On Conjectures About The Simultaneous Pell Equations $x^2-(a^2-1)y^2=1$ and $y^2-pz^2=1$.

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Abstract.

This article shows that the *Qu (2018) conjectures*, the *Yang & Fu (2018) conjectures*, the *Jiang (2020) Conjecture-#1*, the *Tao (2016) Conjecture-#1*, the *Cipu & Mignotte (2007) Conjecture*, the *Ai, Chen, Zhang & Hu (2015) Conjecture*, the *Yuan (2004) Conjecture*, the *Keskin, Karaatlı, et. al. (2017) Conjecture*, the *Cipu (2018) Conjecture*, and the *Cipu (2007) Conjecture* [all of which pertain to the system of Simultaneous Pell equations $x^2-(a^2-1)y^2=1$ and $y^2-pz^2=1$] are wrong or incomplete (incomplete in the sense that they didn't provide complete solutions for the system of equations). This article also introduces simple Java codes for solutions to this class of equations for positive-integers up to$10^{2457600000}$ (and even greater positive-integers depending on available computing power).

Keywords: Nonlinearity; Mathematical Cryptography; PDEs; Difference Equations; Dynamical Systems; Number Theory; Polynomials; Computational Complexity.

1. Introduction & Existing Literature.

Qu (2018) supposedly proved that:

i) where p is a prime number, the system of simultaneous Pell equations $x^2-(a^2-1)y^2=1$ and $y^2-pz^2=1$ (collectively, the "Simultaneous Pell System") has only a positive integer solution $(x,y,z) = (31,8,3)$ for $p=7$ (the "*Qu (2018) Conjecture-#1*") by using a Baker's lower bound and one lemma from Diophantine approximation to determine the lower and upper bounds respectively, on the variables of the equation; and

ii) there is no positive solution to the Simultaneous Pell System for $a=(2,3)$ (the "*Qu (2018) Conjecture-#2*"); and

iii) the Simultaneous Pell System has a positive integer solution only for $a=4$ which is $(x,y,z,p)=(31,8,3,7)$ (the "*Qu (2018) Conjecture-#3*").

Yang & Fu (2018) supposedly developed complete solutions for the Simultaneous Pell Equations $x^2-(a^2-1)y^2=1$ and $y^2-pz^2=1$; and they claimed that:

i) if a ≡ 2 or 3(mod 4), then the Simultaneous Pell System has no positive integer solutions (x,y,z) (the "*Yang & Fu (2018) Conjecture-#1*"); and

ii) for 1< a< 100, the Simultaneous Pell System has <u>only</u> the positive integer solutions (a,p,x,y,z) = (4, 7, 31, 8, 3), (5, 11, 49, 10, 3), (12, 23, 287, 24, 5), (13, 3, 337, 26, 15), (24, 47, 1151, 48, 7), (40, 79, 3199, 80, 9), (41, 83, 3361, 82, 9) and (84, 167, 14111, 168, 13) (the "*Yang & Fu (2018) Conjecture-#2*"). Thus, the Yang & Fu (2018) positive integer solutions [(a,p,x,y,z) = (4, 7, 31, 8, 3), (5, 11, 49, 10, 3), (12, 23, 287, 24, 5), (13, 3, 337, 26, 15), (24, 47, 1151, 48, 7), (40, 79, 3199, 80, 9), (41, 83, 3361, 82, 9) and (84, 167, 14111, 168, 13)] nullify the *Qu (2018) Conjecture-#3,* and the *Cipu & Mignotte (2007) Conjecture* and the *Jiang (2020) Conjecture-#1*. The *Ai, Chen, Zhang & Hu (2015)* positive-integer solutions (where a=5) are (x,y,z,p)=(49,10,3,11) and (x,y,z,p)=(485,99,70,2) and they nullify the *Yang & Fu (2018) Conjecture-#2*.

