The concept of autoISF – a prototype in AAPS

Caveat: *I am not a medically trained person and developed this methd purely based on trial and numerical experimentation. I had no mathematical model of the reaction kinetics of the free fatty acids which are one reason for temporary insulin resistance.*

Many users occasionally complain about „water“ in the pump. Especially at high BG levels things appear to be stuck and users ask for a dynamic adaptation of ISF. This is what I intended to address. In my later use of it I saw that it also helps bringing down glucose from moderately high but constant levels.

In many control systems a PID controller is used, where

- the P-term stands for proportional behaviour. i.e. the higher the glucose deviation the higher the insulin dose. This contribution is included in AAPS.
- the I-term stands for integrated error, i.e. the integral of the glucose deviation over time. Such a contribution is missing in AAPS and I tried to add this in the autoISF. But keep in mind that I am not a trained controller person either.
- the D-term stands for differential behaviour, i.e. the larger the change in glucose the larger the reaction in insulin dosing. This contribution is included in AAPS.

After playing around with several algorithms to acheive such an adaptation I ended up with the following autoISF method:

1. Check there is no COB, otherwise there is interference with the IC settings. In UAM mode and for enthusiasts of the recent „eat, don't bolus“ fraction this is a given.
2. Check that BG is above target_bg.
3. Determine length (*dura05*) and height(*avg05*) of a BG plateau where BG is within +/- 5%
4. Use a weighting system applied to *dura05* and *target_bg* as well as the deviation of *avg05* from *target_bg* to calculate an ISF change factor *liftISF*. This factor behaves similarly to autosense in the way it modifies ISF and is always larger than or equal to 1:

$$\text{liftISF} = 1 + \frac{\text{avg05-target\_bg}}{\text{target\_bg}} * \frac{\text{dura05}}{60} * \text{weightISF}$$

where

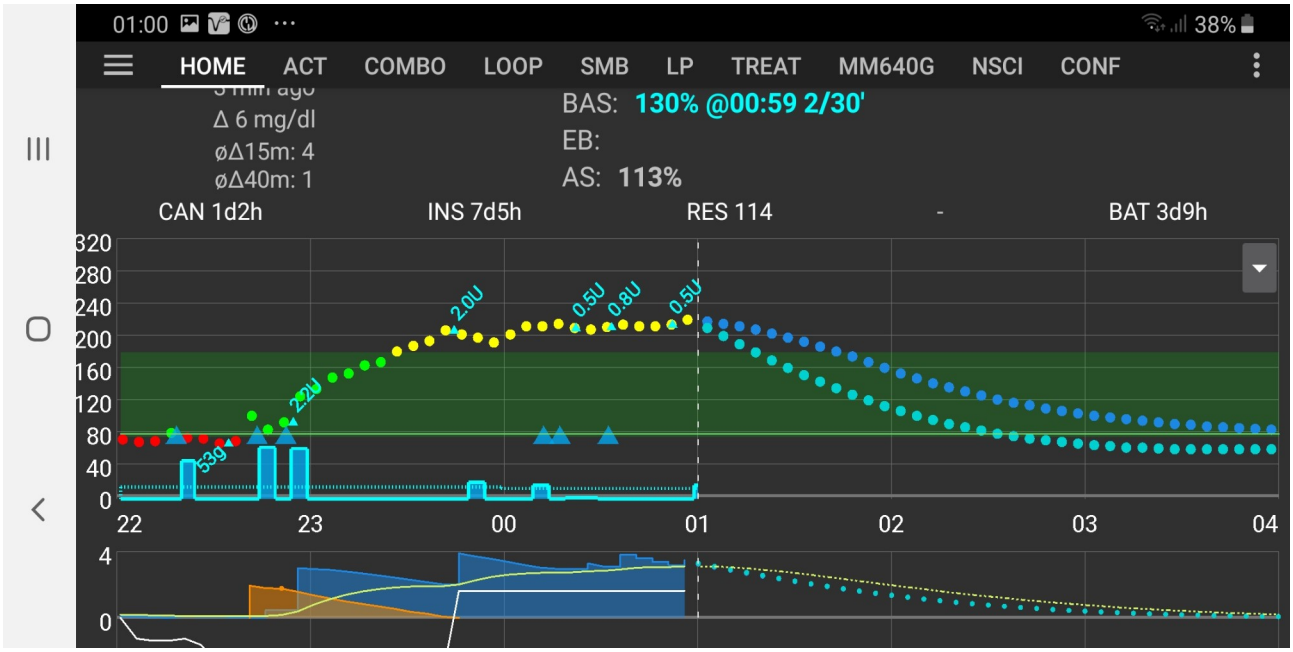
$$\text{weightISF} = (1 - \text{autosense\_min}) * 2$$

