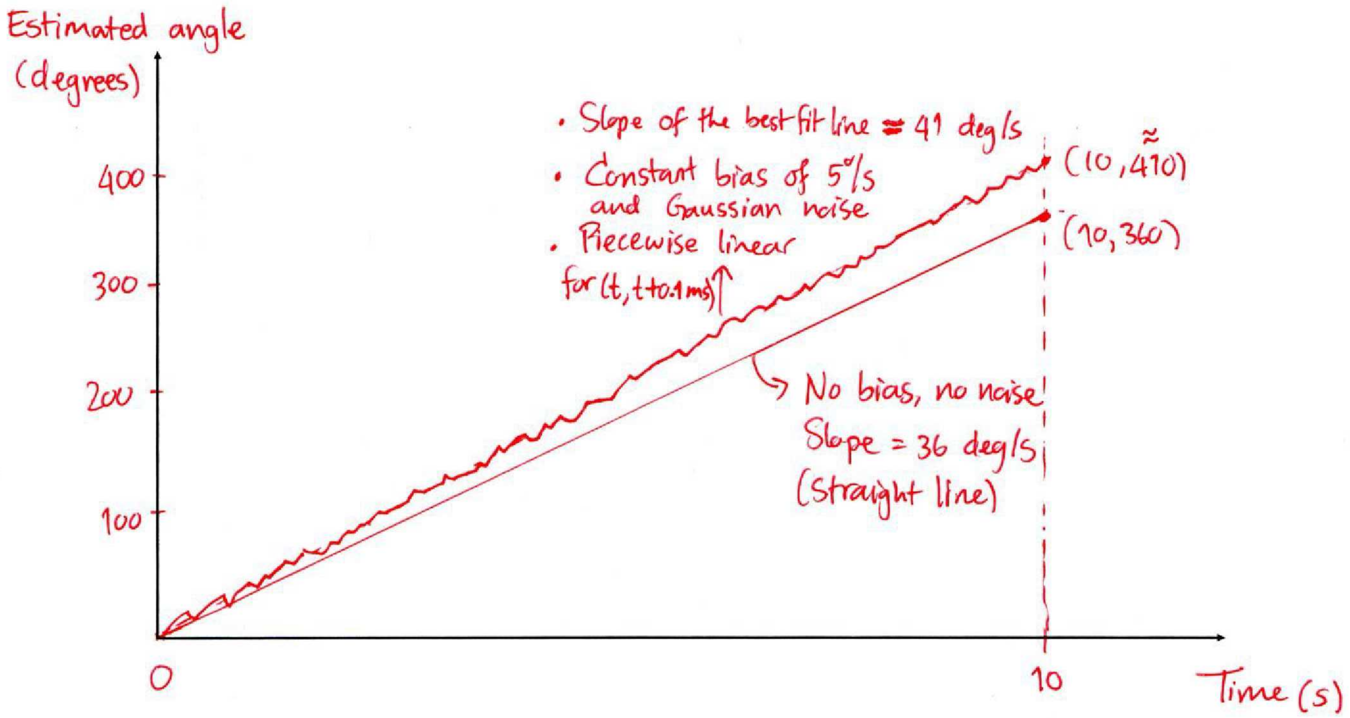
$$\text{Resolution} = \frac{c}{2B} = \frac{3\times 10^8 \text{ m/s}}{2(75\times 10^6 \text{ Hz})} = 2 \text{ m}$$

Inertial sensing

11. *(2 points)* A device rotates around its axis at a constant rate, completing 1 rotation in 10 seconds. If there is no noise and no bias, what angular velocity does the gyroscope on the device report? (You may assume any convenient units for the gyroscope, but state the units.)

$$\omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi \text{ rad}}{10 \text{ s}} = \frac{\pi}{5} \text{ rad/s} = 36 \text{ deg/s}$$

12. *(7 points)* Suppose the gyroscope has a constant bias of 5 degrees per second and also suffers from a small but non-zero amount of Gaussian noise. The gyroscope reports an angular velocity value every 100 ms. Sketch the **angle** estimated from these angular velocity values as a function of time between $t = 0$ and $t = 10$ seconds. You may assume the starting angle to be 0 at $t = 0$. On the same graph, also sketch the angle versus time if there were no bias and no noise. In addition, (1) label the axes, (2) mention the units on the axes, and (3) give the slopes of the best-fit lines for each of the two curves.



This plot assumes that the bias is in the same direction as the rotation of the device, i.e. $\omega = \omega_0 + b = 41$ deg/s. Otherwise, $\omega = (36-5)$ deg/s $= 31$ deg/s.

Networking

13. *(3 points)* Which of the following assumptions does ETX, as described in the paper we studied, make? Circle True or False for each choice.

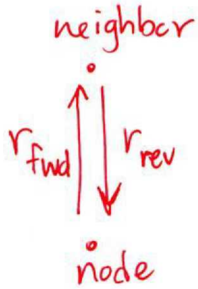
    (a) True / False The link layer receiver sends an ACK each time it receives a packet.