Ai, et. al. (2015) conjectured that the system of simultaneous equations $x^2 - 24y^2=1$ and $y^2-pz^2=1$, where p is a prime, has at most one integer solution for each p, and that the only solutions for that system of equations are (x,y,z)=(485,99,70) for p=2, and (x,y,z)=(49,10,3) for p=11 (the "*Ai, Chen, Zhang & Hu (2015) Conjecture*"). Note that if a=5, then $x^2-24y^2=1$ is equivalent to $x^2-(a^2-1)y^2=1$. However, the results of this article show that there are feasible solutions other than those stated by the *Ai, Chen, Zhang & Hu (2015) Conjecture*.

Tao (2016) conjectured that for the system of simultaneous Pell equations $x^2 - 24y^2=1$ and $y^2-2pz^2=1$ (where p is an odd prime) there is no positive integer solution (the "*Tao (2016) Conjecture-#1*"); and that for the second system of simultaneous equations $x^2-24y^2=1$ and $y^2-3pz^2 =1$ (where $p > 3$ is a prime), there is no positive integer solution (the "*Tao (2016) Conjecture-#2*").

Cipu (2007) conjectured that for positive integers *m* and *b*, the number of simultaneous solutions to the Simultaneous Pell Equations $x^2-(4m^2-1)y^2=1$, and $y^2-bz^2=1$ in positive integers isn't greater than one (the "*Cipu (2007) Conjecture*"). If 2m=a, then $x^2-(4m^2-1)y^2=1$ is equivalent to $x^2-(a^2-1)y^2=1$.

Cipu (2018) stated that if one of the following conditions holds: (i) $2a^2-1$ is not a perfect square, (ii) $\{p(mod8),q(mod8)\}\neq\{1,3\}$; then the equations $x^2-(a^2-1)y^2=1$ and $y^2-bz^2=1$ have solutions in positive integers *iff* $8a^2(2a^2-1)/b$ is a perfect square (the "*Cipu (2018) Conjecture*"). Jiang (2020) claims to completely solve these equations and the Cipu (2018) models when a>1,b are two positive integers where the square-free part of *b* is 2pq and (p, q) are two distinct odd primes (the "*Jiang (2020) Conjecture-#1*").

Cipu & Mignotte (2007) conjectured that for any distinct nonzero integers *a* and *b*, the system of simultaneous Diophantine equations $x^2-ay^2=1$ and $y^2-bz^2=1$, has at most one positive integer solution (x,y,z) for $a=4m^2 - 1$ (collectively, the "*Cipu & Mignotte (2007) Conjecture*"). Note that $(4m^2-1)$ is equivalent to $(\{2m\}^2-1)$.

Yuan (2004) conjectured that for any distinct non-zero integers (a,b), the system of simultaneous Diophantine equations $x^2-ay^2=1$ and $y^2-bz^2=1$, has a maximum of one positive integer solution (x,y,z) for $a=4m(m + 1)$ (the "*Yuan (2004) Conjecture*").

Irmak (2016) also analyzed the system of simultaneous equations $x^2 - 24y^2=1$ and $y^2-pz^2=1$.

Keskin, Karaatlı, et. al. (2017) analyzed the system of simultaneous Pell equations $x^2-(a^2-1)y^2 =1$, and $y^2-pz^2=1$, where p is prime and $a > 1$. Keskin, Karaatlı, et. al. (2017) wrongly conjectured that if the solutions of the Pell equation $x^2-(a^2-1)y^2 =1$ and $y^2-pz^2=1$, are x=xm and y =ym with $m \geq 2$, the system $x^2-(a^2-1)y^2 =1$ and $y^2-pz^2=1$, has solutions only when m = 2 or m = 3 (the "*Keskin, Karaatlı, et. al. (2017) Conjecture*"). In the case of m=3, Keskin, Karaatlı, et. al. (2017) concluded that p=2 and provided solutions of $x^2-(a^2-1)y^2 =1$ in terms of Pell and Pell–Lucas sequences. Keskin, Karaatlı, et. al. (2017) wrongly conjectured that the system of Pell equations $x^2-(a^2-1)y^2 =1$ and $y^2-pz^2=1$ has no solutions when $p \equiv 1 (\mathrm{mod}\ 4)$.