The resulting factor has linear impact on the change of ISF, e.g. *autosense_min* of 0.7 is twice as strong as 0.85. To get a fealing for the magnitudes consider the example of a plateau *avg05* at twice the *target_bg* and lasting already for 60 minutes then *liftISF* would be 1+weightISF.

For algorithm selection and tuning of these factors I made extensive use of my AAPS emulator which I had extended for this purpose to include several prototype algorithms. Such emulation as available on github[1] is still the highly recommended starting point because all the initial calibration happens without risk in the virtual world. The screen shot below is from the early testing phase when the algorithm was still only in the emulator and I figured that applying half of its result might work – which it did in this case. Once I saw an effect large enough but it would not bring me too low, I implemented it directly in AAPS and have been using it since August instead of the regular autosense. Meanwhile I even weakened my regular ISF profile by 10-20% to hover above the target level and autoISF will pull me towards the target from time to time. This

1 https://github.com/ga-zelle/APS27-What-if ; meanwhile upated to AAPS 2.7

reduces my time spent below target, at least in theory. Too many other things were happening during that time so I cannot see the evidence in numbers.



I tried to develop an equivalent algorithm for glucose being too low and then weakening ISF. So far I did not find anything promising.

Please be aware that autoISF only changes ISF, nothing else like TTs or similar. Because it leaves the pump profile intact, it saves a lot of the pumps battery life compared to a method resulting in profile changes driven by automation.

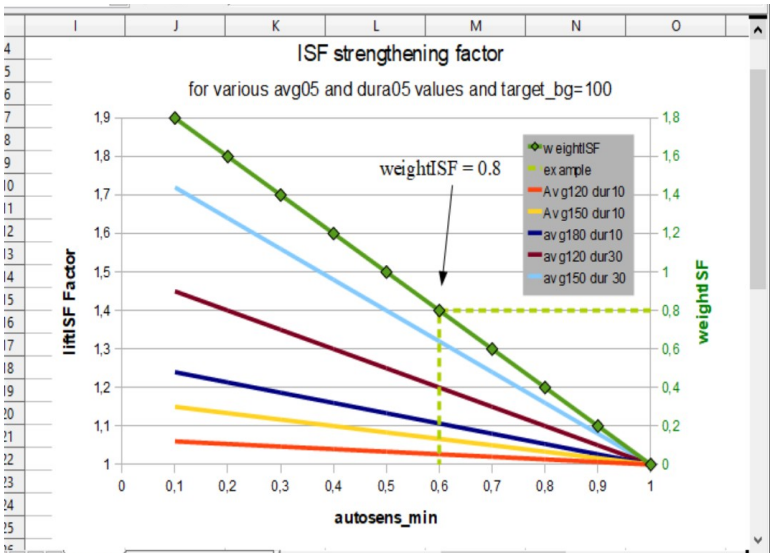
Late November 2020 BerNie also started using this prototype, even in conjunction with Autosense. He observes slightly lower average glucose, slightly less time spent above 180 and minor increase of time spent below 70. The lows could be offset by increasing the target a bit.

The use of autoISF in AAPS

As I am not a java developer I do not know how to add an extra parameter set for autoISF ON/OFF, its scale factor and its upper limit. So in my current solution I highjacked the settings from autosense because I do not use it anyway or rather any longer. The autosense settings are used by autoISF in this way:

1. *autosense enabled or not:* I left that untouched and did not want to interfere with autosense. As a result autoISF is always enabled in principle.