    (b) True / False The applications using the mesh network must use UDP and not TCP.

    (c) True / False A node's radio must transmit packets at exactly one bit rate.

14. *(6 points)* The ETX scheme requires that each node know the packet delivery probability in the forward and in the reverse direction to each neighbor. By "forward", we mean from the node to a neighbor; "reverse" is the opposite direction.

    (a) Explain how a node obtains the forward packet delivery probability.



Each node broadcasts small link probes once every second and remembers probes received from neighbors over the past 10 seconds. Once each neighbor calculates r_{rev}, it sends back the ratio to the node. The node takes each neighbor's r_{rev} as its r_{fwd} to that neighbor. Said differently, r_{rev} is piggybacked on transmissions from neighbors.

    (b) Explain how a node obtains the reverse packet delivery probability.

$$r_{rev} = \frac{\text{\# packets received by node}}{\text{Total \# packets sent from sequence numbers transmitted by neighbors}}$$

Pothole Patrol

15. *(5 points)* One of the stages of processing in the Pothole Patrol is to calculate the xz ratio. What does this stage do, and why?

This stage rejects signal anomalies if the peak x-acceleration is less than some factor t_x times the peak z-acceleration to filter out road anomalies that span the width of the road, e.g. railway crossings, speed bumps, expansion joints. These ~~cause~~ large peak z-acceleration with a relatively smaller x-acceleration, but true potholes only impact one side of the car and should produce large peak z-accelerations together with large peak x-accelerations.

Map matching and map inference

16. *(6 points)* CTrack converts a time-series of RF fingerprints to grid sequence

    (a) Fill in the blank above with one or more words.

    (b) Circle True or False for each statement below based on information in the CTrack paper.

    i. (True) / False An RF fingerprint consists of the identity of a cellular base station and the RSSI value observed by a mobile device.

    ii. (True) / False An RF fingerprint is obtained by a mobile device scanning for cellular base stations.

    (c) The similarity between two fingerprints in CTrack is computed using which of the following factors?

    i. (True) / False The number of common base stations.

    ii. True / (False) The physical distance between the base station and the center of the grid.

    iii. (True) / False The Euclidean distance between the signal strengths of the common base stations.

17. *(3 points)* The map inference paper by Biagnoni and Eriksson uses a map matching step and processes the map-matched output for which of these purposes?

    (a) True / (False) To extract road centerlines.

    (b) (True) / False To remove low-confidence road segments.

    (c) True / (False) To transform the resulting topologically-accurate road map into a more geometrically-accurate, finished map.

Acoustic sensing

18. *(2 points)* How many ultrasonic speakers does the BackDoor system use to make microphones hear inaudible sounds?

At least two, each at a different ultrasonic frequency, e.g. 40 kHz and 50 kHz.

19. *(8 points)* Consider the Backdoor acoustic system. An ultrasonic speaker sends three tones at 40 kHz, 50 kHz, and 52 kHz. Alice uses her smartphone's microphone to record the signal.

   (a) Alice uses a spectrogram app to detect what frequencies she recorded. She does not see any of the three tones on her spectrogram. Why?

   The frequencies of the three tones exceed the range that a microphone can record, i.e. $\leq$ 24 kHz, because they are filtered by the microphone's low-pass filter.

   (b) Instead, Alice notices some other frequency tones in her spectrogram. What are these frequencies?

   Nonlinearity creates f_1+f_2, f_1-f_2, $2f_1$, $2f_2$ from f_1 and f_2.
   The frequencies that fall within the recordable range are 2 kHz, 10 kHz, and 12 kHz.

   (c) According to the paper, which of these can be a reason for the frequency tones observed in part (b):

   i. (True) / False Non-linearities in the microphone's amplifier.
   ii. (True) / False Non-linearities in the speaker's amplifier.
   iii. True / (False) Non-linearities in the microphone's receive chain *after* the filter.

Glimpse

20. Ben Bitdiddle has deployed the Glimpse system to recognize objects. His video runs at 30 frames per second. A new object appears in a frame at time 0. To recognize this object, Glimpse needs to first send the frame to the server. It takes 667 milliseconds from when the frame is sent to when the client receives a response from the server labeling the recognized object. However, by that time, a certain number of frames N would have been captured on the client and stored in the client's active cache.

    (a) *(2 points)* What is N?

    $N = (667 \text{ ms}) \times (30 \text{ frames/s}) = 20 \text{ frames}$

    (b) *(3 points)* Suppose it takes 5 ms for the client to track a recognized object from one frame to another on the client. What is the maximum number of frames that Glimpse can track through in order for it to recognize the object in the latest frame before the new one is available on the client?

    (30 fps)

    $$M \times 5 \frac{\text{ms}}{\text{frame}} \leq \frac{1000 \text{ ms}}{30 \text{ frames}} = 33 \frac{\text{ms}}{\text{frame}}$$

    $M_{max} = 6 \text{ frames}$

End of quiz!