On solutions for Pell Equations, see: Pinch (1988), Catarino (2019), Ddamulira & Luca (2020), Raza & Malik (2018), Nesterenko (2009), and Lenstra (2008). On quantum algorithms for Pell Equations, see: Hallgren (2007).

On the use of Pell Equations in Cryptology (public key networks) and systems/Networks, see: Sarma & Avadhani (2011), Raghunandan, Ganesh, et. al. (2020), Raghunandan (2020) and Muhaya (2014) (ie. each of the equations $x^2-(a^2-1)y^2=1$ and $y^2-pz^2=1$ can be used in cryptoanalysis and in the creation of public-keys). Chu (2008) and Lu & Wu (2016) studied dynamical systems pertaining to Diophantine equations (and each of the equations $x^2-(a^2-1)y^2=1$ and $y^2-pz^2=1$ individually and collectively can approximate Dynamical Systems). Luca, Moree & Weger (2011) discussed *Group Theory* as it relates to Diophantine Equations. Stewart (1980), Jones, Sato, et. al. (1976) and Matijasevič (1981) noted that primes can also be represented as Diophantine equations or as polynomials (ie. each of the equations $x^2-(a^2-1)y^2=1$ and $y^2-pz^2=1$ can represent a prime).

Xu & Cao (2018) noted that: i) functional equations such as $f^m+g^m=1$ can be regarded as the Fermat-type equations over function fields; ii) Fermat-type functional equations can be partial differential-difference equations such as $(\partial f(z_{1,z2)}/\partial z_1)^n + f^m(z_1+c_1,z_2+c_2)=1$ in $\mathbb{C}^2$; and partial difference equations such as $f^m(z_1,\ldots,z_n)+f^m(z_1+c_1,\ldots,z_n+c_n)=1$ in $\mathbb{C}^n$. Similarly, both of the equations $x^2-(a^2-1)y^2=1$ and $y^2-pz^2=1$ can be deemed to be types of PDEs (partial differential equations) - for example, of the type $(\partial f(x_1,x_2)/\partial x_1)^a - p(\partial f(y_1,y_2)/\partial y_1)^a =1$. Similarly, both of the equations $x^2-(a^2-1)y^2=1$ and $y^2-pz^2=1$ can be deemed to be types of partial difference equations such as $f^m(z_1,\ldots,z_n)- f^m(z_1+d_1,\ldots,z_n+d_n)=1$, in $\mathbb{C}^n$. Saleeby (1999) and Liu, Cao & Cao (2012) analyzed Fermat-type differential-difference equations and Fermat-type partial differential equations. On Diophantine Equations in *Functional Analysis*, see Zadeh (2019).

On solutions to Diophantine Equations in Mathematical Physics, Mathematical Chemistry and Computer Mathematics, see: Ren & Yang (2012), Bremner (1986), Papp & Vizvari (2006), Ibarra & Dang (2006), and Rahmawati, Sugandha, et. al. (2019).

2. The Theorems.

Theorem-1: **The *Qu (2018) Conjecture-#*1, The *Yang & Fu (2018) Conjecture-#2* And the Cipu (2007) Conjecture Are Wrong.**

Proof:

Qu (2018) supposedly proved that:

i) where p is a prime number, the system of simultaneous Pell equations $x^2-(a^2-1)y^2=1$ and $y^2-pz^2=1$ (collectively, the "Simultaneous Pell System") has only a positive integer solution $(x,y,z) = (31,8,3)$ for $p=7$ (the "*Qu (2018) Conjecture-#1*") by using a Baker's lower bound and one lemma from Diophantine approximation to determine the lower and upper bounds respectively, on the variables of the equation; and

ii) there is no positive solution to the Simultaneous Pell System for $a=(2,3)$ (the "*Qu (2018) Conjecture-#2*"); and

iii) the Simultaneous Pell System has a positive integer solution only for $a=4$ which is $(x,y,z,p)=(31,8,3,7)$ (the "*Qu (2018) Conjecture-#3*").