2. *autosens_min* is used to derive the weighting factor. The regular range of *autosense_min* is 0.1 – 1.0. As my factor happens to be 1.0 that can be mapped to the autosense range if I divide it by 2. However, I use the complement to 1 as the factor which is somewhat in line with the autosense case where 1 means no effect. So with 0.1 you get a factor of 1.8 which would be 80% stronger than my factor of 1.0. For initial and cautious approximation you should start weak, e.g. at 0.9 which would still give you 20% of my setting.



3. *autosense_max* is used as the upper limit of the resulting weighting factor *liftISF* just like in the autosense case. For reference, my setup uses 1.8 but for safety reasons you should start closer to 1.0 and increase it step by step.

Does it interfere with autosense?

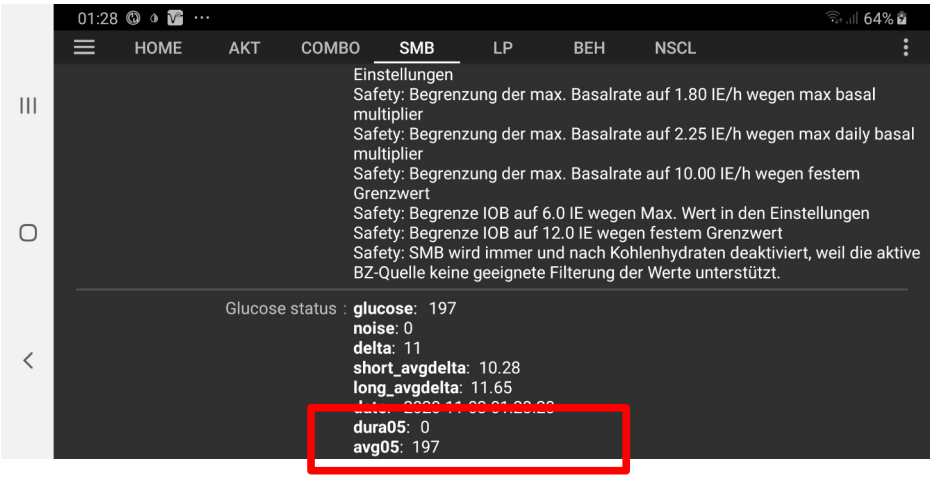
YES, at least as long as you enable autosense. Obviously by setting any of the two, *autosense_min* or *autosense_max* to 1 the autoISF does no longer change ISF but that has an impact on your use of autosense, too. If both limts are close in both worlds, autosense and autoISF, it may work well. Otherwise you might narrow your autosense bandwidth until you are comfortable. At least the code will pick whichever of the two methods has the larger impact on ISF at any point in time as can be seen further down in the second example.

When the BG situation changes then autoISF reacts promptly compared to the sluggish autosens. In that sense there is less of an interference than thaught because they mostly act at different times.

How can you see what it does?

The SMB-tab is the place to check:

1. In *Glucose_status* there are two new items appended, namely *dura05* and *avg05* as mentioned above in the concept section. As long as *dura05* is less than 10m autoISF is not active and there is no point checking elsewhere.