If: $x^2-(a^2-1)y^2=1$ and $y^2-7z^2=1$ (where p=7), then:
$x^2=(a^2-1)y^2+1$, and $a^2 = 1+(x^2-1)/y^2$

The following are derived from simple simulations.
For the equation $y^2 =7z^2+1$:

If y=1, z=0
If y=2, $z^2 = 3/7$, and z isn't an integer.
If y=3, $z^2 = 8/7$, and z isn't an integer.
If y=4, $z^2 = 15/7$, and z isn't an integer.
If y=5, $z^2 = 24/7$, and z isn't an integer.
If y=6, $z^2 = 35/7$, and z isn't an integer.
If y=7, $z^2 = 48/7$, and z isn't an integer.
If y=8, z^2 = 63/7 or 9 which is an integer, and z=3.

Thus, y=8 is the lowest feasible positive-integer value of y, and z=3 is the lowest feasible positive-integer value of z for which the equation $y^2-7z^2=1$ is valid.

If y=8 and z=3, and $a^2=1+(x^2-1)/y^2$, then:
$a^2 = 1+(x^2-1)/8^2$ and then:

If: x=1, then a= 1.00000000000
If: x=2, then a= 1.023
If: x=31, then a=4.0000000000
If: x=424, then a=53.009
If: x=432, then a=54.009
If: x=440, then a=55.008948
If x=2096, then a=262.001879
If x=2400, then a=300.001641

Thus, x=1 and (p,x,y,z,a)=(7,1,8,3,1) are feasible values for the simultaneous Pell Equations $x^2-(a^2-1)y^2=1$ and $y^2-7z^2=1$, and the *Qu (2018) Conjecture-#1*, the *Yang & Fu (2018) Conjecture-#2* and the *Jiang (2020) Conjecture-#1* and the "*Cipu (2007) Conjecture* are wrong. ■

Theorem-2: **The *Qu (2018) Conjecture-#2* and the *Yang & Fu (2018) Conjecture-#1* are wrong.**
Proof:
The two equations that define the system are $x^2 -(a^2-1)y^2=1$, and $y^2-pz^2=1$.
For $x^2-(a^2-1)y^2=1$:

Where a=2, then $x^2-3y^2=1$, and $y^2=(x^2-1)/3$
Where a=3, then $x^2-8y^2=1$, and $y^2=(x^2-1)/8$

The following are derived from simple simulations.
If a=2 and $x^2-(a^2-1)y^2=1$ (that is, [$y^2=(x^2-1)/3$]), then:

If x=1, then y=0.000
If x=2, then y=1.000
If x=7, then y=4.000
If x=26, then y=15.000
If x=97, then y=56.000

If a=3 and $x^2-(a^2 -1)y^2 =1$ (that is, [$y^2=(x^2-1)/8$]), then:

If x=99, then y=35.000000
If x=198, then y=70.002679
If x=396, then y=140.007
If x=577, then y=204.000000
If x=1,154, then y=408.000000

Thus, in the equation $x^2-(a^2 -1)y^2=1$, and for a=(2,3), there are “qualifying” positive-integer values of x and y, and because there are potentially and infinitely many “qualifying” positive-integer values of p and z in the associated equation $\boldsymbol{y^2-pz^2=1}$ in the interval (1;+∞), the *Qu (2018) Conjecture-#2* and the *Yang & Fu (2018) Conjecture-#1* are wrong. ■

Theorem-3: **The Qu (2018) Conjecture-#3 that where p is a prime number, the system of simultaneous Pell equations $x^2-(a^2-1)y^2=1$ and $y^2-pz^2=1$ has only one positive integer solution $(x,y,z,p)=(31,8,3,7)$ for $a=4$; is wrong.**
Proof:
Qu (2018) conjectured that:

i) where p is a prime number, the system of simultaneous Pell equations $x^2-(a^2-1)y^2=1$ and $y^2-pz^2=1$ (collectively, the “Simultaneous Pell System”) has only a positive integer solution $(x,y,z) = (31,8,3)$ for $p=7$ (the “*Qu (2018) Conjecture-#1*”) by using a Baker's lower bound and one lemma from Diophantine approximation to determine the lower and upper bounds respectively, on the variables of the equation; and
ii) there is no positive solution to the Simultaneous Pell System for $a=(2,3)$ (the “*Qu (2018) Conjecture-#2*”); and
iii) the Simultaneous Pell System has a positive integer solution only for $a=4$ which is $(x,y,z,p)=(31,8,3,7)$ (the “*Qu (2018) Conjecture-#3*”).

Let a=4, p=7, z=3,
Then:
3.1) $x^2-(a^2-1)y^2=1$ is equivalent to: $(x^2 -1)/15=y^2$, and $x^2=15y^2+1$
3.2) $x^2-(a^2-1)y^2=1$ is equivalent to: $[1+(x^2 -1)/y^2] = a^2$
3.3) $y^2-pz^2=1$ is equivalent to: $(y^2 -1)/7= z^2$, and $y^2=7z^2+1$

The following are derived from simple simulations.
Where: $x^2-(a^2-1)y^2=1$ is equivalent to: $(x^2 -1)/15=y^2$, and $x^2=15y^2+1$; if a=4, then:

x=1, where y=0;
x=4, where y=1.000000;
x=31, where y=8.000000000;
x=244, where y=63.00000000
x=1921, where y=496.000000
x=2653, where y=685.0016058;
x=2715, where y=701.0099381;
x=3873, where y=1000.004267;
x=3904, where y=1008.008433;

Where: $(y^2 - 1)/p = z^2$, and $y^2=7z^2+1$; a=4, x=31, y=8, then:
p=7, where z=3;
p=63, where z=1;
and thus the solutions (a,x,y,z,p)=(4,31,8,3,7) and (a,x,y,z,p)=(4,31,8,1,63) are feasible.

Given that $x^2-(a^2-1)y^2=1$ is equivalent to: $[1+(x^2-1)/y^2] = a^2$, and if y=8, and p=7 and z=3, then:
If x=0, then a=0.992156742
If x=1, then a=1.000000;
If x=31, then a=4.000000;
If x=400, then a=50.009843;
If x=408, then a=51.009650;
If x=416, then a=52.009464;
If x=456, then a=57.008634;
If x=2096, then a=262.001879;
If x=2400, then a=300.001641;
and thus the solutions (a,x,y,z,p)=(1,1,8,3,8) and (a,x,y,z,p)=(4,31,8,3,7) are feasible.
Thus, the *Qu(2018) Conjecture-#3* is wrong. ■

Theorem-4: The Tao (2016) Conjecture-#1 Is Wrong.
Proof: Tao (2016) conjectured that for the system of simultaneous Pell equations $x^2 - 24y^2=1$ and $y^2-2pz^2=1$ (where p is an odd prime) there is no positive integer solution (the "*Tao (2016) Conjecture-#1*"); and that for the second system of simultaneous equations $x^2-24y^2=1$ and $y^2-3pz^2=1$ (where p > 3 is a prime), there is no positive integer solution (the "*Tao (2016) Conjecture-#2*"). The following are derived from simple simulations.