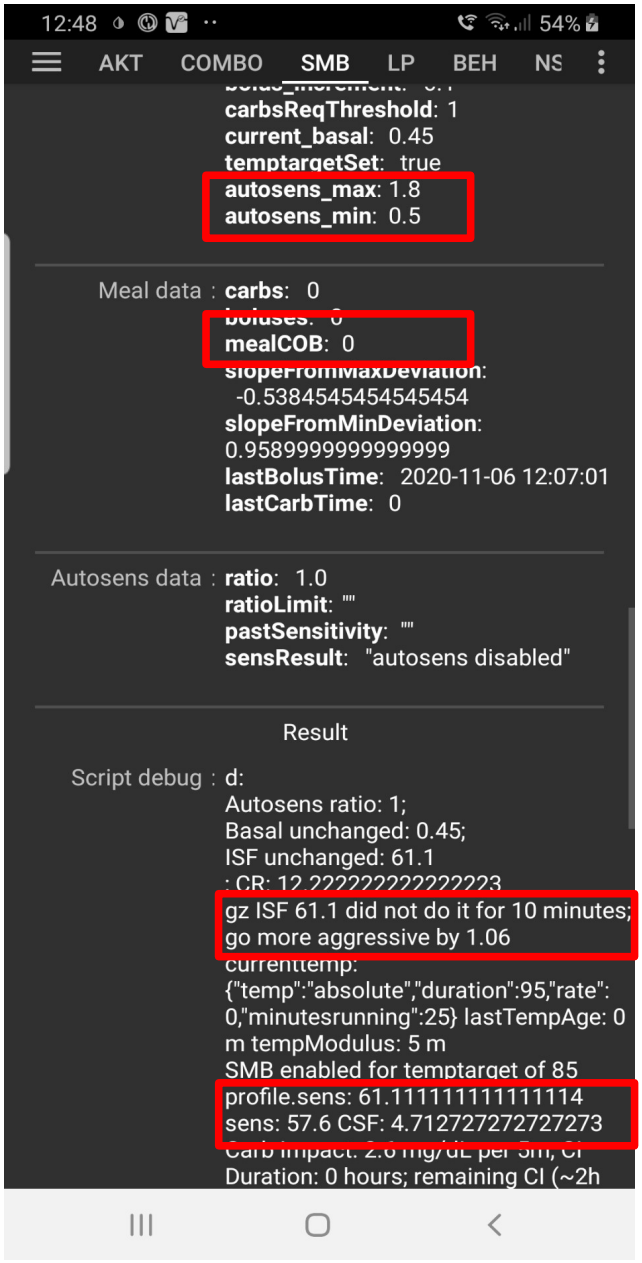


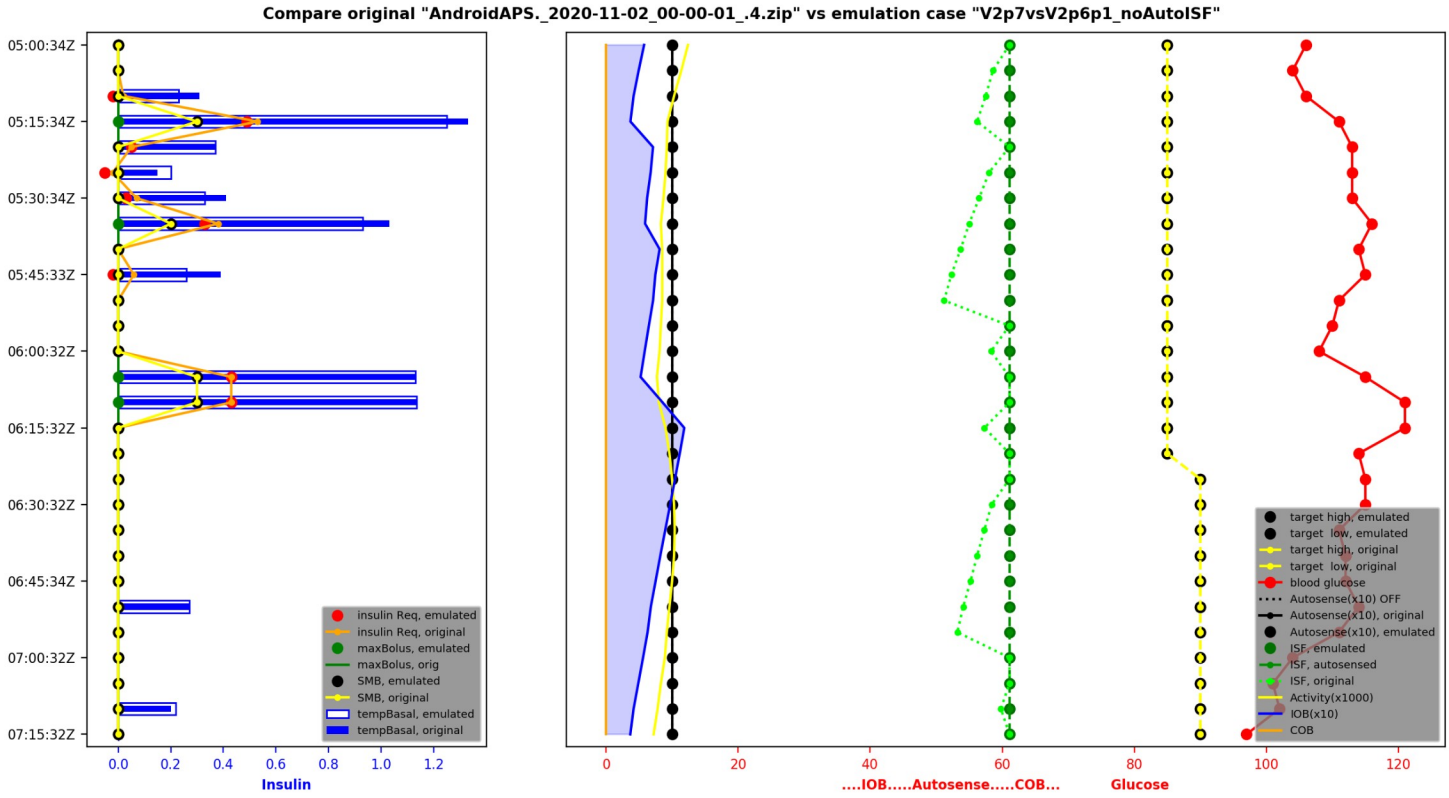
2. In *Profile*, right at the end *autosense_min* was appended, joining up with good old *autosense_max*. For you it serves as a reminder what their current values are.