If a=5 and $x^2-(a^2-1)y^2=1$ (that is, $[y^2=(x^2-1)/24]$), then:
x=1, where y=0.0000000;
x=5, where y=1.000;
x=49, where y=10.000;
x=147, where y=30.0055550;
x=485, where y=99.0000000;
x=534, where y=109.0021024;
x=1,455 where y=297.0005612;
x=2,425 where y=495.0010101

If x=485; y=99, and $y^2-2pz^2=1$ (ie. $z^2=\{y^2-1\}/2p$), then:
2p=2, and z=70;
2p=8, and z=35;
2p=50, and z=14;
2p=98, and z=10;
2p=200, and z=7;
2p=392, and z=5;
2p=9800, and z=1;

and thus, the solution (x,y,z,2p)=(49,10,70,2) is feasible.

If x=485; y=99, and $y^2-3pz^2=1$ (ie. $z^2=\{y^2-1\}/3p$), then:
3p=2, and z=70;
3p=8, and z=35;
3p=50, and z=14;
3p=98, and z=10;
3p=200, and z=7;
3p=392, and z=5;
3p= 9800, and z=1;
and thus, (x,y,z,3p) has no feasible solution where p>3.

If x=49; y=10, and $y^2-2pz^2=1$ (ie. $z^2=\{y^2-1\}/2p$), then:
2p=11, where z=3;
2p=99, where z=1;
and thus, (x,y,z,2p) doesn't have any feasible solution.

If x=49; y=10, and $y^2-3pz^2=1$ (ie. $z^2=\{y^2-1\}/3p$), then:
3p=11, where z=3
3p=99, where z=1;
and thus, (x,y,z,3p) doesn't have any feasible solution where p>3.

Thus, the *Tao (2016) Conjecture-#1* is wrong because the solution (x,y,z,2p)=(485,99,70,2) is feasible. ■

3. Computer Codes For Verifying The Pell Equations.

The following simple Java code (and its variants) can be used to find feasible solutions for (a,p,x,y,z) for the system of Simultaneous Pell equations $x^2-(a^2-1)y^2=1$ and $y^2-pz^2=1$ (and similar Pell Equations), for Positive Integers up to at least $10^{2457600000}$ (and even greater positive-integers depending on available computing power):

```
Int a, p, x, y, z;
Int i, j, k, m, q;
Int b = x**2;
Int c = a**2;
Int d = y**2;
Int e = z**2;
Int f = (b-((c-1)*d));
Int g = d-(p*e);
Int u = (((((1000000000000000000000000000000000000000000000000000000000000000000000000000000000000 **
10000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000)**
10000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000)**
10000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000)**
10000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000)**
10000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000);

For (x=i; i=1; i <= u):
    For (y=j; j=1; j <= u):
        For (z=k; k=1; k <= u):
            For (a=m; m=1; m <= u):
                For (p=q; q=1; q <= u):
                    if(f==1 && g==1):
                        System.out.println("A feasible solution is: "+a+", "+p+ ", "+x+ "," +y+ ","+z+ ".");
                    p += 1;
                a += 1;
            z +=  1;
        y += 1;
    x += 1;
```

4. Conclusion.

The *Qu (2018) conjectures*, the *Yang & Fu (2018) conjectures*, the *Jiang (2020) Conjecture-#1*, the *Cipu & Mignotte (2007) Conjecture*, the *Ai, Chen, Zhang & Hu (2015) Conjecture*, the *Yuan (2004) Conjecture*, the

Keskin, Karaatlı, et. al. (2017) Conjecture, the *Cipu (2018) Conjecture* and the *Cipu (2007) Conjecture* [all of which pertain to the system of Simultaneous Pell equations $x^2-(a^2-1)y^2=1$ and $y^2-pz^2=1$] are wrong or incomplete. The *Tao (2016) Conjecture-#1* is also wrong/incomplete and pertains to the similar system of simultaneous Pell equations $x^2-24y^2=1$ and $y^2-2pz^2=1$. Most of these wrong or "incomplete" conjectures were derived using mostly Modular Arithmetic (which was developed in the early nineteenth century), and that raises the issue of accuracy and usefulness of Modular Arithmetic (and specifically that of *Modulo*).

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