3. In *Meal data* you can check for *mealCOB* = 0 or not. But of course that was already clear from the carb area on the home screen.

4. The *Result / Script debug* holds the really interesting information. The first few lines are an echo of what autosens did to ISF, basal and CR. Thereafter the line(s) starting with „gz...“ are an echo of autoISF, e.g.
   - *gz keep ISF as BG level is only 5m at level 107.5*
     Obviously the 10 minutes minimum time window was not acheived
   - *gz ISF 55.6 did not do it for 10 minutes; go more aggressive by 1.06*
     Here the ISF will become active and strengthen ISF by a factor 1.06
   - *gz ISF reduction 1.6 limited by autosens_max 1.5*
     Here the calculated strengthening of 1.6 is capped to 1.5 as defined in *autosens_max*
   - *gz keep ISF; avg. glucose 90 below target 95*
     Here BG is already low and ISF should not be strengthened
   - *gz keep ISF due to mealCOB of 9.6*
     Here autoISF is deactivated due to presence of carbs

   A few line further down AAPS 2.7 now explicitely shows the ISF as defined in the profile and the final value after applying autosens and autoISF





Example with autosense disabled

These plots and tables were produced by the emulator. The above figure compares the original run including active autoISF against a virtual case where it was not used. Right at the beginning you see a plateau at about 105mg/dl which lasts up to 15m. Shortly after that another plateau develops at about 113mg/dl and lasts for 45m. In both periods the light green line shows continued strengthening of ISF for the original use and that ISF is back to normal as soon as the plateau ends. The bars to the left show more insulin being delivered when autoISF is active. After 06:30Z there is another plateau with strengthening ISF but in spite of that the insulin delivered is unchanged because enough of it was on board.

The table below tells the same story. The 4 columns for ISF mean:

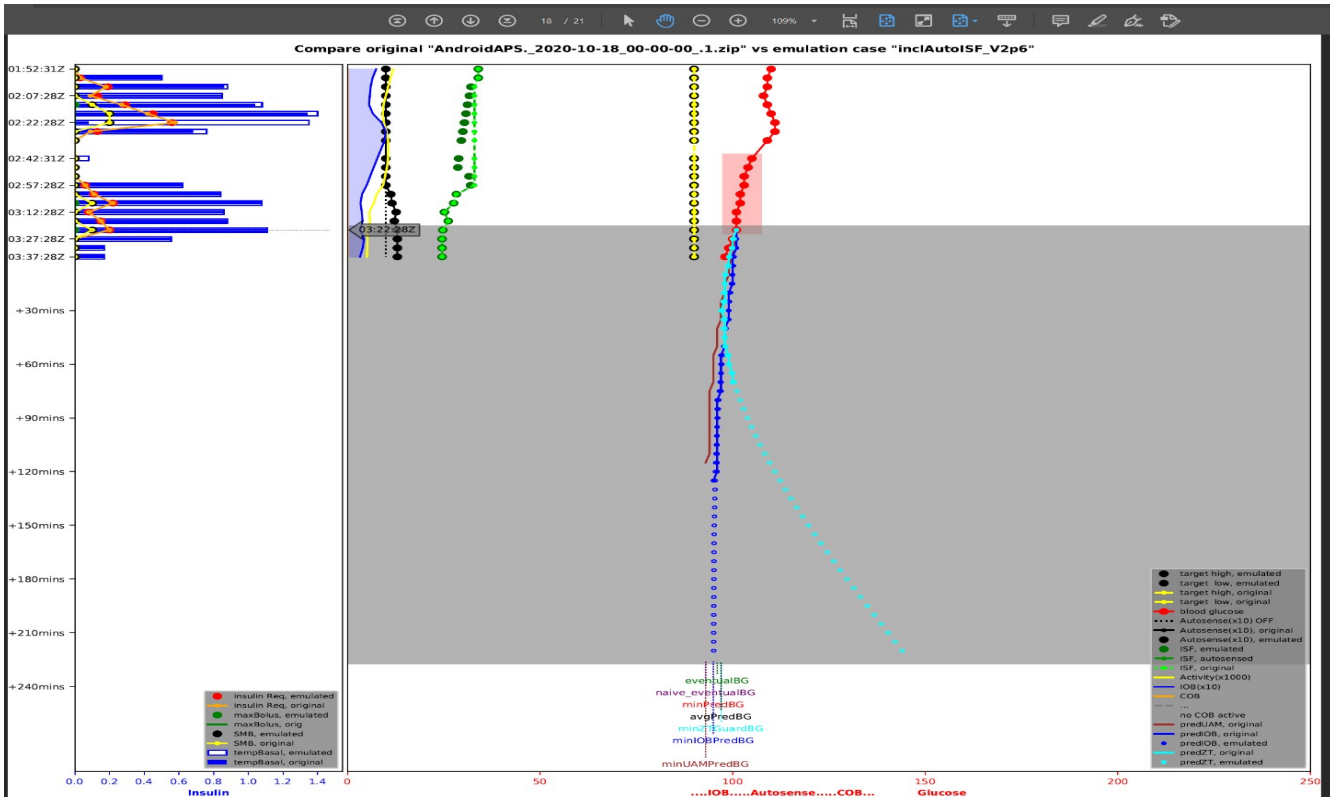
- orig: the original, real use case
- prof: as defined ín the active pump profile
- auto: the prof value potentially modified by autosense
- emul: value in the virtual, simulated situation, in this case no autoISF

UTC		avg.			Auto	--5%	range-	---------ISFs---------				insulin Req		---SMB---		--tmpBasal--	
time	bg	targ	IOB	COB	sens	dura	avg.	orig	prof	auto	emul	orig	emul	orig	emul	orig	emul
05:00Z	106	85.0	0.58	0	1.0	0.0	106.0	61.1	61.1	61.1	61.1	0	0	0	0	0	0
05:05Z	104	85.0	0.49	0	1.0	5.0	105.0	58.6	61.1	61.1	61.1	0	0	0	0	0	0
05:10Z	106	85.0	0.42	0	1.0	10.0	105.3	57.5	61.1	61.1	61.1	0.02	-0.02	0	0	0.31	0.23
05:15Z	111	85.0	0.37	0	1.0	15.0	106.8	56.2	61.1	61.1	61.1	0.53	0.49	0.3	0.3	1.33	1.25
05:20Z	113	85.0	0.71	0	1.0	5.0	112.0	61.1	61.1	61.1	61.1	0.05	0.05	0	0	0.37	0.37
05:25Z	113	85.0	0.68	0	1.0	10.0	112.3	58	61.1	61.1	61.1	-0.02	-0.05	0	0	0.15	0.2
05:30Z	113	85.0	0.62	0	1.0	15.0	112.5	56.5	61.1	61.1	61.1	0.07	0.03	0	0	0.41	0.33
05:35Z	116	85.0	0.59	0	1.0	20.0	113.2	55	61.1	61.1	61.1	0.38	0.33	0.2	0.2	1.03	0.93
05:40Z	114	85.0	0.81	0	1.0	25.0	113.3	53.7	61.1	61.1	61.1	0	0	0	0	0	0
05:45Z	115	85.0	0.75	0	1.0	30.0	113.6	52.3	61.1	61.1	61.1	0.06	-0.02	0	0	0.39	0.26
05:50Z	111	85.0	0.71	0	1.0	35.0	113.2	51.2	61.1	61.1	61.1	0	0	0	0	0	0
05:55Z	110	85.0	0.65	0	1.0	40.0	112.9	61.1	61.1	61.1	61.1	0	0	0	0	0	0
06:00Z	108	85.0	0.58	0	1.0	45.0	112.4	58.3	61.1	61.1	61.1	0	0	0	0	0	0
06:05Z	115	85.0	0.52	0	1.0	0.0	115.0	61.1	61.1	61.1	61.1	0.43	0.43	0.3	0.3	1.13	1.13
06:10Z	121	85.0	0.86	0	1.0	5.0	118.0	61.1	61.1	61.1	61.1	0.43	0.43	0.3	0.3	1.13	1.13
06:15Z	121	85.0	1.19	0	1.0	10.0	119.0	57.3	61.1	61.1	61.1	0	0	0	0	0	0

06:20Z	114	85.0	1.12	0	1.0	0.0	114.0	61.1	61.1	61.1	61.1	0	0	0	0	0	0
06:25Z	115	90.0	1.04	0	1.0	5.0	114.5	61.1	61.1	61.1	61.1	0	0	0	0	0	0
06:30Z	115	90.0	0.97	0	1.0	10.0	114.7	58.4	61.1	61.1	61.1	0	0	0	0	0	0
06:35Z	111	90.0	0.9	0	1.0	15.0	113.8	57.3	61.1	61.1	61.1	0	0	0	0	0	0
06:40Z	112	90.0	0.82	0	1.0	20.0	113.4	56.2	61.1	61.1	61.1	0	0	0	0	0	0
06:45Z	112	90.0	0.75	0	1.0	25.0	113.2	55.2	61.1	61.1	61.1	0	0	0	0	0	0
06:50Z	114	90.0	0.68	0	1.0	30.0	113.3	54.1	61.1	61.1	61.1	0	0	0	0	0.27	0.27
06:55Z	111	90.0	0.63	0	1.0	35.0	113.0	53.2	61.1	61.1	61.1	0	0	0	0	0	0
07:00Z	104	90.0	0.56	0	1.0	0.0	104.0	61.1	61.1	61.1	61.1	0	0	0	0	0	0
07:05Z	101	90.0	0.49	0	1.0	5.0	102.5	61.1	61.1	61.1	61.1	0	0	0	0	0	0
07:10Z	102	90.0	0.42	0	1.0	10.0	102.3	59.8	61.1	61.1	61.1	0	0	0	0	0.2	0.22
07:15Z	97	90.0	0.37	0	1.0	0.0	97.0	61.1	61.1	61.1	61.1	0	0	0	0	0	0

Example with concurrent use of autosense

Thank you to BerNie from de.loopercommunity.org for providing the original, non-autoISF data. This time the comparison is the other way round, i.e. the original run is from BerNie with autosense and automation both enabled and the emulated run shows the changes if autoISF would have been used, too.



Looking at the dark green dots we see autoISF gradually strengthening ISF. From the black dots we see that autosens is only detecting resistance towards the end of this time window. It then dominates the strengthening of ISF. The transparent red-ish box shows the +/- 5% range identified by autoISF as its reason for action at time 03:22Z. However, assuming *autosens_min*=0.6 its influence is less than that of autosens. In this case I do not see any conflict between autosens and autoISF and as *autosens_min* was not active in this time window the factor for autoISF could have been made stronger. But only the user can judge whether extra sensitivity is relevant for him and therefore what level of *autosens_min* is acceptable for autosense and autoISF. The numerical comparisons of ISF look like this:

UTC		avg.			Auto	--5%	range-	---------ISFs---------				insulin Req		---SMB---		--tmpBasal--	
time	bg	targ	IOB	COB	sens	dura	avg.	orig	prof	auto	emul	orig	emul	orig	emul	orig	emul
01:52Z	110	90.0	0.75	0	1.0	0.0	110.0	34	34	34.0	34.0	0	0	0	0	0	0
01:57Z	109	90.0	0.66	0	1.0	5.0	109.5	34	34	34.0	34.0	0.03	0.03	0	0	0.5	0.5
02:02Z	109	90.0	0.61	0	1.0	10.0	109.3	33	33	33.0	32.1	0.18	0.19	0	0	0.86	0.88
02:07Z	108	90.0	0.58	0	1.0	15.0	109.0	33	33	33.0	31.7	0.09	0.13	0	0	0.85	0.85
02:12Z	109	90.0	0.56	0	1.0	20.0	109.0	33	33	33.0	31.2	0.27	0.29	0.1	0.1	1.04	1.08
02:17Z	110	90.0	0.66	0	1.0	25.0	109.2	33	33	33.0	30.8	0.42	0.45	0.2	0.2	1.34	1.4
02:22Z	111	90.0	0.89	0	1.0	30.0	109.4	33	33	33.0	30.4	0.58	0.56	0.2	0.2	0.08	1.35
02:27Z	111	90.0	1.0	0	1.0	35.0	109.6	33	33	33.0	30.0	0.09	0.13	0	0	0.68	0.76
02:32Z	109	90.0	0.97	0	1.0	40.0	109.6	33	33	33.0	29.6	0	0	0	0	0	0
02:42Z	105	90.0	0.78	0	1.0	50.0	109.1	33	33	33.0	28.9	0	0	0	0	0	0.08
02:47Z	104	90.0	0.69	0	1.0	55.0	108.6	33	33	33.0	28.7	0	0	0	0	0	0
02:52Z	103	90.0	0.59	0	1.0	20.0	105.2	33	33	33.0	31.6	0	0	0	0	0	0
02:57Z	103	90.0	0.5	0	1.0	15.0	103.8	33	33	33.0	32.0	0.06	0.06	0	0	0.62	0.62
03:02Z	102	90.0	0.38	0	1.13	20.0	103.4	28.3	32	28.3	28.3	0.11	0.11	0	0	0.84	0.84
03:07Z	102	90.0	0.34	0	1.16	25.0	103.2	27.6	32	27.6	27.6	0.22	0.22	0.1	0.1	1.08	1.08
03:12Z	101	90.0	0.38	0	1.27	30.0	102.9	25.2	32	25.2	25.2	0.08	0.08	0	0	0.86	0.86
03:17Z	101	90.0	0.4	0	1.22	35.0	102.6	26.2	32	26.2	26.2	0.15	0.15	0	0	0.88	0.88
03:22Z	101	90.0	0.34	0	1.29	40.0	102.4	24.8	32	24.8	24.8	0.2	0.2	0.1	0.1	1.11	1.11
03:27Z	100	90.0	0.44	0	1.3	45.0	102.2	24.6	32	24.6	24.6	0	0	0	0	0.56	0.56
03:32Z	99	90.0	0.4	0	1.3	50.0	101.9	24.6	32	24.6	24.6	0	0.0	0	0	0.17	0.17
03:37Z	98	90.0	0.33	0	1.3	55.0	101.6	24.6	32	24.6	24.6	0	0.0	0	0	0.17	0.17